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Making ‘sense’ of dexterity: Its role in scalpel skill acquisition in podiatry students

A thesis submitted for the degree of
Doctor of Philosophy

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Abstract

To work efficiently, effectively and safely as a podiatrist, one needs to have a high level of practical skill and experience, including the proficient use of scalpels. A significant proportion of this proficiency can be attributed to dexterity. The hazards associated with early scalpel skill learning, makes teaching these skills problematic. It becomes a paradoxical dilemma where students can only improve if they are exposed to practice, yet to undertake that practice can be dangerous to themselves, their colleagues and the patients. Despite the inherent risks of practice exposure before proficiency is achieved, there is little research into alternate practice strategies. Anecdotally, teaching practices in Australia and New Zealand have not developed or adapted over time, even in the face of changing motor learning evidence. Thus, three primary studies and a review were undertaken to address, in part, this gap in the research.

To investigate current educational practices when training manual clinical skills, in particular scalpel skills, 16 structured interviews were undertaken across eight podiatry programs in Australia and New Zealand. The teaching of scalpel skills was surprisingly consistent with only small variations in practice arrangements. The key issues identified were pertaining to clinical exposure, student motivation and levels of anxiety, and dexterity.

Subsequently, to identify how dexterity is best measured in the podiatric population, two approaches were undertaken. A systematic search and interrogation of the top nine objective dexterity tests used in a health professional population was performed. From the generalised dexterity tests, the Grooved Pegboard Test, Purdue Pegboard and Finger Tapping Test were the most extensively studied tests, used on a health professional population, providing insight to validity, reliability and feasibility. These results then informed a comparison of 54 novice podiatry students and 54 experienced podiatrists (cross-sectional design) using the identified battery of objective dexterity tests to determine which best differentiated the dexterity level of each group. Minimal relevant between-group differences were identified between novice and experienced scalpel users on generalised dexterity tests.

Further, a sub-group of 27 novice podiatry students were followed-up longitudinally, after a period of scalpel learning, to monitor their self-efficacy, motivation and anxiety and provide further insight into the students' change in state during skill acquisition.

Students demonstrated an increase in self-efficacy and decrease in anxiety over this period.

The concluding study investigated a novel training approach intended to improve the sensory perception of the student and therefore dexterity. This could provide a safer alternative or supplement physical practice in scalpel learning. A randomised controlled trial design was utilised to compare active sensory awareness training to either additional motor practice or usual teaching in a group of 44 novice podiatry students commencing scalpel training. Sensory awareness or additional motor training showed no performance benefit over current teaching practices for scalpel skill acquisition, however, may still provide safer supplementary options for students lacking dexterity.

Overall, these results emphasise the complexity of psychomotor learning and performance evaluation; however, it appears that it is important scalpel training and evaluation continues to be task specific rather than use generalised dexterity tests. Furthermore, generalised dexterity tests should not be used as an indication of podiatric ability, instead further research needs to be undertaken to identify appropriate objective measures of podiatric tasks.

Declaration

I declare that this thesis presents work carried out by myself and does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university: to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text: and all substantive contributions by others to the work presented including jointly authored publications is clearly acknowledged.

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Publications and presentations

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- Causby R, Hillier S, McDonnell M & Reed L 2013, 'Teaching of manual clinical skills in podiatry: theory and recommendations', *Journal of Foot and Ankle Research*, vol. 6, Suppl. 1, P1

- Causby R, Hillier S, Reed L & McDonnell M 2013, 'Self-efficacy, motivation and anxiety in novice podiatry students', *Journal of Foot and Ankle Research*, vol. 6, Suppl. 1, O1

- Oral presentation: Causby R, Reed L, McDonnell MN, Hillier S 2015, 'Teaching scalpel skills, does it make sense? A comparison of sensory and motor practice methods.' Australasian Podiatry Conference, Gold Coast, 6-8th May.

- Poster presentation: Causby R, McDonnell MN, Reed L, Hillier S 2014, 'Measuring Dexterity: Comparing Expert and Novice Podiatrists', ANS (Australasian Neuroscience Society) Sensorimotor Satellite Meeting, Adelaide, 1st February

- Oral presentation: Causby R, Reed L, McDonnell MN, Hillier S 2013, 'Teaching psychomotor skills to Podiatry students', World Podiatry Congress, Rome, 17-19th October.

- Poster presentation: Causby R, McDonnell MN, Reed L, Hillier S 2013, 'Self-efficacy, motivation and anxiety in novice Podiatry students', World Podiatry Congress, Rome, 17-19th October.

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- 2015 School of Health Sciences Travel Scholarship (University of South Australia): $1000 Australasian Podiatry Conference, Gold Coast, Queensland, Australia 2015

- 2013 Experience Plus grant (University of South Australia): $ 3300 To facilitate and run a PhD and Honours education and networking event: 'Turbocharge your writing and presenting your research'.

- 2013 School of Health Sciences Travel Scholarship (University of South Australia): $1000 Federation of International Podiatrists: World Congress Podiatry, Rome, Italy 2013.

- 2012 APERF grant: $2300 for costs associated with "Improving dexterity in novice podiatry students" study.

- 2011 APA (Australian Postgraduate Award) Scholarship $32,500 per year (3 years)

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- Reviewer, 'Applied Neuropsychology: Adult' journal (2015)

- Reviewer, 'Advances in Health Science Education' journal (2015)

Additional activities related to PhD

- 2013 ATN-LEAP Learning Employment Aptitudes program – Leadership and Communication

- 2012 – 2013 Student Representative – School Research Management Committee

- 2012 – 2013 Student Representative for 15 Research proposal panels

Additional skills obtained

- Psychomotor testing – Including the use of Signal and Spike software
- Mixed model statistical analysis
- Qualitative research – Content Analysis

Glossary and abbreviations

ANZPAC – Australian and New Zealand Podiatry Accreditation Council

ARAT – Action Research Arm Test

AsTex® – Tactile Discrimination Test

ATM – Awareness Through Movement

CIMT – Constraint Induced Movement Therapy

CNS – Central Nervous System

CSPDT – Crawford Small Parts Dexterity Test

DST – Dynamical Systems Theory

EEG – Electroencephalogram

EMG - Electromyography

FHD – Focal Hand Dystonia

FI – Functional Integration

fMRI – Functional Magnetic Resonance Imaging

FTT – Finger Tapping Test

FMA – Fugl-Meyer Assessment

GDT – Generalised Dexterity Test

GF – Grip Force

GFavg – Average Grip Force (for the Grip-lift task)

GFsd – Standard Deviation of Grip Force (for the Grip-lift task)

GF:LF – Grip Force to Lift Force Ratio (for the Grip-lift task)

G-MVC – Grip Strength / Grip Maximum Voluntary Contraction

GPT – Grooved Pegboard Test

GSM – Gibson Spiral Maze

IMI – Intrinsic Motivation Inventory

KP – Knowledge of Performance

KR – Knowledge of Results

LFDn – Lift Duration (for the Grip-lift task)

M1 – Primary Motor Cortex

MacQ – MacQuarrie Test for Manual Dexterity

MMDT – Minnesota Manual Dexterity Test

MRI – Magnetic Resonance Imaging

MRMT – Minnesota Rate of Manipulation Test

O'Con (F) – O'Connor Finger Dexterity Test

O'Con (Tw) – O'Connor Tweezers Dexterity Test

OSCE – Objective Structured Clinical Examination

PET – Positron Emission Tomography

P-MVC – Maximum Pinch Grip / Pinch Grip Maximum Voluntary Contraction

PP – Purdue Pegboard

rCBF – Regional Cerebral Blood Flow

rTMS – Repetitive Transcranial Magnetic Stimulation

S1 – Primary Somatosensory Cortex

SMA – Supplementary Motor Area

SRTT – Serial Reaction Time Test

STAI – State Trait Anxiety Inventory

TMS – Transcranial Magnetic Stimulation

VMIQ – Vividness of Movement Questionnaire

VTT – Visuomotor Tracking Test

1 Literature review and background

1.1. Introduction

In Australia, podiatry (originally termed chiropody) has evolved from an unregistered, unregulated trade often working out of the back of pharmacies, to a university-trained profession. Initially, qualifications were gained abroad (most commonly from the United Kingdom) or practitioners were trained via a simple apprenticeship model. The training was heavily focused on manual clinical skills. Since then podiatry has developed into a health profession in its own right, with the capacity to diagnose and work autonomously on any condition involving the foot and lower leg (*Podiatry Practice Act (SA)* 2005). Within Australia and New Zealand it is now a university-trained profession with a minimum of a bachelor degree to gain registration. In some countries the conversion to the podiatry title is reflective of this. Qualifications in other countries can range from a diploma to a Doctor of Podiatric Medicine; the transition from vocational training to tertiary education is becoming well established across the developed world.

Despite podiatry training now residing within the higher education sector for in excess of 30 years, research training and the espousal of research qualifications by podiatrists has only been relatively recent. Consequently, the impetus for podiatry-related research and therefore the research base for many aspects, including podiatric training, remain weak.

To work efficiently, effectively and safely as a podiatrist, one needs to have a high level of practical skill and experience, including the proficient use of scalpels, forceps, clippers and other small instruments. An inability to use such instruments can impact on someone's success as a podiatrist or be of substantial detriment to the health and safety of the patient. For example, in the case of a patient with a diabetic ulcer, inappropriate debridement can be a significant hazard, potentially resulting in the loss of

a limb and greatly affecting quality of life, morbidity and mortality. The Australian and New Zealand Podiatry Accreditation Council (ANZPAC) (*Accreditation Standards for Podiatry Programs for Australia and New Zealand v1.1* 2009) recommends a minimum of one thousand hours of clinical experience to be embedded within the program to meet accreditation standards and for graduates to meet registration requirements.

A significant proportion of the proficient use of the aforementioned instruments and performance of manual clinical skills can be attributed to dexterity. A high level of dexterity is required to facilitate safe and efficient practice of tasks such as simple callus and wound debridement right up to minor orthopaedic-type surgical procedures depending on the training and capability of that practitioner. A task analysis of podiatric management in the primary care setting, undertaken by Levy and Lepow in 1979, determined 65% to be dexterity-related (Lauf & LeCompte 1982). Whilst changes in scope of practice and education may have resulted in changes to this figure, it would be hard to argue that the importance of dexterity has lessened.

The hazards associated with using a scalpel, particularly during early learning or when dexterity may be lacking, makes teaching these skills problematic. It becomes a paradoxical problem where students can only improve if they are exposed to practice, yet to undertake that practice can be dangerous to themselves, their colleagues and in the case of patient clinics, the patients involved. An injury can be detrimental to someone's physical well-being, but may also be of psychological stress to the student, potentially resulting in decreased confidence and anxiety, acting as a further barrier to effective motor learning.

Hence, it would be prudent to explore safe and effective teaching practices in an evolving education environment. Anecdotal evidence suggests that training practices have not adapted or developed over time, despite the changes in motor learning theory, and that similar teaching practices are employed for the teaching of scalpel skills throughout Australia and New Zealand. In recent years, the change in our understanding of neuroplasticity and change in motor learning theory has facilitated an increase in research on how it applies to a variety of fields. However, few, if any, novel attempts to improve the motor learning of scalpel skills have been trialled. Furthermore, to date there is little research into this area within the podiatry discipline or involving novice podiatry students. Much of the research on motor learning is

undertaken on pathological populations (such as stroke), sporting populations, in child development or has a focus on simple motor skill learning such as number sequence learning using a keyboard, making generalisation of findings to the health professional context difficult. Furthermore, much of the research undertaken on the learning of complex motor skills is often contradictory or inconclusive.

Thus, the aims of this thesis are three-fold:

Firstly, to identify, through qualitative means, how manual clinical skills, particularly scalpel skills are being taught in Australia and New Zealand. From these data we hope to clarify the anecdotal evidence surrounding teaching methods, identify further issues which may exist with respect to teaching scalpel skills and identify any alternate models or strategies employed to facilitate motor skill learning.

Secondly, to identify tests suitable to evaluate the dexterity possessed by podiatry students so that change may be quantitatively measured in a relevant manner, and identify the psychological antecedents contributing to or resulting from performance change in podiatry students learning scalpel skills.

Thirdly, to trial an alternate and safer model of training scalpel use in a podiatry context to determine if it is as effective, or better than, current teaching practices.

1.2. Background

The need for dextrous performance of scalpel skills is important. However, the factors contributing to dexterity, and how this fits with teaching is not well understood, and thus is the focus of this research. In order to understand these factors we need to understand the current theories behind motor control, motor learning and skill acquisition. The following provides an overview of these concepts and how they apply to this research.

1.2.1. Motor control

Motor control depicts more than just the output we recognise as voluntary movement but is a description for the movement-based behaviour that encapsulates:

> *"...perception and action systems, with cognition affecting both systems at many different levels" (Shumway-Cook & Woollacott 2011, p.45).*

A number of theories have been used to describe and conceptualise motor control in the past. Early thinking was that movement was merely reflex action involving the central nervous system (CNS). However, this thinking evolved to consider the CNS as a hierarchical structure, facilitating top-down control. That is to say, the higher anatomical levels govern those below (Shumway-Cook & Woollacott 2011; Zwicker & Harris 2009). The late 1980s saw a further shift in thinking, instead considering the CNS as multiple systems acting together at multiple levels (Zwicker & Harris 2009). The current understanding is that each level of the nervous system may act on the other depending on the movement (Shumway-Cook & Woollacott 2011). Figure 1.2-1 outlines the evolution of the models describing the CNS and associated motor control theory.

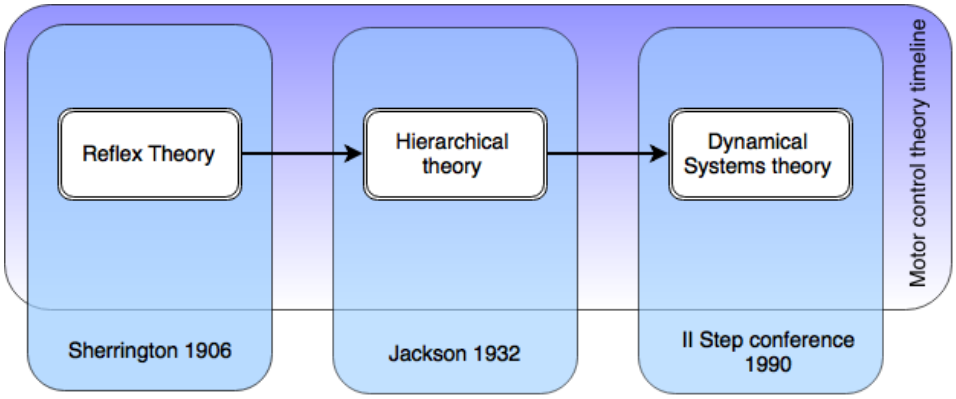

Figure 1.2-1: Evolution of motor control theory over time
(based on diagram and information in Mathiowetz and Haugen (1994))

These multiple theories may be related to how we historically considered the structure and function of the central nervous system. The first theory derived by Sherrington (1906), was that movement was a reflex-based action, whereby specific afferent input would result in a reflex or stereotyped motor output (Mathiowetz & Haugen 1994). Resultant motor output would elicit further feedback which could then trigger other reflexes or stereotypical movement in a loop-like process (Mathiowetz & Haugen 1994). Thorndike (1927) also influenced this belief by proposing that rewarded responses tended to be repeated, whilst non-rewarded responses were not (Mathiowetz & Haugen 1994). It was this theory which influenced Adams's (1971) closed-loop theory of motor control. However, due to a number of shortcomings with the reflex theory, including the fact that deafferented animals were able to demonstrate coordinated movement devoid of sensory input (Mathiowetz & Haugen 1994; Polit &

Bizzi 1979), this evolved into a theory that the nervous systems was in fact hierarchical. One of the first to describe this was Jackson (1932b) who proposed that motor control involved a top-down approach, in which the higher cognitive centres had control over the lower processes (Mathiowetz & Haugen 1994). This theory did not allow for bottom-up processing, which presents obvious limitations.

Bottom-up processing or reflex action examples include the well-known experiment which showed that cats were able to ambulate on treadmills after having their spinal cords transected (Shik & Orlovsky 1976); or for a more common day occurrence, when someone steps on a pin or something hot and rapidly withdraws the lower limb before a feedback signal is able to be processed consciously. Within the hierarchical model, however, the concept of an open-loop system of control was introduced, which could be utilised in movements which lacked sufficient time for sensory feedback (Schmidt & Lee 2011). This is an anticipatory model whereby feedforward control occurs to predict the required movement parameters. With good evidence of anticipatory actions occurring prior to the intended movements (Belen'kii, Gurfinkel & Pal'tsev 1967; Bouisset & Zattara 1981; Cordo & Nashner 1982; Haggard, Newman & Magno 1999; Horak et al. 1984; Mathiowetz & Haugen 1994; Zattara & Bouisset 1988) this theory was well accepted. However, one of the shortcomings of this theory is the sheer number of motor plans that would be required and integrated into the CNS for each of the many actions we may need to produce. Even a small variation in the environment would elicit the need for a unique movement pattern (Mathiowetz & Haugen 1994).

Current contemporary thinking is that motor control is best explained with a more integrated theory incorporating multiple concepts. This has been termed Systems Theory, Dynamic Action Theory or Dynamical Systems Theory (DST). The underpinning principle is that movement may be influenced by the task requirement, the environment in which it is to occur and elements inherent to the individual themselves (Shumway-Cook & Woollacott 2011). Shumway-Cook and Woollacott (2011) illustrate this with the following Figure 1.2-2.

Figure removed for copyright reasons.
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Figure 1.2-2: Elements contributing to motor control model
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An underlying principle of the DST is that elements within the system behave collectively, without the need for a higher centre to issue instructions, rather in a self-organising manner (Kamm, Thelen & Jensen 1990; Shumway-Cook & Woollacott 2011). Thus, so called 'higher' centres and 'lower' centres have an influential effect rather than a controlling effect on each other. Both closed-loop and open-loop processes function cooperatively together in parallel. As part of this self-organisation the system falls into a preferred (but not obligatory) pattern termed an 'attractor', often returning to this subsequent to perturbation or interruption (Kamm, Thelen & Jensen 1990, p.770). The analogy presented is of a ball rolling into a sandpit settling in the bottom of a pit-type *attractor well* (Kamm, Thelen & Jensen 1990). This attractor well is commonly the movement pattern that requires the least amount of energy. A second important concept is that 'control parameters' can affect movement or force transition to a different attractor (Kamm, Thelen & Jensen 1990). These control parameters may vary and change over time. For example with a child learning to walk, the first control parameter may be overcoming an increase in weight through the need to build up muscle strength. However, once this has been achieved the next control parameter which may be inadequate is balance. As each of these control parameters are overcome in order to achieve the required movement, the final product will remain the same, yet there is a multitude of ways that subsystems may interact to achieve this purpose (Kamm, Thelen & Jensen 1990). As the self-organisational nature starts to take effect, the initial variance of these components will settle into a functional pattern, archetypal

of the ‘attractor wells’. However, any change in the subsystem will result in instability of the original form whilst a new form emerges (Kamm, Thelen & Jensen 1990).

1.2.1.1. Systems approach to motor control

Based on the DST of motor control, voluntary movement involves the interaction of all three systems: sensory (perceptual), cognitive and motor (action). The interaction of the perceptual and action systems, referred to wholly as the sensorimotor system, is pivotal to skilled performance. Integration of these systems is complete, complex and not simply sequential. For example, even from the outset the motor system is involved in the collection of sensory information, controlling the visual system to gather the most appropriate task-dependent information. Similarly, throughout movement the sensory system provides multiple streams of task-relevant sensory feedback. However, sensory feedback is inherently slow. Sensorimotor loop delays can result in unstable movement with constant over-shooting of the target. To overcome this we rely on a feedforward model which enables the motor system to predict state variables based on stored knowledge acquired from previous experiences (Shadmehr, Smith & Krakauer 2010).

Our current understanding of this interaction is as follows: perceptual information, particularly visual and haptic signals are combined to provide an accurate representation of the requirements to achieve the intended task, eliminating prevalent yet unnecessary afferent noise (Ernst & Bülthoff 2004; Wolpert, Diedrichsen & Flanagan 2011). Most commonly, a greater weighting is given to the visual cues rather than haptic or proprioceptive signals, which can at times lead to perceptual ambiguity (Ernst & Bülthoff 2004). A combination of feedforward and feedback processes are employed to plan, modify and coordinate the required movement. The representation of the mapping from the planned actions to the subsequent motor commands is called an ‘inverse model’ (Mussa-Ivaldi 1999; Wolpert & Kawato 1998). Wolpert and Kawato (1998) propose a system where the basic idea is that multiple inverse models exist to control the system and each is augmented with a corresponding forward model to initiate and control movement, with the brain containing multiple pairs of corresponding forward and inverse models.

Using feedforward processes (the forward model) a motor plan may be determined based on previous experiences, however it is suggested that rather than having one central model for the complete repertoire of movements and their contexts, a modular

system of control is utilised (Mussa-Ivaldi 1999; Wolpert & Kawato 1998). This avoids control models which could be transient, high in error rate, slow to adapt or at risk of interrupting already learned models (Mussa-Ivaldi 1999; Wolpert & Kawato 1998). Instead, a function is defined that may assign to every possible state of the system and its relevant environment a specific action, for example the position or velocity, with each set of modules suitable for one or more contexts (Mussa-Ivaldi 1999). This modular approach to model representation also allows us to generate new behaviours and handle situations which have not been encountered through the combination of modules (Mussa-Ivaldi 1999), thereby enhancing motor learning. This model also proposes separate representations for movement planning and execution (Mussa-Ivaldi 1999). Furthermore, the forward models will not only predict the expected outcome of a motor plan, but also estimate the position and velocity of the limbs (Miall & Wolpert 1996; Mussa-Ivaldi 1999) and predict sensory consequences (Shadmehr, Smith & Krakauer 2010).

Once the intended movement has been executed the inverse model provides feedback, including comparing the resultant and intended motor plan. In the instance where feedback shows an inappropriate movement resulting in over-shooting or under-shooting of the intended movement, the result is the switching-off of the inverse plan for that motor activity so that an alternate strategy may be executed (Wolpert & Kawato 1998). This important error-based feedback, which loops back into the system to allow comparison is an important driver of motor learning and is discussed in more detail in Section 1.2.2.2 (Wolpert, Diedrichsen & Flanagan 2011). Feedback then combines with the predictions to form 'beliefs' which are then used to update internal models and guide future actions (Shadmehr, Smith & Krakauer 2010). Bhushan and Shadmehr (1999) provide evidence that we learn to compensate for changes in limb dynamics through the combined adaptation of forward and inverse models of the limb and that it was the adaptation of the forward model which played the dominant role in motor learning. Thus, our future actions are "based on a statistically optimal integration of sensory observations with our predictions" (Shadmehr, Smith & Krakauer 2010, p.97). A practical example of this overall process is when someone intends to lift a milk carton which they are expecting to be full, but instead is almost empty. The devised motor plan results in greater force being applied than required, with a subsequent overshooting of the target requirement. At this point visual, tactile and kinaesthetic feedback

intervenes and attempts to rapidly modify the motor plan to avoid the milk carton being thrown and milk being spilt.

1.2.2. Motor learning and skill acquisition

We are not born with the knowledge and ability to undertake these motor control processes; instead, they must be learned and refined.

There are a number of descriptions for motor learning. This includes that motor learning is:

"..a set of processes associated with practice or experience leading to relatively permanent changes in the capability for skilled movement" (Schmidt & Lee 2005, p.327)

From birth, motor learning is vital to our development. Procedural learning, such as learning to walk, balance, grasp and manipulate are important accomplishments, showcasing our ability to learn and our capacity for neuroplastic change. This ability to learn and refine complex tasks follows us into adulthood as we learn to drive a car, play a guitar or as illustrated within this thesis, to use a scalpel safely, efficiently and effectively.

Schmidt and Lee (2011, p.327) describe four concepts which underlie motor learning:

- Learning is a process of acquiring the capability for producing skilled actions
- Learning occurs as a direct result of practice or experience
- Learning cannot be observed directly, as the processes leading to changes in behaviour are internal and are usually not available for direct examination; rather, one must infer that learning processes occurred on the basis of the changes in behaviour that can be observed
- Learning is assumed to produce relatively permanent changes in the capability for skilled behaviour; for this reason, changes in behaviours caused by easily reversible alterations in mood, motivation, or internal states (e.g. fatigue) are not thought of as due to learning

Shumway-Cook and Woollacott (2011) expand on these to outline that motor learning is more than just motor processes but also involves learning new strategies for sensing as

well as moving. This relates to the search for task solutions, where a task solution is a new strategy for perceiving and acting (Newell 1991).

As outlined above, learning cannot be observed directly; we rely on performance change to infer that learning has occurred, as learning is inherent to the individual and unable to be directly measured. However, a difference between performance and learning still exists; "Performance is an action in response to specific cues and is transitory in nature, whilst learning is more permanent and results from practice of the skill or past experience with it" (Oermann 1990, p.202). For example, the trial-error approach characteristic of some motor learning may improve overall performance over time but can show large inter-trial variability, particularly during early learning, which needs to be taken into account when making inferences from performance evaluation (Wolpert, Diedrichsen & Flanagan 2011). It is important to understand from these concepts that learning is a sustained change in behaviour and therefore in order to infer learning has occurred retention of the change in behaviour needs to be observed. This may not always be reflected in the literature.

As outlined above, perception also plays an important part in motor learning. The importance of the sensory system to motor learning was evidenced by a series of studies by a group in the United States of America (Pavlides, Miyashita & Asanuma 1993; Sakamoto, Arissian & Asanuma 1989) who showed firstly that removal of the somatosensory cortex of three cats detrimentally affected motor learning (Sakamoto, Arissian & Asanuma 1989). Furthermore, that by ablating the primary sensory area for the hand in four monkeys, the monkeys could perform previously learned tasks but were unable to learn new hand skills (Pavlides, Miyashita & Asanuma 1993). The importance this concept plays is reflected within many of the theories of motor learning.

1.2.2.1. Theories of motor learning

No theory alone has been able to sufficiently explain all the characteristics observed in skill acquisition; instead, many theories, which have developed in parallel, have contributed to our currently held understanding. Some of these focus on motor learning from a neurophysiological perspective, whilst others approach motor learning from a performance-based perspective identifying the associated performance characteristics that may be observed whilst learners transition from one stage to the next temporally (Shumway-Cook & Woollacott 2011). An understanding from both perspectives is

required to appreciate the intricacies of skill-acquisition as they relate to learning scalpel skills. A brief overview of theories that have shaped our understanding from each of these perspectives is outlined below, beginning with those linked to the performance-based observations, and relate to the following quote:

"Reductionism applies in motor control as much as in as (sic) the rest of science; we need reduced systems in order to build up from the simple to the complex" (Krakauer & Mazzoni 2011, p.636)

Performance-based theories

Possibly the most cited performance-based theory (at least within the medical literature) was proposed by Fitts and Posner (1967), who proposed that learning a motor skill comprises three phases: the **cognitive** stage, **associative** stage and **autonomous** stage (Kaufman, Wiegand & Tunick 1987). These stages are related back to the attentional demands required by the learner, with an increased level of attention needing to be directed to the task early in learning which then diminishes in the later stages. The first, cognitive stage requires the greatest cerebral resources to appreciate the task and develop strategies in order to achieve the required outcome (Kopta 1971; Shumway-Cook & Woollacott 2011). Learning may be explicit at this stage and performance quite varied whilst the most appropriate strategy is determined and refined (Shumway-Cook & Woollacott 2011). The associative stage shows less performance variation, as the chosen strategy is now practised, using more implicit processes and further refining performance (Shumway-Cook & Woollacott 2011). Finally, during the third autonomous stage, task performance is seemingly optimised, requiring less attentional resources and is performed almost automatically (Ackerman 1992; Kopta 1971). Ackerman (1988) further refined this theory, introducing the concept that three phases based on Fitts and Posner's (1967) stages corresponded with different aspects of ability; phase one corresponds to demands on general abilities, phase two is associated with demands of perceptual speed ability and the final phase is predominantly non-cognitive psychomotor ability (Ackerman 1988; Ackerman & Cianciolo 2000). Ackerman (1988) emphasise that the ability-performance relationship was sensitive to the consistency and complexity of the task.

Other theories proposed to specifically address the physical characteristics observed during the motor learning process include that by Bernstein (1967), who proposed a

theory around the constraint of degrees of freedom of certain body parts early in the learning process. This helps to make the task simpler through muscle co-contraction, thereby promoting a concentrated effort on specific muscle groups during the early stages. As control and proficiency improves, movements can be refined by relaxing these limitations. This theoretical model was corroborated by Vereijken et al. (1992) and applied to temporal stages exhibited throughout the learning process termed the Systems Three-stage Model (Shumway-Cook & Woollacott 2011). The three stages of novice, advanced and expert represent the gradual release of degrees of freedom via decreased co-contraction of agonist and antagonist muscles and result in increasing efficiency and coordination of motion (Shumway-Cook & Woollacott 2011).

The final theoretical model from the performance-based temporal perspective is the two-stage model proposed by Gentile (1972, 1987), which focusses on the aims of the learner during each stage. In the first stage, the goal is to develop an understanding of task dynamics, including understanding the overall goal, developing movement strategies and understanding relevant environmental features. During the second stage, termed the fixation or diversification stage, the goal is refinement of the movement. This includes being able to adapt to changing task and environmental demands (Shumway-Cook & Woollacott 2011).

Neurophysiological-based theories

Zwicker and Harris (2009) outline that three models in particular predominate the motor learning literature: Closed-loop theory (Adams 1971), Schema theory (Schmidt 1975) and most recently DST which is based on an earlier theory outlined by Bernstein (1967) and outlined earlier in Section 1.2.1. Each of these may be linked back to the motor control theories outlined earlier.

One of the early neurophysiological theories, introduced by Adams (1971) was based around closed-loop processing; the performed movement is compared with the stored memory of the intended movement and fed back into the system to modify the motor plan. This relies on a memory trace used in the selection and initiation of movement, and a perceptual trace formed through practice used as a reference point for continuation of movement (Shumway-Cook & Woollacott 2011; Zwicker & Harris 2009). This theory makes some assumptions: that sensory feedback is vital to learn motor skills and that movement is only enhanced by repetition with minimisation of

error (Zwicker & Harris 2009). However, it has since been demonstrated that motor learning is possible in the absence of sensory feedback, albeit only simple motor tasks were investigated and repetition of movement (in the absence of visual feedback) did show considerable degradation (Rothwell et al. 1982; Zwicker & Harris 2009). Furthermore, it is now well-recognised that variability in practice can actually enhance motor learning (Zwicker & Harris 2009). Whilst this early model can still adequately explain aspects of volitional movement, it is unable to suitably account for the acquisition of novel skills.

Thus, Schmidt (1975) revised the original closed-loop theory into a model of open-loop processing, termed Schema Theory. This purports that there are generalised rules of movement which can be applied to a variety of contexts. After a movement is performed, a variety of components may be stored in the short-term memory. These are the initial movement conditions, movement parameters used in the motor program, the outcomes from the movement and any sensory consequences. These may then be translated into a longer-term memory in the form of two schemas, a Recall Schema relating to the motor system and a Recognition Schema relating to the sensory system (Schmidt 1975). When we want movement to occur, the Recall Schema initiates the generalised motor plan that most closely resembles the desired movement and the Recognition Schema monitors and re-evaluates the movement (Zwicker & Harris 2009). This Recall Schema may then be modified by the overall experience in preparation for future movements. However, a number of shortcomings with this theory have been identified. As previously described, evidence of the ability of cats to ambulate in the absence of higher control does not support this thinking. Further to this, evidence from the early work of Bernstein (1967) challenges the likelihood and efficiency of the number of individual schemas required for the large number of joints, degrees of freedom, muscles and muscle units in order to control the body for such a broad variety of tasks (Mathiowetz & Haugen 1994), given the variety of movement patterns which may eventuate from simple change in environmental context alone (Mathiowetz & Haugen 1994). Thus, further evolution saw a theory of motor learning developed which considered the interaction between perception and action within a task and uniquely considered environmental constraints. This was termed the Ecological Theory (Newell 1991). Subsequent to this thinking, further progression has resulted in what is now the most commonly held theory, the DST. This theory has derived from the early work of

Bernstein (1967) described in detail previously as it applies to motor control (Section 1.2.1). This theory considers the person, the task and the environment (Figure 1.2-2) (Kamm, Thelen & Jensen 1990; Mathiowetz & Haugen 1994; Zwicker & Harris 2009) and considers a parallel control arrangement where systems may have an *influence* above or below rather than complete control.

1.2.2.2. Types of learning

Each of the motor learning theories outlined above have evolved from a need to describe the behavioural and performance changes observed inferring learning has taken place. However, advances in functional imaging capabilities have now enabled insights into the changes occurring at the neurophysiological level. This has spawned evidence for a number of models of learning which work on differing time-scales, may differ neurologically, are influenced by variable types of feedback and input, but can be linked with neurophysiological observations. These include:

- Error-based (fast) learning
- Reinforcement-based (success-based) learning
- Use-dependent learning
- Structural learning.

All of which are involved in the learning of novel skills such as scalpel use. Karni et al. (1998) outline evidence which suggests that motor learning occurs in a number of stages: fast learning (within-session), a consolidation period where changes are seen 6-8 hours after practice and then slow learning showing more gradual improvements over a number of weeks. Fast learning (within-session) is often also termed error-based learning, due to the method by which the person adapts each of the subsequent process as a consequence of the error-feedback available. However, slower performance gains triggered by practice may take hours to become effective, developing in a more latent manner (Karni et al. 1998). These slower forms of learning are different from rapid error-based learning and include forms such as reinforcement learning (success-based learning) and use-dependent learning. Unlike error-based learning, reinforcement learning only provides information about the relative success or failure of the overall task or movement; in the case of failure this does not include by how much or even the direction of error (Krakauer & Mazzoni 2011). Whilst reinforcement learning enables

further improvement after zero-error within the error-based learning system, it is a much slower learning process. Even in the absence of error or outcome information, simple repetition or replication of movement can result in a change to the motor system (Wolpert, Diedrichsen & Flanagan 2011). This change reduces movement variability introducing a bias toward that movement (Wolpert, Diedrichsen & Flanagan 2011).

Error-based learning and reinforcement learning may occur in parallel (Wolpert, Diedrichsen & Flanagan 2011). Diedrichsen et al. (2010) demonstrate on 17 right-handed healthy participants that use-dependent plasticity and adaptation in error-based learning may occur simultaneously, even when applied to movements in opposing directions. This was achieved through an experiment where participants undertook 15 active movements using their shoulder and arm to move an onscreen cursor or line in a visuomotor task in one particular direction (use-dependent plasticity) followed by 15 active movements constrained by a force channel in an alternative direction (error-based learning). Following the trials, participants displayed an initial movement designed to mediate the constrained movement (error-based learning), but this rapidly dissipated after four to five movements, and continued to alter to a movement corresponding to the use-dependent learning.

Most recently a fourth model of learning, termed structural learning has been proposed to explain the learning-to-learn phenomena (Braun et al. 2009). Braun et al. (2009) outline that in structural learning, knowing general rules which govern different (but similar) tasks will speed up learning. For example, driving a racing car versus a standard car will require different control parameters. However, if the person learning to drive the racing car has driven a sports car, go-kart and variety of other cars then an understanding of how the parameters may vary between these cars will enable faster learning, as the required strategy sits within the same structure (used to describe a parameter sub-space which can be applied to driving a car). This reduces the need to search the complete parameter space and can hasten learning.

It appears that long-term memory formation is dependent on slow-learning rather than fast-learning processes, and is not dependent on the performance level achieved during initial training (Joiner & Smith 2008). Furthermore, it is believed that whilst both fast-learning and slow-learning follow different time courses, they also necessitate different elements (spatial versus motor planning) and physiological processes (Karni et al.

1995). Dayan and Cohen (2011) highlight that the actual duration of each of these learning categories may vary dramatically depending on the complexity of the task being learnt. For example, fast learning may extend over a much greater period for learning a complex musical piece compared to finger sequence learning. According to Bayesian theory, it has been demonstrated that the learning rate may decrease as sensory noise increases, and may increase after a period of absence of sensory information (Krakauer & Mazzoni 2011). For example, when a screen cursor indicating hand position is blurred in a specific reaching task there was a reduction in the rate of learning. However, the rate of learning increased when it was preceded by a block of trials with no visual feedback (Krakauer & Mazzoni 2011).

Hikosaka et al (1999) suggest that procedural motor learning involves the development of a spatial and motor representation in parallel, but that the spatial representation develops quicker and is stronger earlier in practise whilst the motor representation develops more slowly, but increases in strength over time. However, the spatial representation is subject to degradation without practice. Hikosaka et al. (1999) also suggest that as they occur in parallel, either may lead the learning process depending on the task being learnt, i.e. if explicit processes are not involved. As stated in Spaeth (1972) and Gomez and Gomez (1984), in the early stages of motor learning visual feedback is most influential, whereas in the later stages kinaesthetic feedback is more helpful which corresponds with Hikosaka's (1999) theory.

For fast learning, described as error-based learning, the modification of errors may continue in rapid succession until an almost zero error-rate is achieved (Wolpert, Diedrichsen & Flanagan 2011). Early, fast (within-session) motor learning has been evidenced by rapid changes at a cortical level supported by both animal and human studies using functional Magnetic Resonance Imaging (fMRI)(Karni et al. 1995), focal Transcranial Magnetic Stimulation (TMS)(Classen et al. 1998), Electroencephalography (EEG), and Positron Emission Tomography (PET)(Seitz et al. 1990; Shadmehr & Holcomb 1997; Van Mier et al. 1998). These changes occur rapidly, within minutes of movement commencement. In the study by Classen et al. (1998), some participants showed cortical change within five minutes of starting a motor learning task, however cortical change was not evident in all participants until 30 minutes of training had been completed. These rapid changes are purported to be the consequence of decreasing the inhibition of existing latent intracortical connections (Jacobs & Donoghue 1991; Karni

et al. 1995). Hlustik et al. (2004) also provide support for the engagement and increased activation of Primary Somatosensory Cortex (S1) during the acquisition of a motor skill. It is important to note that the brain areas involved can vary, dependent on whether motor learning is occurring. For example, the pre Supplementary Motor Area (preSMA) is activated during learning but not during performance of a learned button sequence (Nakamura, Sakai & Hikosaka 1998).

There is research both supporting and contradicting reports that cortical expansion is occurring in error-based learning. Karni et al. (1995) found that fast-learning had the effect of actually decreasing cortical activation in the first instance (habituation) using fMRI, but then the active area enlarged (enhancement) during transition to the slow-learning processes. Shadmehr and Holcomb (1997) support this, showing increased blood flow only in the Prefrontal Cortex. However, other PET based studies found that in early learning often Premotor, Primary motor, Somatosensory and Supplementary Somatosensory areas were activated (Seitz et al. 1990; Van Mier et al. 1998). Sanes and Donoghue (2000) suggest that the reason we are seeing an apparent discrepancy with data showing cortical expansion but decrease in activation may relate to differences between fMRI and PET, or changes in the movement parameters which were controlled for by Karni et al. (1995). Using EEG, Andres et al. (1999) supported an increased intracortical expansion in early learning, which was more pronounced in bimanual rather than unimanual skill acquisition. Hlustik et al. (2004) found cortical changes in the Primary Motor Area (M1) and S1 over a three week period of motor skill acquisition in two separate groups. Functional MRI was used to evaluate cortical changes weekly whilst completing four key sequence tasks, three simple and one complex, before and after a prescribed practice period. Practice consisted of either the sequential movement used in testing (fine-skill group) or a sponge-squeezing task (gross-skill group). During this period they found that both groups improved their performance of the testing sequence in the practised and non-practised hand, although only the practised hand showed significantly better performance. The performance for either of the groups was not significantly different ($p = 0.058$) but demonstrated a trend toward an improved performance by the fine-skill group. The cortical changes observed included a significant increase in the volume of M1 during the practice period with the greatest increase during the first time period. Again, there was not a significant difference between the two groups. Additionally Hlustik et al. (2004) found that index finger

tapping speed increased in the fine-skill group and that performance on the 9-hole peg test and grip strength test improved in both the fine-skill and gross-skill group, matching the observed increase in cortical representation. There was a significant increase in the S1 region activated during this period compared with the control group, but this was neither as large as changes in M1 nor significantly different between the two intervention groups. In discussion, Hlustik et al. (2004) postulate that the observed improvements in both intervention groups suggest a phenomenon of transfer and generalisation whereby practice of one activity resulted in improvement in another.

Whilst motor learning results in obvious change to the motor system itself, there is also a symbiotic relationship with the sensory system. It is well understood that a sensory experience will result in change within the somatosensory cortex (Jenkins et al. 1990; Ostry et al. 2010; Recanzone et al. 1992; Xerri et al. 1999). However, in conjunction with motor system activation and modification, changes within the cortical substrate of the somatosensory system may also occur. For example proprioceptive changes have been observed following visuomotor adaptation in manual tracking and reaching tasks whilst holding the handle of a robotic arm (Cressman & Henriques 2009; Ostry et al. 2010; Van Beers, Wolpert & Haggard 2002).

An important aspect of this sensorimotor adaptation is active motor engagement. Held and Freedman (1963) used visual manipulation to identify that adaptation will only occur when active rather than passive arm movement occurred. Shadmehr, Smith and Krakauer (2010) outline that this occurs due to a lack of sensory prediction error during passive movement. Ostry et al. (2010) also showed that passive limb movement by a robotic arm was insufficient to invoke sensory change; active engagement of the motor system for motor learning is required.

In addition to the impact these proposed models of learning have on scalpel skill acquisition there are also supplementary mechanisms by which motor learning can be positively influenced, such as observational learning, perceptual learning and through an understanding of implicit and explicit mechanisms.

Observational learning

One of the major advances in our understanding of motor learning and neurophysiological correlates stems from the discovery of mirror-neurons. Observing someone perform a particular action will activate the observer's own mirror-neurons,

which may be beneficial for learning of complex skills (Adams 1987; Wulf & Shea 2002; Wulf, Shea & Lewthwaite 2010). First discovered in the brains of Macaque monkeys, mirror-neurons were initially found to discharge when the monkeys either observed or performed a particular motor action (Cattaneo & Rizzolatti 2009; Gallese et al. 1996; Rizzolatti et al. 1996a). Furthermore, mirror-neurons fired when the monkeys could not see the triggering feature of a motor act but could understand its goal (Umilta et al. 2001), or when an action wasn't directly observed but the associated sound was heard (Kohler et al. 2002). Thus, mirror-neurons are believed to be responsible for imitation, and understanding another's actions and intent, in part through matching with their own motor repertoire (Cattaneo & Rizzolatti 2009; Rizzolatti 2005; Rizzolatti & Craighero 2004; Rizzolatti, Fogassi & Gallese 2001). Objective magnetic stimulation and neuroimaging studies have been used to argue that this is comparable in humans, showing similar neural activation patterns during the performance and observation of a particular task (Decety et al. 1997; Fadiga et al. 1995; Iacoboni et al. 1999; Rizzolatti et al. 1996b).

An example of this in human participants was provided in a study by Cattaneo et al. (2007) who found that when typically-developing healthy children were observing two actions: grasping a piece of food and putting it in their mouth, and grasping an object and putting it in a box, the children's mouth-opening muscles activated for the food action, indicating an understanding of action intent. Functional MRI evidence also supports such activations in the mirror-neuron system for observations of motor action with and without context. Actions undertaken in context elicited much greater activation within supposed mirror-neuron regions than motor action alone (Iacoboni et al. 2005). The level of activation or response of the mirror-neuron system is also influenced in part by other motivational factors (Cheng, Meltzoff & Decety 2007). Cheng, Meltzoff and Decety (2007) found an increased haemodynamic response in the mirror-neuron system and extrastriate body area whilst participants were watching food grasping movements being performed via video recording when motivated to eat, concluding that this was 'facilitating the preparation or intention to act' (pg. 1979).

Based on TMS studies Cattaneo and Rizzolatti (2009) suggest that the so-called mirror-neurons can code simple movements. However, there is also evidence that only motor actions which are present in the motor repertoire activate the motor mirror-neuron system (Cattaneo & Rizzolatti 2009). If the movement does not exist in the observer's

repertoire then it appears to only be recognised visually rather than activate the motor system (Rizzolatti & Craighero 2004), although this remains controversial. Maslovat et al (2010) showed that when learning a novel dual-limb coordination skill, benefits to the observation-only group were restricted to cognitive-perceptual improvements. One of the supporting studies for this notion found that mirror-neuron activation in dancers increased over time if they experienced a period of motor training in which they became skilled in performing the same steps they were observing (Cross, Hamilton & Grafton 2006). It is postulated that an observed action is subdivided into simpler action components which are coded in the modular motor system (Buccino et al. 2004). When the movement is novel to the observer, another learning mechanism is evident whereby previously observed substituent elements of motor acts are recombined into a new motor pattern or sequence (Buccino et al. 2004). Findings from fMRI studies looking at the observation and subsequent acquisition of novel motor plans suggest that additional cortical areas are recruited in order to decompose the actions into their basic motor elements and recombine them into a new action, reflecting action-goal and specific motor patterns (Buccino et al. 2004; Ferrari, Bonini & Fogassi 2009; Vogt et al. 2007).

Buccino et al. (2004) studied naïve participants who observed guitar chords being played by an expert. The first condition required participants to imitate the shown chord, the second required participants to perform one of three non-chord actions learnt during practice, the third required participants to observe two different chords and the final condition required participants to perform a guitar chord of their own choice. All conditions caused activation of the mirror-neuron system with the strongest response in condition one, during imitation of the demonstrated chord.

Observational learning is particularly effective if combined with physical practice (Shea et al. 2000b; Shebilske et al. 1992; Wulf, Shea & Lewthwaite 2010). In a study by Stefan et al. (2008), researchers found that coupling observation and execution significantly increased short term cortical reorganisation of the motor cortex. Furthermore, a recent meta-analysis has shown that combining observational learning with practice is more effective than practice alone, particularly for serial tasks rather than continuous or discrete tasks (Ashford, Bennett & Davids 2006). However, this response is reduced when observing movements which have not previously been performed by the observer (Calvo-Merino et al. 2005; Calvo-Merino et al. 2006). Further evidence confirms that watching someone else undertake a *learning* process will

facilitate adaptation when required to perform the same action (Mattar & Gribble 2005; McCullagh & Caird 1990; Shea, Wulf & Whitacre 1999; Shebilske et al. 1998; Shebilske et al. 1992; Wulf, Shea & Lewthwaite 2010). Shea et al. (1999) explain that it is likely that observation allows the learner the opportunity to extract important information which they would be unable to do if preparing and executing the required movements themselves.

The mirror-neuron system is neither wholly innate nor fixed in its state, but able to undergo plastic change in response to sensorimotor learning (Catmur, Walsh & Heyes 2007). Thus, it is both able to influence sensorimotor learning and change in response to sensorimotor learning.

Perceptual learning

"Perceptual learning involves relatively long-lasting changes to an organism's perceptual system that improve its ability to respond to its environment" (Goldstone 1998, p.585)

Perceptual learning is a form of implicit (non-declarative) memory which involves an improvement in sensory discrimination through the storage of information of complex representations of the objects with which we interact (Gilbert, Li & Piech 2009; Gilbert, Sigman & Crist 2001). An example of this is our ability to discern the value of a coin amongst others based on its size and the contours provided on its surface. The more this is practised the better we become at it. Perceptual learning occurs at different processing levels at varying speeds and is affected by top-down influences (Fahle 2005). It is partly through maximising perceptual learning we hope to improve scalpel skill acquisition in novice podiatry students.

There is a great deal of contradictory information regarding whether there is a need to give attention to a task in order for learning to occur. Some suggest that passive learning, reinforcement processes or stimulation processes may all still result in perceptual learning occurring (Seitz & Dinse 2007). However, whilst plastic change in the cortex as a consequence of perceptual learning has been shown within many sensory modalities (i.e. visual, audiological and tactile) there may be differences in each response or the elements necessary for perceptual learning to occur. Tactile-specific literature often strongly supports the notion that attention is necessary for learning to occur (Darainy, Vahdat & Ostry 2013; Noppeney et al. 1999; Rosenkranz & Rothwell

2012). However, in their review Seitz and Dinse (2007) reflect on instances in which passive stimulation of the skin (Dinse et al. 2005; Klein et al. 2004; Pilz et al. 2004) and transcranial magnetic stimulation (Pleger et al. 2003; Tegenthoff et al. 2005) can induce learning and result in cortical changes with little or no attention given. They hypothesise that sensory stimulation needs to be sufficient to exceed a certain learning threshold in order for change to occur. This may be via an increase in attention, temporal parameters or through an increase in frequency or intensity of the stimulus.

Perception itself involves the early stages of information processing and therefore influences the time course of early processes in addition to the processes themselves (Goldstone 1998). It may be that the learner is exposed to the environmental stimuli first, enabling them to process temporal and spatial aspects prior to the need to respond physically, thereby potentially increasing efficiency when motor action is required (Schmidt & Lee 2011). This is particularly evident when the learner is actively engaged, and attention given to the relevant aspects, rather than through passive observation (Darainy, Vahdat & Ostry 2013; Rosenkranz & Rothwell 2012; Schmidt & Lee 2011). Thus, perceptual learning also occurs early during information processing which shifts the foundation for all subsequent processes (Goldstone 1998). Furthermore, future learning is dependent on current learning and previous and subsequent changes which have already occurred. In this way the constraints may evolve with individual experience (Goldstone 1998).

It has been shown that improvements in perceptual training resulted in similar effects on both kinetic and kinematic measures of motor learning (Darainy, Vahdat & Ostry 2013). Perceptual and motor learning can presumably occur in parallel, however perceptual training alone in the absence of movement would be sufficient to modify error-based learning and individual movements (Darainy, Vahdat & Ostry 2013). There is increasing evidence of the ability of somatosensory learning to facilitate motor learning (Darainy, Vahdat & Ostry 2013; Huang et al. 2011; Rosenkranz & Rothwell 2012; Vahdat, Darainy & Ostry 2014). An example of this is visuomotor adaptation of a reaching task. A study by Huang et al. (2011) which investigated model-based (adaptation) and model-free learning processes (use-dependent plasticity and operant reinforcement) showed that visuomotor adaptation could enhance motor learning. This has been further supported in a study by Rosenkranz and Rothwell (2012), who provided evidence of reduced intracortical inhibition within the primary motor cortex

subsequent to a somatosensory frequency discrimination task, thereby enhancing motor learning. Eight healthy volunteers performing a vibration discrimination task resulted in an increase in the integration of proprioceptive input with motor cortex excitability (using transcranial magnetic stimulation), whilst performing a cutaneous discrimination exercise had the opposite effect. There was a significant correlation between the integration of proprioceptive input in the motor cortex and subsequent improvement for motor learning of the Abductor Pollicis Brevis muscle ($r = 0.89$, $p < 0.008$) (Rosenkranz & Rothwell 2012). Vahdat, Darainy and Ostry (2014) investigated this further in an experiment observing changes in the functional connectivity of motor areas which were functionally independent to changes in the sensory system, after somatosensory discrimination training. They identified change in the motor system which was not linearly related to change within the somatosensory system and which did not simply mirror changes in this system, including an increase in the functional connectivity of frontal motor areas of the brain and cerebellum. They also found that those who underwent greater perceptual learning also exhibited greater amounts of motor learning ($r = 0.64$, $p = 0.01$). Thus, perceptual training may provide a good training option when physical practice is either not possible or not practical (Schmidt & Lee 2011).

Goldstone (1998) outlines that perceptual learning may occur via four predominant mechanisms, attentional weighting, imprinting, differentiation and unitisation (or chunking). *Attentional weighting* refers to the way in which perception can adapt to tasks and environments through an increase in attention to the required dimensions and features, or a decrease in attention to irrelevant stimuli. Another way in which someone can adapt to an environment is via directly imprinting to it. This process of *stimulus imprinting* suggests that receptors are developed which are specialised for specific stimuli and thus able to process the stimulus with greater speed, accuracy and general fluency (Goldstone 1998). The third proposed mechanism is via increased *differentiation.* These include: the selective weighting of discriminating cells, the expansion of regions dedicated to discriminating cells, the narrowing tuning of discriminating cells and finally, shifting attentional "magnifiers" to critical regions. An example of differentiation is the increased tactile sensitivity found in the fingers of professional violinists (Goldstone 1998). Finally, *unitisation* is the opposite of differentiation, whereby improved efficiency is achieved by integrating smaller functional parts into single wholes. For example when reading words, rather than

interpreting individual letters we may immediately group them into words in order to improve the speed of our reading (Goldstone 1998). The mechanism which may be applied is dependent upon the needs of the specific tasks and stimuli (Goldstone 1998).

Whilst perceptual learning can be highly specific, as previously outlined, there may be instances whereby perceptual training may be able to transfer not just within, but also across sensory modalities. For example, visual discrimination training of certain shapes may translate to improvements in tactile discrimination of those shapes (Goldstone 1998). Goldstone (1998) states that when perceptual learning involves changes to early perceptual processes then less generalisation is likely to occur, however this is based on evidence provided in the visual domain and may vary between sensory modalities (Fahle 2005). Fahle (2005) explain that perceptual learning is highly specific for low-level features such as orientation and that to achieve optimal performance irrelevant signals and noise have to be eliminated as early as possible during processing. In order to prevent interference of learning one task with performance in other tasks the early level changes are activated in a task-dependent way from the top-down. As easier tasks do not have to involve the early level processing, improvement is more likely to generalise (Fahle 2005).

Evidence for occupation-related improvements in haptic sense exists, particularly for professional musicians (Ragert et al. 2004) and Tai Chi practitioners (Kerr et al. 2008). In professional pianists, Ragert et al. (2004) found a linear correlation between a two-point spatial discrimination task and amount of piano practice performed. Likewise, Kerr et al. (2008) found that attentional focus in Tai Chi practitioners improved tactile acuity on a Grating Orientation Test (GOT). Can we expect a similar change in health professionals requiring increased perceptual ability? Mueller et al. (2014) investigated the perceptual ability of physiotherapists, advanced manual therapists, physiotherapy students and a control group on a haptic threshold test and tactile acuity test. They found haptic threshold increased in the health professionals, but that this exhibited a ceiling effect (i.e. there was no difference between physiotherapists and advanced manual therapists). This use-dependent increase in haptic threshold also diminished the effect of age-related decline. However, they found that this improved ability was not replicated for tactile acuity. The authors theorise that this is due to a lesser need for physiotherapists and advanced manual therapists to have superior (passive) tactile acuity rather than haptic ability.

Implicit versus explicit learning

Learning may be split into explicit and implicit categories, also known as declarative or procedural processes respectively. Explicit processes involve the learning of factual knowledge or event-related knowledge. Conversely, implicit learning involves procedural knowledge. This may include priming (word completion), associative learning (classic or operant conditioning), non-associative learning (habituation or sensitisation) and skills and habits (Vidoni & Boyd 2007). Implicitly learned skills are considered to be more reliable in attention demanding conditions and result in a more stable performance during episodes of fatigue, mental stress or when multi-tasking (Hardy, Mullen & Jones 1996; Masters 1992; Masters et al. 2008; Masters, Poolton & Maxwell 2008; Maxwell et al. 2001; Poolton, Masters & Maxwell 2005, 2007). Implicit learning plays a big part in skill acquisition, occurring without any conscious knowledge. Vidoni and Boyd (2007, p.146) outline the defining principle of implicit learning as a "capacity to acquire skill through physical practice without conscious recollection of what elements of performance improved". A good example of this was the experiment by Nissen and Bullemer (1987), who presented a Serial Reaction Time Task (SRTT) which required two groups of participants to respond to a series of lights as they lit up. For the first group the lights illuminated randomly, whilst in the second group the lights were presented in a 10-trial repeated sequence. Without any prior knowledge by the participants that the sequence repeated, implicit processes enabled them to acquire knowledge of the sequence demonstrated by a significant decrease in reaction time compared with the random sequence group. Further neurophysiological support for this implicit learning comes from a number of similar studies. Grafton et al. (1992) demonstrate an increase in regional cerebral blood flow (rCBF) in brain regions associated with motor learning (M1, SMA and thalamus), whilst undertaking a test for implicit motor learning (pursuit rotor test). In a second study utilising a SRTT participants showed decreasing reaction times, together with increasing cortical representation shown with TMS for the muscles corresponding with muscles involved in the task to the point at which explicit knowledge of the repeating sequence was achieved (Pascual-Leone, Grafman & Hallett 1994).

Implicit learning and explicit learning often occur in parallel, albeit usually on a different timeline. Implicit and explicit learning are thought to engage different areas of the brain (Honda et al. 1998; Keele et al. 2003; Posner, DiGirolamo & Fernandez-

Duque 1997; Vidoni & Boyd 2007) and utilise qualitatively different memory encoding processes (Verdolini-Marston & Balota 1994). In many instances, implicit learning can occur more rapidly than explicit learning or declarative knowledge in skill acquisition. Sun, Merrill and Peterson (2001) introduce the bottom-up model of learning, showing how participants may develop procedural knowledge in advance of any form of declarative knowledge. "That is, learning of explicit knowledge is through the (delayed) explication of implicit knowledge" (Sun, Slusarz & Terry 2005, p.161). This theory coincides with the many reported results from tests of implicit learning such as the SRTT as reported above. Willingham, Nissen and Bullemer (1989) show how implicit knowledge may occur without concurrent explicit knowledge, and likewise explicit knowledge may occur without implicit learning taking place. They concluded that the timeline order for which implicit or explicit learning occurs depends on the task concerned. Willingham and Goedert-Eschmann (1999) suggest that explicit memory can be used whilst implicit learning is occurring in parallel, to a point at which it is no longer necessary. For example when learning a tennis stroke for the first time, the explicit steps are carried out until the process is automatic. However, further to this Boyd and Winstein (2001), suggest that explicit knowledge can aid performance when implicit processes are not available. Having or developing explicit knowledge may enhance or impede implicit learning, which will be discussed later.

1.2.2.3. Role of practice in motor learning

Finally, undoubtedly one of the most influential factors attributed to motor learning and skill acquisition would be 'practice'. According to the Schema Theory, actual repeated execution of the skill is the key to the development of a complete representation and a critical part of acquisition of expertise (Wanzel, Ward & Reznick 2002). However, whilst continued practice is important for improvement, the rate of improvement is related to the amount left to improve, whereby the poorer the initial performance the higher the rate of learning (Schmidt & Lee 2011; Shumway-Cook & Woollacott 2011). Thus, learning curves formed are a negatively accelerated function of the amount of practice. Whilst there may be other various factors which can influence the learning curves, such as fatigue, the resulting function is so consistent that it is termed and recognised as the 'Law of Practice' (Schmidt & Lee 2011). However, Heathcote, Brown and Mewhort (2000) suggest that an exponential function fits practice data better than the power function originally proposed. Independent of this, it remains clear that

the representative function is related to ceiling and floor effects. Achieving the last five percent or more of improvement in performance may be the hardest to achieve as participants approach their peak physiological capability. Schmidt and Lee (2011) highlight how this effect may cause a misinterpretation of study findings. For example, if the performance curve of two different study populations were compared but at different points along the practice curve it may create the illusion of a substantial group difference when there is in fact none.

There are multiple factors relating to practice and acquisition, both intrinsic to the task itself, such as practice scheduling, or extrinsic to the task which may influence the effect on motor learning (Figure 1.2-3). We will discuss each of these factors in turn, beginning with those intrinsic to the task being learnt.

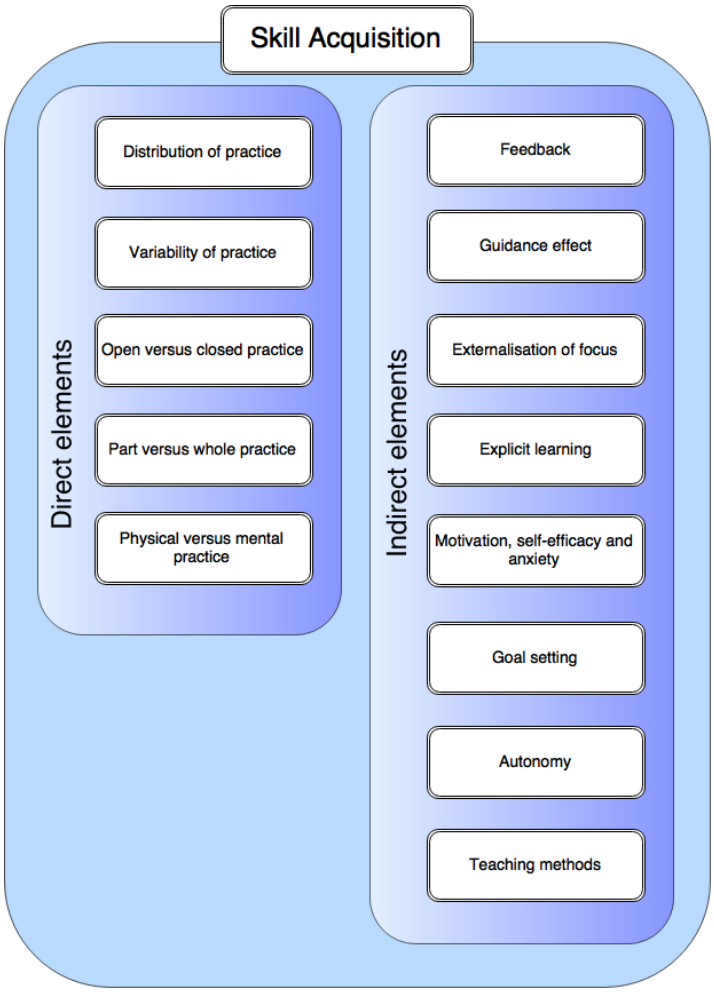


Figure 1.2-3 Direct and indirect practice elements affecting skill acquisition

Direct practice elements influencing motor learning

Distribution of practice

The effects of fatigue, presence of contextual interference and a number of other factors may affect how practice influences learning. Contextual interference occurs when multiple skills are practised in a single session, thereby increasing the cognitive load associated with learning (Shumway-Cook & Woollacott 2011). These factors will have varying influence as a consequence of the structure by which we practise. There are a number of ways practice schedules can be structured. The first is distributed practice, also known as spaced or intermittent practice, defined as a session in which the amount of rest between practice sessions is equal to or greater than the practice sessions themselves (Shumway-Cook & Woollacott 2011). The converse of this is massed or blocked practice where the practice time is greater than the rest period. This is useful to describe extremes of practice, but as noted by Schmidt and Lee (2011) practice may not always be that dichotomous, instead relevant to the context and experiment being undertaken. To further describe how the practice structure influences learning, it is believed that breaks in practice will decrease the detrimental effects of fatigue (Schmidt & Lee 2011). However, independent of this, performance differences still exist in favour of distributed practice schedule with retention or transfer tests suggesting distributed practice has a greater long-term beneficial effect on learning than just the temporary and transient effect which may be attributed to reducing fatigue (Schmidt & Lee 2011). By allowing greater gaps in practice, there is a greater opportunity for consolidation to occur (Shea et al. 2000a). Consequently, a large body of literature advocates that distributed or spaced practice is superior to massed practice in the acquisition of simple motor tasks (Balasundaram, Aggarwal & Darzi 2010; Donovan & Radosevich 1999; Wulf & Shea 2002). This benefit is much clearer for continuous tasks rather than discrete tasks, where the evidence may depend on the task being undertaken (Schmidt & Lee 2011; Shumway-Cook & Woollacott 2011). However, a review undertaken by Donovan & Radosevich (1999) highlight that we must be clear on the limitations within this evidence base as research has mostly only been undertaken on simple tasks and there is uncertainty about the effectiveness of distributed practice on more complex tasks with greater cognitive demands. It is also purported that an increase in contextual interference may increase cognitive demand which may positively affect learning in simple tasks (Magill & Hall 1990), however may be of

detriment if the task is more complex (Wulf & Shea 2002). Wulf & Shea (2002) also advocate for a fresh look at the evidence, reporting that in tasks for which memory and processing demands are high, particularly in instances involving low-skilled learners, the benefits of distributed practice are not evident, and instead may overload the student. In the meta-analysis undertaken by Donovan & Radosevich (1999) comparing the effects of massed practice versus distributed practice, they found decreasing effect sizes as the complexity of the task and cognitive demand increased. In fact, they found that overall task complexity negatively correlated with effect sizes ($r = -0.25$, $p < 0.05$), whilst mental and physical requirements did not. Also, effect sizes for acquisition and retention were similar ($d = 0.45$ and $d = 0.51$) and not significantly different from one another ($p = 0.35$). However, this may have been influenced by the choice of only a 24-hour retention period. Finally, Donovan & Radosevich (1999) also found that the greater the rigour of the reviewed article, the smaller the calculated effect size. They postulated that with the inter-trial interval, the optimal time period differed depending on the complexity of the task.

A number of examples demonstrating the influence of practice distribution on tasks undertaken by health professionals are available. Mackay et al. (2002) trialled massed practice compared with distributed practice on a virtual trainer (surgical), the first report involving medical training on a more complex task. They found improved retention for one of the distributed practice groups in addition to a reduced time taken to complete the task during the training phase. However, it should be noted that a second distributed practice group which completed only 15 minutes of training compared to the full 20 minutes, showed no significant effect, either suggesting that learning was time dependent or that other confounders may be involved. A study by Savion-Lemieux and Penhune (2005) involving 58 healthy volunteers with less than three years musical experience on a timed motor sequence task, found over a five day practice period that the amount of practice did not affect learning and retention, with a similar rate of learning across the one, three or six block practice groups. Rather, it was the distribution of practice which was more important for improvements in learning and retention, reportedly a consequence of consolidation (Savion-Lemieux & Penhune 2005). This is consistent with the understanding of the benefits of consolidation on motor skill learning (Brashers-Krug, Shadmehr & Bizzi 1996; Krakauer & Shadmehr 2006). Moulton et al. (2006) also report conflicting findings when they compared

distributed and massed training on a microvascular anastomosis task. Both the distributed and massed training groups showed significant improvements between pre- and post-testing; however there were no significant differences between the groups. The distributed group showed significantly superior scores for a variety of computer-based measures compared to the massed group on retention testing, but this did not extend to other measures. A transfer test (performing an anastomosis) undertaken on a rat as part of the study showed that the distributed group performed significantly better than the massed group on all expert-based outcome measures. All distributed group participants successfully completed the clinical transfer task, which was not the case for the massed group, albeit outcome differences for this measure were not supported statistically.

Variability of practice

There is research to indicate that internal models learned for one movement can generalise to other movements (Conditt, Gandolfo & Mussa-Ivaldi 1997; Krakauer 2006). However, it is likely that the transfer of skill is proportional to the similarity of the two movements (Gomez & Gomez 1984). Practising the skill in a variable manner is believed to better generalise learning allowing for better transfer (Catalano & Kleiner 1984; Shumway-Cook & Woollacott 2011; Wulf & Schmidt 1997), as predicted by Schmidt (1975) who outlined that an increase in the amount or variability of practice could strengthen the motor schema. Wulf and Schmidt (1997) found variability of practice in the form of amplitude change and temporal parameters for a computerised visuomotor tracking task was able to significantly improve implicit learning. This supports the notion that open learning in a variable environment could be beneficial. An example of practice variability, depending on the task, could include: temporal changes, a change in the force requirements, or even a change in target position. For example, if you were practising shooting a basketball then you may practise from different positions on the court, different distances from goal or perform a rapid jump shot compared to a slow set shot.

Open versus closed practice

Diverse opinions exist regarding the relative success of open versus closed motor skill learning. An open motor skill is one that is performed in a variable environment in which regulatory conditions are constantly changing. The closed motor skill is the

converse of this; there is no variability of regulatory conditions and therefore is not subject to inter-trial variability (Gomez & Gomez 1984). This may include learning the required skills in a real-world environment (such as in a hospital) versus laboratory-based skills instruction (at the university). Closed motor skill learning will often occur more rapidly as only one movement needs to be learnt and subsequent practice is only concerned with refinement of that movement (Gomez & Gomez 1984). In an open motor skill a repertoire of movements is required with sufficient variation to accommodate the changing environment.

Gomez & Gomez (1987) provided evidence of the need to teach in an open environment in an experiment with nursing students learning blood pressure testing. In this study one group was taught blood pressure testing in a college laboratory, whilst another was taught in a hospital ward environment, both with the aid of an instructor. The ability of both groups to undertake the learned task was then evaluated in a nursing home environment with raters using a pre-established criteria checklist. The open environment group demonstrated higher criteria-checklist scores for accuracy of technique and confidence, but not for an index of discrepancy calculated from the actual blood pressure readings. However, the checklist for the assessment task also included cognitive ability in addition to motor skill performance, possibly confusing the appropriate interpretation of findings specific to motor skill learning.

This suggests that scalpel skill learning should not only occur in a workshop or laboratory setting, instead ultimately occurring in an open environment to enable a full repertoire to be learnt and appropriate performance strategies determined (Gomez & Gomez 1984). In contrast, Knight (1998) highlights that the literature around this topic does not consider the effects of anxiety and arousal, and that observed outcome differences are more likely to be subject to the personalities of the students and other factors.

Part versus whole practice

When learning new motor skills the task may be learnt as a whole, or if able, broken down into discrete components which can be combined later. If a skill is learnt in components, then an important difference is whether practice is undertaken in a blocked, serial or random manner. If practice is blocked then one would undertake extensive practice on one task or component before moving on to the next, rather than

rotating through each of the components in a serial order or randomly practising a number of tasks or components. One of the major differences as a consequence of the different approaches is the varying influence of contextual interference. Random practice, alternating between tasks and the task requirements will clearly have much greater contextual interference than a blocked practice approach.

Research on simple tasks has shown that practice with high contextual interference may initially result in a detriment to performance during acquisition but result in superior performance on transfer or retention testing (Brydges et al. 2007; Hall & Magill 1995; Magill & Hall 1990). However, once again this may not be the case in more complex tasks such as those undertaken by health professionals (Wulf & Shea 2002) and may be dependent on the task itself, with randomised practice more effective for skills with parameter modifications originating from the same generalised motor program. However, some authors feel the learning benefits of contextual interference are more likely to occur when the skill variations are from different classes of movement (Hall & Magill 1995; Magill & Hall 1990; Rose & Christina 2006).

Brydges et al. (2007) evaluated this phenomenon in health professionals by comparing whole practice with two part-practice groups (blocked and random) on a bone plating task. They found whole practice to be better during post-testing when a high degree of interlimb coordination was required. Another interesting finding was that task variability in the acquisition sessions (randomised practice) improved retention, independently of how well they performed during the practice session, and that this could improve the generalisation of the skills (Krakauer 2006; Shea & Kohl 1991).

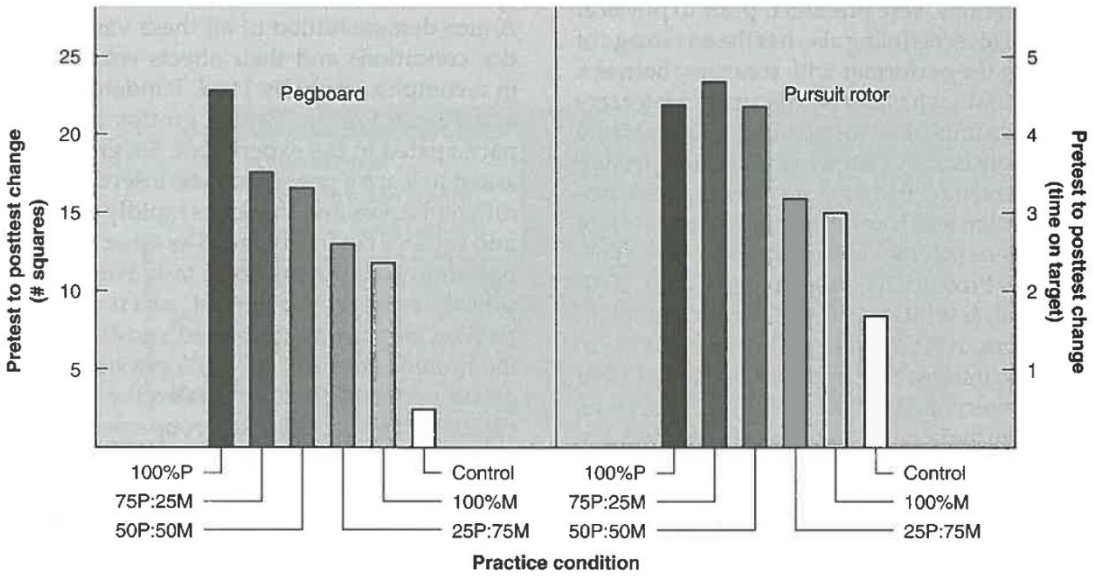
Del Rey, Whitehurst and Wood (1983) suggest that random practice may not be effective until learners understand the dynamics of the task. Furthermore, benefits may also be influenced by factors such as a person's level of experience (Del Rey, Whitehurst & Wood 1983; Del Rey, Wughalter & Whitehurst 1982; Rose & Christina 2006). Del Rey, Whitehurst and Wood (1983) reason that novice performers would not benefit from random practice schedules as much as more advanced performers. This is concurrent with the cognitive demand requirements outlined as part of the 'stages of learning' proposed by Fitts and Posner (1967) earlier Section 1.2.2.1, and may be related to the need to understand the task dynamics.

Physical versus mental practice

As with motor skill acquisition in sport and music, mental practice can improve quality of performance in students studying in the health professions (Arora et al. 2011). Stalling (1976) is credited with the Information Processing Model which conceptualises the application of mental imagery (Bachman 1990). This theory encapsulates learning as a closed loop system of sensory input, central processing, motor output, and feedback (Bachman 1990). Mental imagery is conceptualised in this framework as an element of central processing that serves to facilitate the transfer of the psychomotor skill information into the long-term memory by prolonging the storage of information in the short-term store (Bachman 1990).

Doheny's study (1993) investigating the effect of mental imagery in learning an intramuscular injection task included four research groups: mental practice only, relaxation only, combined mental practice and relaxation, and a control group. Within these groups she identified low and high imagers based on the Vividness of Movement Imagery Questionnaire (VMIQ). Doheny (1993) found that less than a third of each of the mental imagery, or mental imagery plus relaxation group used the prescribed techniques with considerable group cross-contamination. This was attributed in part to elements of environmental and intrinsic influences such as fear and stress. However, it was found that those classed as high imagers on the VMIQ were the most likely to use mental imagery and gave a more acceptable performance, independent of their assigned group. It is possible that this merely represents the individuality in student learning styles and their ability or desire to use such techniques. The study participants felt that actual practice was most helpful and that mental practice was only useful when combined with physical practice (Doheny 1993).

A good example of the interactive effect of mental practice and physical practice conditions was demonstrated in the research undertaken by Hird et al. (1991) who demonstrated significant improvements over time on a pegboard and pursuit-motor task for mental and physical practice groups. However, the greater the proportion of physical practice compared to mental practice, the greater the improvement (Figure 1.2-4).



P = Physical practice, M = Mental practice; Ratios of type of practice undertaken by each group provided.

Figure 1.2-4: Pre-test to post-test change on Pegboard and Pursuit rotor tasks (Reprinted with permission, from R.A. Schmidt and T.D. Lee, 2011, *Motor control and learning: A behavioral emphasis*, 5th Ed. (Champaign, IL: Human Kinetics), 360. Adapted from Hird et al. 1991, "Physical practice is superior to mental practice in enhancing cognitive and motor task performance," *Journal of Sport and Exercise Psychology* 13(3): 281-293).

The role of mental imagery in complex skill learning has been further confirmed with electrophysiological studies, such as that by Pascual-Leone et al. (1995) who demonstrated via repetitive Transcranial Magnetic Stimulation (rTMS) that mental practice alone led to the same plastic changes in the motor system as those created by repeated physical practice on a five-fingered piano sequence task. Performance changes were evident in the mental practice group although to a lesser degree than those made by the group undertaking physical practice alone.

Indirect practice elements influencing motor learning

Feedback (intrinsic and extrinsic)

Generally speaking, without feedback, learning will not occur (Gomez & Gomez 1984). Feedback can occur both intrinsically (inherent) to the learner employing the sensory system, (kinaesthetic, visual, cutaneous and auditory input) (Wierinck et al. 2005), or via extrinsic (augmented) feedback such as from an instructor (Gomez & Gomez 1984; Oermann 1990). The role played by these two different types of feedback changes in importance along the learning spectrum. Mars et al. (2005) found that timing-dependent activation of the anterior cingulate, part of the brain responsible for error

detection and correction, was activated by extrinsic feedback early in the learning process and via intrinsic feedback later in the learning process.

Augmented feedback can be positive or negative and may take a number of forms. It may be feedback on the performance itself (knowledge of performance (KP)) or the outcome (knowledge of results (KR)) and can be provided concurrently or at the conclusion of the task (Gomez & Gomez 1984; Wierinck et al. 2005; Wulf, Shea & Lewthwaite 2010). There is still debate on the optimal timing, frequency, amount of feedback and the intervening role of contextual interference on the learning process. Early opinion suggested that a decrease in feedback over trials or even a short delay may enhance motor learning, however a review by Wulf and Shea (2002) highlights how this is not necessarily the case for complex skill learning. Gomez & Gomez (1984) suggest that augmented feedback should occur soon after the performer has had the time to organise and consolidate movement and intrinsic feedback. However, a delay in feedback may not affect learning provided there is no contextual interference, including from recommencement of the motor performance (Gomez & Gomez 1984). Terminal feedback provided intermittently as a summary at the conclusion of a number of trials rather than every trial can also impact learning, showing benefits in transfer testing; the ideal number of trials for this to occur will vary depending on the complexity of the task (Schmidt et al. 1989; Shumway-Cook & Woollacott 2011).

Research investigating motor skill learning of a dental procedure using virtual reality found no difference in continuous and intermittent augmented feedback on retention and transfer after four months without practice, but both were superior to the control condition which did not receive any training or feedback (Wierinck, Puttemans & van Steenberghe 2006). In another relevant small study, O'Connor et al. (2008) found that both KR feedback, and KR feedback with concurrent instruction were significantly better than a control group on a laparoscopic suturing task. There were no significant differences between the two feedback groups. Porte et al (2007) showed superior suturing performance on retention testing for a group receiving verbal feedback compared with two groups receiving computer generated feedback; they were the same on all other measures. Contrary to this, Stefanidis et al. (2007) found that limited feedback, combined with access to video tutorials on a laparoscopic training task, was superior to the group which received intense feedback but limited video tutorial access.

Guidance effect

Excessive feedback may also have a detrimental effect on learning. Wierinck et al. (2005) studied students undertaking preparation of a dental cavity and found that excessive information provided by a virtual reality trainer overwhelmed the students and had a negative effect on learning. The authors proposed that when augmented feedback is provided too frequently, the learner becomes dependent, no longer adequately using intrinsic mechanisms and is consequently unable to perform as well when it is withdrawn (Wierinck et al. 2005). This is termed the 'Guidance Effect' (Buchanan & Wang 2012; Salmoni, Schmidt & Walter 1984). Wulf & Shea (2002) suggest that the reliance on external feedback, underpinning the guidance effect theory, is less relevant in a complex task due to an increased number of contributing elements, decreasing the likelihood that feedback will encompass all aspects and lead to dependence. Buchanan & Wang (2012) also recently challenged the guidance effect, suggesting that constant feedback can be beneficial, but requires a suitable model that utilises visual augmented feedback whilst concurrently emphasising proprioceptive processes, thereby maximising intrinsic and extrinsic mechanisms in parallel. However, this theory is in its infancy and may be restricted to a specific model of visual rather than other forms of sensory feedback.

Externalisation of focus

The reviews by Wulf & Shea (2002) and Wulf et al. (2010) introduced a number of studies which suggest that feedback and explicit guidance with an extrinsic focus rather than a focus on the body movements themselves results in improved motor learning. The study example used was from an earlier study of theirs using a ski simulator task which encouraged participants to focus on the ski platform itself and not the movement of the feet (Wulf, Höß & Prinz 1998). This technique has also been successfully used in guiding a golf swing, tennis backhand and numerous other sports, in a variety of study populations with differing levels of experience (Wulf et al. 2002; Wulf, Shea & Lewthwaite 2010). Wulf and colleagues believe this effect is generalisable to the acquisition of other real world skills and therefore applicable to motor learning in the health professions.

Wulf et al. (2010) report that this externalisation of focus promotes the utilisation of unconsciousness or automatic processes rather than a more conscious type of control which accompanies an internal focus. This conscious control may actually have the

effect of constraining the motor system. This theory has been supported by physiological studies showing a higher frequency of low-amplitude movement adjustments and decreased EMG activity when an external focus is adopted (Vance et al. 2004; Wulf, McNevin & Shea 2001; Zachry et al. 2005)

Explicit learning

In Section 1.2.2.2, we discussed how implicit learning (procedural knowledge) differs to explicit learning (declarative knowledge). As outlined, implicit learning can occur even without explicit knowledge or an understanding of the task. However, explicit knowledge of a task can aid in improving performance and overall learning of that task or impede learning depending on the circumstances. One way that this explicit knowledge may be acquired is via extrinsic feedback, as discussed. The impact of prior explicit knowledge relevant to implicit learning is uncertain. Although, it does seem that the type, timing and meaningfulness of the information is important (Boyd & Winstein 2001).

If we go back to the SRTT example used earlier when discussing implicit learning, it is easy to see how explicit knowledge of the repeated sequence could improve performance. Willingham, Nissen and Bullemer (1989) demonstrate that participants who developed explicit knowledge of the repeated sequence over a series of trials outperformed those who had not. However, explicit information may also be provided, like 'how-to' instructions. Boyd and Winstein (2001) present experiments where prior explicit information provided was beneficial to implicit learning on the SRTT. An example of prior explicit knowledge benefitting complex learning would be how a novice racing car driver with declarative knowledge of a racetrack configuration or working knowledge of physics as it applies to car motion may perform better during a race and improve at a greater rate than one who did not. Furthermore, recent studies have found that explicit knowledge, or the ability to verbalise task requirements improves task performance in overlearned skills (Crump & Logan 2010; Ghilardi et al. 2009; Krakauer & Mazzoni 2011). This contradicts the original belief that as things become well-practiced and automatic they no longer utilise explicit control (Krakauer & Mazzoni 2011).

Results on the SRTT and other tasks are contradictory with some authors finding explicit information able to enhance implicit learning (Curran & Keele 1993;

Willingham, Nissen & Bullemer 1989), whilst others argue that explicit knowledge may in fact impede learning (Green & Flowers 1991; Vidoni & Boyd 2007; Wulf & Weigelt 1997). One suggestion is that this may be the consequence of neural competition between the implicit and explicit memory systems during learning (Poldrack et al. 2001; Vidoni & Boyd 2007). It may be that rules outlining task requirements are unable to be expressed explicitly, or that the cognitive demand imposed by instructions disrupts the formation of an implicit motor plan (Green & Flowers 1991; Wulf & Weigelt 1997).

Explicit knowledge may be acquired internally via intrinsic feedback mechanisms (Vidoni & Boyd 2007). However, it is currently not known how this differs to explicit knowledge acquired extrinsically (KR) except that it is likely to have a lower cognitive load (Vidoni & Boyd 2007). In their study, Vidoni and Boyd (2007) found that internally acquired explicit knowledge did not disrupt learning, but did affect the variability of performance during the acquisition phase. Thus, it may be that the effect of explicit information on implicit learning may be dependent on the population, the task concerned and how explicit knowledge is obtained (Vidoni & Boyd 2007).

The only example found comparing implicit and explicit learning on a complex task in health professionals was a study by Masters et al. (2008). They compared three groups: an observation only group, an observation with instruction group, and an observation with guidance group on a suturing and knot-tying task. Minimal differences were determined between the groups, particularly on the retention test. However, there seemed to be a number of associated issues with the study. Firstly, the conditions which would reportedly invoke implicit or explicit learning were inconsistent with common thinking and definition. For example, the cohort considered the observation only group were represented as learning via explicit processes, whilst the observation *and* guidance group were considered to be learning implicitly. Furthermore, there appears to be insufficient differentiation between each of the conditions and little consideration of the possible influence of feedback on the groups.

Motivation, self-efficacy and anxiety

According to sociocognitive theory, feedforward, self-regulatory mechanisms will influence performance and learning through cognitive, motivational, affective and decisional processes (Bandura 1997; Bandura & Locke 2003). This can apply to motor learning. Some of the psychological factors which may contribute to motor learning

include intrinsic motivation and self-efficacy at one end of the spectrum and anxiety at the other. Kaufman, Wiegand and Tunick (1987) state that motivation contributes significantly to the acquisition and retention of a learned skill and whilst a certain level of arousal is required, anxiety is detrimental to the learning process. Each of these factors may also display a degree of interdependency; evidence consistently demonstrates a high correlation between an individual's self-efficacy, motivation and performance (Bandura & Locke 2003).

There are two forms of motivation identified, intrinsic and extrinsic (Deci, Koestner & Ryan 1999; Prat-Sala & Redford 2010). Intrinsic motivation is characterised as a desire to perform a task for no apparent reward other than the enjoyment or desire to perform that task, whereas extrinsic motivation exists when another reward, including recognition, exists (Deci, Koestner & Ryan 1999; Prat-Sala & Redford 2010). The literature investigating the effect of pre-training motivation on post-training performance is conflicting, with evidence that in a range of administrative, managerial and academic domains it may correlate positively (Warr & Bunce 1995), negatively (Tannenbaum et al. 1991) or not at all (Mathieu, Tannenbaum & Salas 1992; Noe & Schmitt 1986). In the only example specific to the health professional context, Thuraisingam, MacDonald and Shaw (2006) identified motivation as important in the successful learning of practical skills during a qualitative investigation of endoscopy trainees (Mageau & Vallerand 2003; Vallerand & Rousseau 2001).

Self-efficacy also plays an important role.

"Perceived self-efficacy refers to beliefs in one's capabilities to organise and execute courses of action required to produce given attainments" (Bandura 1997, p.3)

Improved self-efficacy has been linked positively with motivation (Bandura & Locke 2003; Colquitt, LePine & Noe 2000; Gist & Mitchell 1992) and inversely with anxiety (Bandura & Locke 2003; Chen et al. 2000; Colquitt, LePine & Noe 2000; Gist & Mitchell 1992; Martocchio 1994), itself affecting performance. A number of reported experiments found that lower self-efficacy was the major predictor of anxiety, even more than an individual's susceptibility to anxiety (Bandura 1997). Subsequently, self-efficacy may mediate anxiety and the effect anxiety has on performance (Bandura 1997; Chen et al. 2000). Therefore, boosting self-efficacy may be an important strategy in teaching. These findings are consistent within the educational psychology literature;

self-efficacy has been shown to interact with motivation, affective processes, fear and anxiety and therefore subsequent behaviour (Bandura 1997; Prat-Sala & Redford 2010). For example, students with greater self-efficacy are more likely to be intrinsically motivated, show greater perseverance and feel less stressed (Prat-Sala & Redford 2010). Self-efficacy is also likely to improve as a result of learning, experience and feedback (Gist & Mitchell 1992), with a corresponding decrease in anxiety. Capa, Audiffren and Ragot (2008a, 2008b) support this theory, hypothesising that achievement motivation and task difficulty have an impact on effort and the amount of cognitive resources used to perform the task. To extrapolate this, students who show improvements in learning scalpel techniques should have a subsequent increase in intrinsic motivation, potentially improving performance further.

"Anxiety is defined as a state of anticipatory apprehension over possible deleterious happenings" (Bandura 1997, p.137).

Finally, anxiety is considered to have a negative effect on motivation to learn (Colquitt, LePine & Noe 2000) and learning and performance (Thuraisingam, MacDonald & Shaw 2006). As previously discussed, anxiety may be heavily influenced by an individual's motivation and self-efficacy. One hypothesis is that someone more anxious prior to performing a task may have fewer cognitive resources available for that task (Chen et al. 2000; Kanfer & Ackerman 1989; Kanfer & Heggestad 1997).

Generally, performance in learning has been linked to a number of factors, including trait-like individual differences such as cognitive ability, and state-like differences such as an individual's self-efficacy and anxiety. State-like factors are relevant to certain tasks or situations, with a greater potential for change over time (Bandura 1997; Chen et al. 2000). It is likely that state-like constructs mediate the effect that more distal trait-like characteristics have on learning performance (Chen et al. 2000). In a meta-analytical study on training motivation, which includes (but is not limited to) skill acquisition, Colquitt, LePine and Noe (2000) found that a model partially mediated by factors proximal to the learner such as cognitive ability and anxiety best explained more distal factors such as skill acquisition. These proximal factors, including such things as pre-training self-efficacy, could explain 73% of the variance in motivation to learn, 87% of the variance in declarative knowledge and 29% of the variance in skill acquisition outcomes. The relevant mediating antecedents, such as motivation to learn, was a

significant predictor of four performance outcomes including: skill acquisition, declarative knowledge and post-training self-efficacy and reactions to training as an attitude outcome (Colquitt, LePine & Noe 2000).

Artificially manipulating self-efficacy has a positive effect on performance and this can be achieved at both an individual and group level (Bandura & Locke 2003), providing a potential strategy for educators to lower anxiety and improve performance and motor learning. There are consistent findings that managing perceived self-efficacy is of greater benefit than merely managing anticipatory anxiety in avoidance behaviour (Bandura 1997), and therefore may be a more suitable method of managing students learning to use scalpels. For example, Stevens et al. (2012) found that practice on an easier version of a stick balancing task improved participants' self-efficacy and transfer of learning from pre- to post- testing. Self-efficacy explained 55% of the variance of the post-test performance.

Goal setting

Another way motivation may be manipulated during skill acquisition is by goal setting. This may be via goals set by the learner or the teacher, both of which have been shown to be beneficial to performance during learning and on a retention test (Boyce 1992; Schmidt & Lee 2011). Whilst goal setting, particularly for absolute goals of moderate difficulty, has been found to have an influence on motor learning and skill acquisition (Kyllo & Landers 1995; Schmidt & Lee 2011) in both sports (Locke & Latham 1985) and rehabilitation, it has not been tested for complex skill learning in the health professions. Kanfer et al. (1994) outlined how the results of a meta-analysis by Wood, Mento and Locke (1987) show that the effect of goal setting may be reduced when considering more complex skills. Furthermore it is important to consider the detrimental impact negative feedback may have on learning if set goals are not achieved (Wulf, Shea & Lewthwaite 2010). This is particularly important since the primary benefit derived from goal setting is believed to be as a consequence of the competitiveness it introduces and subsequent positive effects on motivation (Locke 1996; Schmidt & Lee 2011).

Autonomy

Interestingly, when students have the ability to *choose* when or if they receive feedback about an individual psychomotor performance, they learnt the task better with improved

retention (Chiviacowsky & Wulf 2002, 2005). The effect is negated when participants are required to pre-select whether to receive feedback or not (Chiviacowsky & Wulf 2005), suggesting that their choice is related to their own perception of performance, with a preference for feedback after a good performance (Chiviacowsky & Wulf 2005, 2007). Further investigation confirmed that feedback after a 'good' trial is more effective than providing feedback after 'poor' trials (Chiviacowsky & Wulf 2007; Wulf 2007). In the study by Chiviacowsky and Wulf (2007) 'good' feedback groups and 'poor' feedback groups showed similar inter-trial variation suggesting that the mechanism is not related to a reduction in response variability subsequent to feedback. It has been postulated instead that these findings relate to the motivation and engagement of the student in the learning process (Chiviacowsky & Wulf 2007; Wulf 2007; Wulf, Shea & Lewthwaite 2010). This phenomenon has been supported through performance-based studies (Badami et al. 2011) and neurophysiological studies, involving fMRI and EEG of the cortex during motivationally relevant positive and negative feedback (Nieuwenhuis et al. 2005). Further evidence for motivation as a driver is provided by Chiviacowsky and colleagues (2012) who found that manipulating the participant's own perception of what constituted a good performance (to make a good performance more achievable) improved self-efficacy, resulted in greater accuracy and less variability on retention and transfer tests.

The benefits of autonomy are not limited just to feedback but also other aspects of motor learning including during observational learning. In one study, not on a health professional population, one of the study groups with autonomy over viewing a video modelling a skilled performance (basketball shot) showed superior learning to participants who did not have control over video viewing (Wulf, Raupach & Pfeiffer 2005).

Wulf et al. (2010) argue that the effectiveness of many of the benefits derived from practice conditions outlined earlier, such as observational or self-directed learning, are to a large extent the result of optimised motivational states of the learner. This theory was first suggested by Titzer et al. (1993) who found a research group having autonomy over their practice schedule outperformed both block and random practice groups on a barrier knock-down task. This is further evidenced by the findings of Post and colleagues (2011) on a non-dominant hand dart-throwing task, whereby having an element of autonomy over when to practice resulted in improved performance. This is

consistent with other elements of individual control and remains an important consideration when interpreting study findings.

Teaching methods

The teaching methods employed may also have a direct impact on motor learning and skill acquisition. Although the evidence is not clear, it seems a balanced approach to teaching is needed, utilising multiple methods, based on factors such as learning styles of the students (Knight 1998), the need for feedback (Milde 1988), anxiety and supervisory capacity. Love et al. (1989) compared two teaching methods, self-directed and laboratory-based learning, amongst nursing students for ten separate psychomotor skills ranging from catheterisation to suture removal. All students were provided with learning packages for self-directed learning, whilst one group attended additional laboratory skills sessions. Findings on two different clinical examinations showed no differences between the experimental groups on either examination. Contrary to this, Baldwin, Hill & Hanson (1991) found that teacher-facilitated learning resulted in an improved performance over those who undertook self-directed learning on a blood pressure taking task. However, the influence of augmented feedback and subjectivity of the measures used need to be taken into account when interpreting the results of this study. There were no differences in the self-reported confidence levels of students in the two groups (Baldwin, Hill & Hanson 1991).

A single-blinded randomised controlled study, comparing computer-based training and a traditional lecture and feedback technique on surgical stitches knot-tying skills, favoured the traditional method (Rogers et al. 1998). However, the authors acknowledge that a major difference between the two groups was the provision of augmented feedback to this group. Differences in explicit versus implicit instruction and practice between the two groups were not clear. This and other methodological issues make the interpretation of results difficult.

There have been improvements in the simulation learning models available. However, they do not seem to have considerably improved motor learning. A study by Anastakis et al. (1999) found that a variety of surgical training skills learnt on low-fidelity bench models were equivalent to training on cadavers. Also, in a small study, Naik et al. (2001) showed that intubation skills learnt on models transferred well into the operating room. Matsumoto et al (2002) compared a high-fidelity model, low fidelity model

(plastic cups) and didactic learning of an ureteroscopic procedure and found the use of both models to be superior to didactic learning, but no significant difference between the high or low fidelity versions. This was reinforced by Grober et al. (2004) who found that students who trained in microsurgery anastomosis on a low fidelity model performed equal to those who trained on rats. In addition to improved physical models there has also been an increased use of virtual reality trainers. Seymour et al. (2002) found that virtual reality training significantly improved operating room skill, although Hogle (2008) found that the predictive validity of a laparoscopic virtual trainer did not justify the high cost. Interestingly, Hogle (2008) also found that participants who were experienced video gamers performed better on the virtual trainer, but that this did not result in improved clinical performance.

In summary, our understanding of motor learning has developed substantially over the years. Motor learning theory has evolved from a closed-loop model to one where there is recognition of the perceptual, cognitive and motor systems working symbiotically in parallel. Feedforward processes based on internal models and feedback mechanisms all contribute to a coordinated motor output. This evolution of understanding in motor control theory has also meaningfully contributed to our current knowledge of motor learning and the contributing elements. In particular, we have a much better grasp of the processes of learning including error-based learning, reinforcement-based learning, use-dependent learning and structural learning. Further to this is the contribution of various types of learning such as observational learning, perceptual learning and implicit and explicit processes. However, much of the research is undertaken using simple motor tasks and as identified by numerous authors these findings may not be appropriate to complex tasks, such as the use of scalpels.

Various factors contribute to the relative success of these motor learning antecedents and processes. As discussed, these may be directly related to the physical process of practice such as the distribution and variability of practice or may indirectly influence practice and learning outcomes such as the role of feedback and psychological related aspects. These all play an important part in the acquisition of particular skills and need to be considered during the teaching of psychomotor skills such as scalpel use.

1.2.3. Dexterity

Reaching, grasping and efficient manipulation of the hand is the epitome of effective coordination, incorporating all of the factors and the underlying theory outlined previously. This is recognised by the term 'dexterity'. A common definition used to describe dexterity is a:

> *"manual ability that requires rapid coordination of gross or fine voluntary movements, based on a certain number of capacities, which are developed through learning, training and experience"* (Poirier 1988, pp.71-72).

Whilst this definition does not refer specifically to hand ability, it was written in the context of hand performance. Dexterity involves a wide variety of elements or capacities. In podiatry practice, performing a nail wedge resection (removal of an ingrown toenail) requires predominantly slow, precise fine motor actions and relies on good sensory perception, compared with callus debridement which requires a combination of rapid gross motor actions together with good visuomotor control and tactile feedback.

An example of precision motor learning relating to a dextrous performance is prehensile grasping, reaching and object manipulation (Touwen 1995), a good example of which is scalpel use. In part this is a consequence of the arm's dynamics changing over a relatively short time scale when we grasp objects and perform manipulation (Shadmehr, Smith & Krakauer 2010). It is believed that there is a relationship between the development of prehensile reaching with the maturation of underlying brain function (Forssberg et al. 1991; Touwen 1995). For example, whilst the development of the pincer grasp neural mechanisms may have matured by age one, it may take another two years for mature anticipatory precision grip force control to appear and children are able to use pincer grasp efficiently and automatically (Forssberg et al. 1991). Thus, the precision required within the sensorimotor system for efficient prehensile performance and relevance to scalpel use makes it an ideal task to study in a healthy population. The literature concerning motor control and the motor learning processes involved with prehensile development provides an important foundation for dexterity testing which can be applied to the podiatry and podiatry student population.

1.2.3.1. Evaluating dexterity

Dexterity has been evaluated in a number of contexts, for a variety of purposes including occupational aptitude, to evaluate underlying brain function, child development and motor learning. It has been evaluated in children, adolescents, adults and the elderly, and in numerous clinical populations. There is currently no gold standard measure nor agreed consensus regarding the best method to measure dexterity. One of the reasons for this may be the wide array of elements which contribute to a dextrous performance. Traditionally, evaluation has been through the use of functional tests which evaluate performance at a certain time point.

It is also likely that the broad range of contributing elements, the underlying purpose of the test and varying populations of interest forms part of the reason for the wide assortment of generalised dexterity tests (GDTs) which have been developed. Some of the GDTs are commercially available whilst others are custom and purpose built tests of dexterity and used for a specific task. Bear-Lehman and Abreu (1989) suggest that GDTs should be chosen which best represent assessment needs, whilst being different to the training task itself. Thus, one of the aims of this dissertation is to determine which tests best represent podiatric clinical experience and development of clinical skills without simply recapitulating the task itself.

Recently, there has been an increased use of virtual trainers in health professional clinical training and evaluation, particularly in the medical professions. Furthermore, technological advancement has resulted in the ability for us to measure neurophysiological changes such as cortical change associated with motor learning. However, the use of virtual trainers and neurophysiological tests are expensive and difficult to acquire or perform, making them currently unsuitable for use in podiatric training and evaluation. Consequently, the search for appropriate tests for use on a health professional population was restricted to GDTs. A systematic search and evaluation of the psychometric properties of tests was undertaken and is presented in Chapter 3.

1.2.3.2. Interventions to improve dexterity

"Behavioural performance could be improved through better state estimation (improved forward models, or improved processing of sensory feedback) or through better motor execution (improved signal-to-noise ratio in motor output). Which of these

processes is the rate-limiting step in skill learning is unknown" (Krakauer & Mazzoni 2011, p.640).

The research literature investigating the effect of interventions to improve dexterity has addressed a variety of issues. These include developmental coordination issues, injury (such as stroke) or to develop and refine skills beyond usual daily activity requirements. As an example, workforce groups such as chefs, surgeons or podiatrists need to reach an expert-like ability with knives or scalpels. Amongst the possible interventions, most have targeted the motor system. However, as previously outlined there may be times that this is unfavourable due to inherent dangers or other barriers and consequently alternatives may need to be sought. With an increasing understanding of perceptual-motor integration and an adoption of the DST of motor control, the focus may be on targeting the sensory-perceptual system rather than primarily the motor system. The following section outlines some of the strategies employed in improving dexterity in a healthy population.

Targeting the motor system

A search of the peer-reviewed literature identified few articles targeting motor practice to improve hand function for a healthy population. One which was identified investigated the effects of shaping exercises often used in conjunction with constraint induced movement therapy (CIMT) as part of stroke rehabilitation (Taub et al. 1994). The concept of *shaping* is to perform structured tasks of increasing complexity aimed at gradually introducing elements of normal hand function (Brogårdh et al. 2010). These tasks are usually performed in conjunction with intense feedback from the practitioner. Brogårdh et al. (2010) compared an intervention group of healthy adults undertaking shaping exercises, to a control group also made up of healthy adults undertaking standard hand exercises and measured subsequent change in dexterity using the Purdue Pegboard (PP) and TMS over a short time period. They found a significant improvement in the shaping exercise group on the PP and a forward shift in the excitable region of the motor cortex via magnetic stimulation.

In a second study, Yadav and O'Regan (2010) evaluated increases in dexterity in the non-dominant hand through forced increased use during specific daily activities (such as cleaning teeth or shaving). Dexterity was found to improve in the non-dominant hand using a simple 'circle-dot' test. However, this study used participants as their own

control rather than having a separate control group and found significant improvement in the dominant (non-practised) hand, raising concerns about their interpretation of findings.

Targeting the sensory system

As outlined earlier, changes to the somatosensory system can have a substantial influence on the motor system. Despite this, few studies have looked at improving hand function, let alone dexterity via sensory training (Liepert 2010; Pollock et al. 2014; Schabrun & Hillier 2009). Unfortunately, these are predominantly studies involving passive sensory training rather than active techniques. For example, of the 14 controlled studies reviewed by Schabrun and Hillier (2009), only six utilised active sensory training, none of which evaluated upper limb motor function. Passive sensory training includes techniques such as synchronous or asynchronous peripheral nerve stimulation which does not produce muscle stimulation, or is paired with other forms of electrical stimulation. Passive sensory training has been found to be effective in improving hand motor function (Liepert 2010; Pollock et al. 2014; Schabrun & Hillier 2009), however our focus is on active techniques for this thesis. Active sensory training involves an active engagement of the learner via education, proprioceptive training, the localisation and discrimination of sensation and other sensory practice techniques. Unfortunately, many of the studies which used active sensory training techniques in the reviews above involved only the lower limb or did not evaluate motor learning.

Despite the lack of evidence for active sensory education techniques reported in these reviews, active sensory training or re-education is not new, with reports of it being used in a stroke population extending as far back as 1959 (Forster & Shields). Of the studies involving active sensory training, many originated in the context of stroke rehabilitation or other clinical populations with only a small number presenting data on a healthy population. The most recent of these was a study by McDonnell, Hillier and Esterman (2013) who evaluated an algorithm to be applied to hemiparetic patients and included the use of proprioceptive training and other active sensory training techniques. Whilst sensory training was only delivered to participants with specific identified sensory loss, results for the participant cohort showed significant improvements overall for patients on functional hand measures or tests incorporating functional hand measures (Action Research Arm Test (ARAT), Fugl-Meyer Assessment (FMA), Motor Activity Log (MAL), Pinch Grip Strength (P-MVC), Grip Strength (G-MVC) and Finger Tapping

Test (FTT)) (reported p values between < 0.001 and 0.009). Another study in the same year investigated the use of a home sensory re-education tool comprising 12 small tubes made up of different sensory elements (Kalron et al. 2013). An initial seven week period of occupational therapy sessions was provided involving repeated exposure to non-specific stimuli varying in textures, shape, size, weight, handedness and temperature. Subsequent to this a three week home program of 20 minutes per day, for five days per week was undertaken using the training tool comprising of twelve tactile stimulation elements. Significant improvements were found on the nine-hole peg test (Mean (SD) = 26.8(4.4)) versus 22.6 (3.2), p = 0.03) and functional dexterity test (Mean (SD) = 38.6 (4.4) versus 33.8 (4.9), p = 0.02). However, this did not utilise a cross-over design to eliminate time or order effects meaning the results may have been the result of intervention over time, independent of what that intervention was. Interestingly, sensory assessments including Semmes Weinstein monofilaments and two-point discrimination did not show any significant differences.

In a subacute stroke population, Helliwell (2009) sought to investigate improvements in the motor function of the upper limb. Unfortunately, many of the recruited participants were either lost to follow-up or excluded leaving only one participant. This, together with reported compliance issues means study findings are unlikely to be sufficiently generalisable to be relevant to this thesis. Similarly, Smania et al. (2003) reported findings of a study investigating sensory training on stroke survivors. Training involved tactile discrimination, object recognition, joint position sense, weight discrimination, reaching and grasping, item grouping, and daily life activities, but they only studied four participants, making suitable conclusions difficult.

Byl et al. (2003) compared sensory training and fine motor practice in a crossover design study on 18 participants who had suffered a stroke. Each intervention lasted four weeks, with the order randomised but no reported washout period in between. Sensory training consisted of a broad variety of activities grouped according to the following headings: Use stress-free hand strategies in all hand activities, Improve sensory discrimination, Quiet the nervous system and Reinforce learning with mental rehearsal. This included activities such as shaping the hand around objects, reading braille books, placing the hand in a box full of tactile objects (such as rice), putting cloth tape on the skin to increase sensory stimulation and mental practice. Sensory and performance testing of the hand was undertaken using tests of graphaesthesia, kinaesthesia,

stereognosis, and digital reaction time, plus the PP, G-MVC and range of motion testing. During the sensory training period, significant within-group gains were assessed in sensory discrimination, fine motor function and musculoskeletal measurements ($p \leq 0.005$, $p < 0.025$ and $p < 0.05$ respectively). These results were independent of the order in which the interventions were undertaken. During motor training significant improvements were seen in tests of fine motor skills and musculoskeletal measures ($p < 0.02$ and $p < 0.05$ respectively). Interestingly, those undertaking motor training first, followed by sensory training, demonstrated a greater improvement in fine motor skills (Byl et al. 2003).

Zeuner et al. (2002) undertook a trial of sensory training via braille reading on a population of patients suffering from focal hand dystonia (FHD) and healthy participants. The only motor outcome reported was the time required to write a paragraph. The FHD group did not show a significant improvement over the eight week intervention period. A one year follow-up was undertaken with three of the FHD patients who did report individual improvements, but did not include the healthy controls (Zeuner & Hallett 2003). Hence, this was a small cohort presented more like case studies. Thus, we cannot be confident that any improvement was the result of the sensory training.

A number of additional case studies and case series have been published outlining improvements in motor function subsequent to sensory training; whilst contributing to the body of literature, these are of low evidence level and therefore making conclusions relating to this research should be considered with caution. Byl, Nagajaran and McKenzie (2003) investigated sensorimotor training in a cohort suffering from FHD. In a case series of three participants they found mixed results relating to improved motor performance, reporting some positive findings such as a 23.9% increase in fine motor skill and 31.9% increase in musculoskeletal skills, however none of the participants showed improvements on the digital reaction time test or PP, two well recognised psychomotor tests. In another case study involving a patient suffering neuritis secondary to leprosy Nakada and Uchida (1997) implemented a sensory re-education program incorporating five stages: feature detection and recognition, correction of the pattern of prehension in the hand, control of force for grasping objects, maintenance of grip force during movement and manipulation of objects. There were observed and reported improvements in activities of daily living. A number of studies and reviews

investigating sensory re-education after nerve repair surgery were evident. A systematic review undertaken by Miller, Chester and Jerosch-Herold (2012) summarised the evidence from these, stating that many of the articles suffered from methodological issues such as low sample sizes, a lack of blinding and poor randomisation. In spite of this, the review provided limited evidence to support the use of early or late sensory re-education subsequent to nerve repair surgery (Miller, Chester & Jerosch-Herold 2012)

In addition to studies of clinical populations, research aimed at improving dexterity in healthy populations has also been undertaken. Yamada et al. (2010) undertook a study to evaluate the effect of perceptual learning on hand function. Eighteen healthy volunteers undertook a perceptual tactile task requiring them to discern the length of six sticks of different lengths. We assume that a large component of the perceptual training is visually biased; however, we cannot eliminate the possibility of tactile or proprioceptive processes playing a part. They showed a significant improvement in hand skill improvement ratio via a ball rotation task ($p = 0.022$). Manjunath and Telles (1999) undertook a study on three separate groups. Two groups undertook yoga, one group by choice, the second mandated by an employer and the third group was a control group. Manjunath and Telles (1999) found a significant change in tweezers dexterity subsequent to yoga training in the first group. However, the second intervention group only made a slight improvement in dexterity which did not reach statistical significance. The researchers thus reported the improvements observed to be motivation related, as the major difference between the two yoga intervention groups was the participants 'choice' to attend. This introduced a significant bias to the study.

Feldenkrais method

One active sensory training method available is the Feldenkrais method, an awareness training technique first developed by Moshe Feldenkrais (1904-1984). Feldenkrais method is "… an educational system that develops a functional awareness of the self in the environment" (Buchanan & Ulrich 2001, p.316), believed to "…stimulate the plastic properties of the nervous system and to explore and fill-in gaps and missing links in a person's neuromuscular self-image through a sensory-motor awareness" (Lyttle 1997, p.262). The role of the Feldenkrais method within motor control paradigms has been discussed by Bate (1994). Within this article the authors have started to consider the similarities which exist between Feldenkrais method and the DST of motor learning (Buchanan & Ulrich 2001).

"Dynamic systems theory (of motor learning) and Feldenkrais method hold in common the principle that multiple subsystems interact to produce behaviour. Changing a subsystem and, thus the relationship among subsystems might cause a behaviour to change" (Buchanan & Ulrich 2001, p.320).

There are two main mechanisms which may be used in Feldenkrais method, Awareness Through Movement (ATM) and Functional Integration (FI). The ATM process "…facilitates the learning of strategies for improving organisation and coordination of body movement by developing spatial and kinaesthetic awareness of body-segment relationships" (Connors et al. 2010, p.1642). ATM lessons (unlike FI lessons) are usually conducted in a group setting. The practitioner verbally guides participants through a sequence of gentle movements based on functional activities such as reaching. A qualitative study evaluating the elements of Feldenkrais ATM sessions was undertaken by Connors et al. (2010). They identified a number of motor learning aspects incorporated within individual elements varying from intrinsic feedback to mental practice and imagery. The most prevalent elements identified across the 16 lessons were variability of practice, repetition, intrinsic feedback, and exploratory learning which is consistent with current concepts of motor learning principles, in particular the DST (Connors et al. 2010). Feldenkrais lessons focus on attending to sensory information present during exploratory movements. In this way, participants can improve perception sensitivity and therefore adapt motor behaviours more easily (Buchanan & Ulrich 2001). However, Ives (2003) contradicted this, stating that the Feldenkrais method was not effective at changing motor performance, due to an "…inappropriate attentional focus and an overemphasis on kinaesthetic training" (p.120).

The Feldenkrais method has been trialled for the management of a broad variety of conditions including Multiple Sclerosis, cancer (colon, breast, genital, other), neck and shoulder issues, and chronic back pain (Ernst & Canter 2005; Hillier & Worley 2015). It has been reported to be successful in managing chronic pain, back pain, increasing hamstring length, improving balance and gait speed in older adults, and in the management of other musculoskeletal disorders (Connors et al. 2010; Connors, Pile & Nichols 2011). Unfortunately, much of the research lacks adequate control and suffers from other serious methodological problems (Ives & Shelley 1998).

There have been two systematic reviews undertaken on Feldenkrais method as an intervention. The first review by Ernst and Canter (2005) has recently been updated by Hillier and Worley (2015), who reviewed 14 randomised controlled trials, including six which comprised the original review. The authors reported a high risk of bias of the articles reviewed. Pooled data supported the effectiveness of Feldenkrais ATM for improving balance in the elderly population. Data from single studies also supported evidence for a decrease in perceived exertion, improved body image perception, and for dexterity (Hillier & Worley 2015). Only two studies specifically addressed the use of Feldenkrais method on dexterity. The earliest of these was a study by Johnson et al. (1999) who measured the effect of Feldenkrais method compared with sham in an eight week cross-over randomised controlled study on hand dexterity in 20 people with Multiple Sclerosis. Dexterity measures utilising a 9-hole peg test did not show a significant difference in performance.

In a more recent study, which acted as the impetus for this research, Bitter, Hillier and Civetta (2011) trialled sensory awareness training based on the Feldenkrais method, compared with sham relaxation sessions to improve dexterity in a group of healthy university students. Training sessions were 40 minutes duration with performance testing immediately before and after training. The dexterity of the dominant and non-dominant hands was assessed using the PP, a Grip-lift task using a manipulandum and via self-perceived changes. The manipulandum is a device used to measure grip-force variables when lifting an unknown weight (explained in more detail in Chapter 4, Section 4.2.1.3). A significant difference was found on the PP in favour of sensory awareness training when data for the two sensory awareness groups (dominant and non-dominant hands) were pooled. There was also a desirable decrease in maximum grip force on the manipulandum, indicating improvement in dexterity.

Whilst the suitability of the Feldenkrais method to improve motor learning has attracted significant debate, the evidence for psychological benefits is reportedly more clear (Ives 2003; Ives & Sosnoff 2000). Of note, and relevance to this thesis are two studies by the same group investigating the effects of Feldenkrais method on anxiety (Kerr, Kotynia & Kolt 2002; Kolt & McConville 2000). Kolt and McConville (2000) compare the effects of two weeks of Feldenkrais method ATM, relaxation or no treatment (control) on 54 undergraduate physiotherapy students. Anxiety was evaluated via the Composed-Anxious scale of the Profile of Mood States-Bipolar form (Lorr & McNair 1982) at four

time points: prior to intervention, prior to the fourth session, directly after the fourth session and one day later. The authors reported a significant effect on anxiety for the Feldenkrais group over time compared to control (but not the relaxation group) for the female cohort only at the last two time points. The same research group (Kerr, Kotynia & Kolt 2002) completed a subsequent study investigating the effects of one 1-hour Feldenkrais ATM lesson and a 10 week hourly ATM series on state anxiety in volunteers who were either new or familiar to Feldenkrais method using the State-trait Anxiety Inventory (STAI)(Spielberger 1983). They found that state anxiety was decreased over both the single lesson ($p < 0.005$) and the series of lessons ($p < 0.005$), with a significantly greater reduction in state anxiety scores of new students compared to students familiar with Feldenkrais method ($p < 0.05$). However, it is important to note that there was not a control group and only three of the new students completed the entire 10 weeks of intervention.

1.3. Summary

Over time there has been a large change in thinking with respect to motor control and motor learning. Part of this change has included a greater recognition of the role that perception and sensation plays in both feedforward and feedback mechanisms, and how this then influences motor output.

With this increased recognition, particularly in relation to sensory dysfunction, there has been an increasing focus on the sensory system. A prime example is in the area of stroke rehabilitation, a common cause of sensory dysfunction. Passive sensory training and active sensory training have been used to improve sensory recovery and the effect it has on motor outputs is no longer being overlooked. Unfortunately, however there continues to be a much greater emphasis on passive techniques (sensory stimulation) rather than active processes such as sensory awareness training. The little research which exists on active sensory training techniques has focussed either on rehabilitation populations or on the lower limb.

Limited research on active sensory training of the upper limb in a healthy population has shown positive outcomes. However, this research evaluated immediate change rather than retention testing or the possible transfer effects required for it to be useful in a real-life functional capacity. If it is to be effectively used as an alternate when motor

practice is neither possible nor sufficiently safe, such as learning of scalpel skills in novice podiatry students, further research is required.

Thus, the intention of this thesis is to:

Identify how scalpel skills (manual clinical skills) are taught and assessed in podiatry programs in Australia and New Zealand

Determine which objective tests of dexterity are most commonly used and best suited to evaluating scalpel skills in a podiatry (health professional) population

Evaluate from a battery of selected objective GDTs and psychological inventory, which outcomes best correlate (represent) the level of experience of novice podiatry students or experienced podiatrists

Evaluate via a randomised controlled trial, the effectiveness of active sensory awareness training compared with additional motor practice on dexterity in novice podiatry students.

2. How scalpel skills are taught in Australia and New Zealand and associated issues (study one)

2.1. Introduction

Podiatry training has evolved from a master-apprentice model into university-based education, with the minimum requirement of a degree to practice in Australia and New Zealand. This has necessitated university podiatry programs to balance the need for sound theoretical knowledge worthy of a degree and the recommendation of 1000 hours clinical practice to meet registration requirements in Australia, with similar requirements elsewhere (*Accreditation Standards for Podiatry Programs for Australia and New Zealand v1.1* 2009). In order to meet these requirements most university programs in Australia and New Zealand have an associated clinic with the aim to maintain a practical and clinical focus as well as providing a community service. However, with increasing student numbers and subsequent pressure on clinical resources, including limited clinical placement options (*Data capacity and clinical placements across Australia: A discussion paper* 2008; *Mapping clinical placements: Capturing opportunities for growth - supply (clinical training provider) study* 2011), there is a need for an efficient but also safe approach to teaching manual podiatry skills. Scalpel skills were the focus of this study due to the integral role they play in podiatric practice, the high level of dexterity required, the anxiety the students seem to experience and the potential risks involved when learning scalpel skills.

Despite this need, there is a scarcity of podiatric literature and research to inform suitable teaching strategies or curricula development around clinical skills, particularly scalpel skills.

Therefore, the aims of this study were:

1. to determine the current approaches being used to teach manual skills, in particular scalpel skills, in university podiatry programs in Australia and New Zealand,

2. to explore what issues, challenges and innovations exist with the teaching of scalpel skills.

The method chosen was via structured interviews and subsequent analysis. This would allow sufficient flexibility for exploration of the topic, could capture the dearth of programs and staff without the associated costs of focus groups, whilst maintaining sufficient consistency required for a structured analysis of the data (see 2.2.3)

2.2. Methods

Ethics approval was obtained from the Human Research Ethics Committee at the University of South Australia (protocol no. 0000025089) (Appendix C).

2.2.1. Recruitment

A purposeful maximum variation sampling strategy was employed (Patton 2002, p.243) We targeted Program Directors for their ability to provide a global program overview and knowledge of curricular development, in addition to a nominated staff member involved in on-the-ground teaching chosen to provide a diversity of opinion and to increase the richness and strengthen the credibility of the data (Graneheim and Lundman (2004). An e-mail was sent to each podiatry Program Director at the eight universities in Australia and New Zealand offering podiatry programs at the time of the study. The e-mail invited the Program Director and another staff member from within his or her program to participate in a structured interview. Willing participants were then emailed an information sheet (Appendix D), consent form (Appendix E) and copy of the interview questions (Figure 2.2-1).

2.2.2. Data collection

Once a completed consent form was returned, an interview time was negotiated to occur face-to-face, or via telephone for participants located interstate to the researcher. A structured interview guide was used for each interview (Figure 2.2-1) with clarification sought by either party if required during the interview. Interviews were undertaken by the principal researcher (RC) only to ensure consistency. Questions were determined to

guide the interviewee to provide information related to the research aims. These questions were arranged under headings relating to the relevant areas. The headings were: how skills are taught, evaluation of skills and management of poor performers. The interview guide was developed in conjunction with the research team and piloted on two University of South Australia Podiatry teaching staff not involved in its development for content validity and to evaluate ease of use. No changes were made as a result of piloting. All interviews were recorded with either a Phillips Digital Voice Tracer 7790 (local) or 'Skype®' Voice over Internet Protocol (VoIP) (Microsoft Corporation) technology together with 'Call recorder™ (Ecamm Network, LLC)' software (interstate) for later transcription by the interviewer for analysis.

1) **How are manual clinical skills (scalpel skills) taught in your program?**
   a) How is this sequenced?
   b) Are skills taught implicitly, explicitly or both?
   c) If explicit teaching occurs, which elements of manual clinical skills do you teach explicitly?
   d) Does all the teaching occur in a single session? If not, how many sessions? What time period is there in between sessions?
   e) How much practice do the students get?
   f) Do students get extrinsic feedback or is it purely intrinsic?

2) **At what point of the podiatry program are they taught these skills?**
   a) When do students first try these skills on a human?
   b) When do the students first try these skills on a member of the public?
   c) Is student competency formally assessed prior to them seeing a member of the public? If so how?

3) **How many staff members are involved?**
   a) Are they contract, continuing staff or others?

4) **What issues do you think exist in teaching manual clinical skills generally, or in your program?**
   a) What do you think works best/worst? Why?

5) **How are manual clinical skills evaluated throughout the podiatry program?**
   a) In the evaluation of manual clinical skills, which elements do you look for or think are important?
   b) Do you assess students for explicit knowledge of step by step procedure as well as demonstration of implicit understanding?
   c) What explicit knowledge you assess or look for?

6) **How are poor performers identified?**
   a) What issues do you think contribute to being a poor performer?
   b) If a poor performer is identified, what strategies are employed to help that student?

Figure 2.2-1: Structured Interview Questions

2.2.3. Data analysis

Analysis of the transcribed data began when all interviews were completed. A conventional content analysis was used (Hsieh and Shannon 2005) to allow a systematic and objective means of describing and quantifying the studied phenomena (Downe-Wamboldt 1992; Elo & Kyngäs 2008; Krippendorff 2004) whilst maintaining a high level of flexibility with respect to research design (Elo & Kyngäs 2008; Harwood & Garry 2003). 'Conventional content analysis design is most appropriate when existing theory or research literature on a phenomenon is limited' (Hsieh & Shannon 2005, p.1279). Other commonly used approaches included grounded theory or phenomenology, which are similar in analytical process to content analysis but aim to develop a theory or a more comprehensive understanding of the lived experience (Hsieh & Shannon 2005), both of which are not relevant to this study purpose. A content analysis sits predominantly within a naturalistic paradigm (Hsieh & Shannon 2005) and is a method of qualitative analysis which can contain small quantitative elements (for example where it can be applied to determine frequency) as well as the qualitative information (Harwood & Garry 2003). A combination of quantitative content analysis and an inductive qualitative content analysis was used in this study. Results were represented in two ways: a quantitative reporting of frequency of program structure and teaching methods to answer research aim one, and the results from a more in-depth probe of relevant issues, successes and strategies using inductive qualitative analysis to answer research aim two. Further details regarding course structure and participant reporting information were elicited from the relevant university webpages and via the Australian and New Zealand Podiatry Accreditation Council (ANZPAC) webpage.

A quantitative inductive process was undertaken as there was little previous research knowledge about the training of scalpel skills to inform a framework for analysis (Elo & Kyngäs 2008). 'Typically qualitative content analysis is a technique that enables analysis of open-ended data to be structured for purposes of diagnosis' (Harwood & Garry 2003, p.479). Data analysis starts with reading all the transcribed data repeatedly and consecutively to obtain a sense of the whole (Hsieh & Shannon 2005). Then codes were defined from the data whilst reading the transcripts for the inductive analysis and used to structure participant statements for later categorisation. This may be achieved through making notes in the text or highlighting words which capture key thoughts or concepts (Hsieh & Shannon 2005). Care was taken to ensure meaning, intention and

context were elicited and coding was not limited to mere counting of themes (Downe-Wamboldt 1992). An analysis of manifest content, and not latent content (such as non-verbal communication), was employed (Downe-Wamboldt 1992).

The 'unit of analysis' for text evaluation, were the individual interviews as recommended by Graneheim and Lundman (2004). Each transcribed interview manuscript was read independently by the primary researcher (RC) and another researcher (MM) who was not involved in the interview or transcription processes. Open coding of each transcript was undertaken independently by both researchers and transferred to a spreadsheet (Hsieh & Shannon 2005). Meaning units were determined from interview content relating to the same central meaning (Graneheim & Lundman 2004). Each meaning unit was then labelled with a code by the researcher that summarised and categorised the data. Examples of this can be found in Table 2.2-1 below. After initial coding, the two researchers independently categorised the coded data and then met to discuss the coding and categorisation and ensure consensus. Krippendorf (2004) recommends that suitable categorisation can occur when all related data (meaning units) are incorporated into a single category and neither falls between groups nor fits into more than one group. A category may also be divided into sub-categories (Graneheim & Lundman 2004).

The two reviewers also identified themes independently until all groups of coded data were classified (Graneheim & Lundman 2004). Themes are a way to link underlying meaning which may exist across categories and involves interpretation of the coding and categorisation (Graneheim & Lundman 2004). For example, this may include the theme of 'insufficient resources' as something which may affect the teaching process involved, the relative success and failures involved with teaching and how poor performers are managed, i.e. it traverses a number of the categories and was determined through interpretation of the coding (Table 2.2-1).

Trustworthiness of the data collection and analysis process, incorporating credibility, dependability and transferability, was ensured in several ways. To ensure credibility two participants were interviewed from each site. To ensure dependability, interviews were recorded and data analysis was undertaken independently by two researchers with diverse clinical backgrounds. The primary researcher was a podiatrist involved in teaching scalpel skills (RC) whilst the second researcher was a research active

Physiotherapist academic (MM) who could challenge discipline-specific assumptions. Further details about the primary researcher are reported in addition to participant characteristics as part of the results, as the question of the researcher's qualifications, experience and perspective is important in relation to their interpretation of the available data, potential biases and influence on participants (Patton 2002). Transferability of the study was supported by detailed reporting of the context, selection and characteristics of participants and the data collection process (Graneheim & Lundman 2004).

Table 2.2-1 Examples of codes, sub-categories, categories and theme as part of content analysis

Meaning Unit	Code	Sub-category	Category	Theme
"If too many educators then (students) find that too confusing to go from educator to educator"	Student confusion in teaching	Consistency in teaching	Teaching related issue	Issues
"Practising on inanimate objects works well"	Successful use of inanimate object	Inanimate objects	Teaching related success	Successes

2.3. Results

Interviews were conducted between November 2011 and January 2012 with 16 experienced educators, representing two from each of the eight university podiatry programs in Australia and New Zealand at that time. The nominated staff members participating in the interviews were full-time salaried or sessional staff experienced with teaching manual clinical skills including scalpels skills. Participants had an average of 20.5 years of experience with a standard deviation of 8.9 years. Three educators who participated in the study had also taught, either in the university or clinically in the United Kingdom. The primary researcher who conducted the interviews and reported the study was an educator with ten years' experience, currently undertaking a series of research projects as part of a Doctor of Philosophy program (RC). The second researcher, involved in the coding and analysis only, was a Physiotherapist and neuroscience researcher with experience both clinically and as an educator (MM).

Two categories and six subcategories were determined from the analysis and are shown in Figure 2.3-1. The category titles have been used as the headings for reporting of findings in the following section.

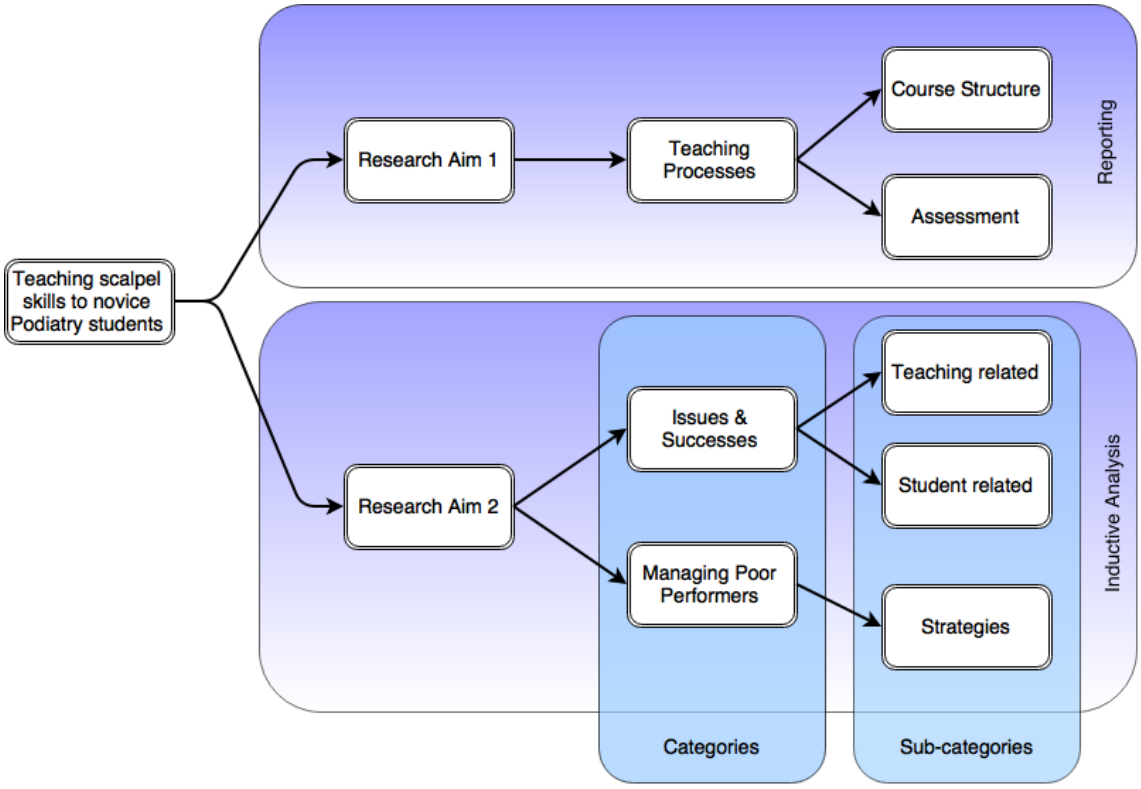


Figure 2.3-1: Resulting structure of content analysis

2.3.1. Teaching practices

In order to address research aim one, interview questions were asked regarding the structure, methods and timing of teaching manual clinical skills, particularly scalpel skills, to novice podiatry students. Two distinct areas emerged: detail regarding the program structure itself and detail regarding the assessment of manual clinical components.

2.3.1.1. Program structure

There was diversity in the reported content and structure of university programs offered around Australia and in New Zealand (Table 2.3-1). Programs ranged from a three year Bachelor degree to graduate entry Masters and Doctor of Podiatric Medicine programs.

When students are taught

The time when scalpel skills were introduced to students varied from second semester of first year to the second semester of second year, with a tendency for the shorter

university programs to introduce these skills earlier. The timing of when students first used a scalpel on a member of the public also varied, again from second semester of first year, to the first semester of third year. The duration between first learning scalpel skills and first seeing a member of the public was as short as four to five weeks and as long as almost a year later (Table 2.3-1).

Table 2.3-1 Structure of podiatry programs for teaching scalpel skills in Australia and New Zealand

University	Degree	First Taught	First Patient Contact	Duration between teaching and contact (No. of Semesters)
1	4 year Bachelor	2nd year preclinical	2nd year 1st Semester/ 2nd Semester	0 - 1
2	3 year Bachelor	2nd year, 1st Semester	2nd year, 1st Semester	0
3	4 year Bachelor - Masters (double degree)	2nd Year, 2nd Semester	3rd Year, 1st Semester	1
4	4 year – Bachelor & Masters (double degree)/ 2 year GE Masters	2nd Year, 1st Semester	3rd Year, 1st Semester	2
5	4 year Bachelor / 3 year GE Doctor of Podiatric Medicine	1st Year, 2nd Semester	2nd Year, 1st Semester	1
6	4 year Bachelor/ 2.5 year GE Masters	2nd Year, 1st Semester	2nd Year, 2nd Semester	1
7	3 year Bachelor	1st Year, 2nd Semester	2nd Year, 1st Semester	1
8	4 year Bachelor	2nd Year, 1st Semester	2nd Year, 1st Semester	0

How students are taught

All eight programs taught scalpel skills in clinics or skills laboratories with seven of the programs reporting this was preceded with the theoretical aspects provided in either large lecture format, tutorials or via written or recorded means (such as written manuals or DVDs).

Four of the programs reported using video, DVD or another alternate multimedia arrangement in addition to live demonstration of the technique. At least two of the programs reported providing a copy, or making the video available, for students to view at their convenience. One program also reported the capability to use video streaming to allow multiple students to watch a live demonstration on screens if required.

One program reported teaching students to use the scalpel handle without a blade attached first, to allow them to develop the technique initially without the risk of damage to themselves. More commonly, a structured approach was used incorporating demonstration and then initial practice occurring on inanimate objects including oranges, avocadoes, soap, cork, alginate, potatoes, fleecy web, wax, candles, chicken wings or even blue tac® in a peg. Subsequent progression of training was often to undertake debridement of wax from a fleecy web or other backing, attached to a colleague's foot or in one instance where only the fleecy web was attached to the foot. One program extended this to include embedding small seeds within the wax to replicate corns (Heloma Dura). Table 2.3-2 shows the approach and objects described for use in each of the programs.

Participants from five programs reported that students would then advance to debride actual callus from fellow students. However, it was reported that this was not always possible as many of the students were too young to have developed significant skin pathology.

Table 2.3-2 Aids used in teaching scalpel skills

University	Fleecy web & wax	Fleecy web only	Other inanimate
1	✓		✓
2	✓		
3	✓		✓
4	✓		✓
5	✓		
6		✓	
7	✓		
8	✓		✓

The final step in training of scalpel skills for the students was to then start treating members of the public within the university clinic setting (Table 2.3-1), using scalpels on a case-by-case basis when required. All but one of the programs managed a university-based clinic as part of their program. The remaining program used a university-staffed clinic based in a public health institution.

The greatest diversity in clinical teaching of scalpel skills between programs occurred with respect to the duration and structure of the clinical practice arrangements, including scalpel use. Six of the programs explicitly discussed using a large tutorial block or skills laboratory. This block could be dedicated to scalpel practice once per week and then students moved on to an alternate clinical skill in subsequent weeks (massed practice), compared to another program which reported having short sessions dedicated to scalpel practice prior to patient clinics which were repeated weekly but students were introduced to other clinical skills as the weeks progressed (distributed practice).

There was a diversity of opinions from interview participants, even within a single program, on whether students should be allowed to take instruments home to practise on family members or friends. Whilst a small number (three) of the programs encouraged

this, others forbade the practice and the remaining programs fell somewhere in the middle (see Table 2.3-3). Three programs provided optional clinic times which students could use for further scalpel skill practice and four stated that whilst they did not encourage students to take instruments out of the clinic, should students choose to, they could; this was more commonly the case in instances where students had to purchase their own instruments as part of the program.

Before commencing practice on patients, four programs used a mentoring system with more experienced students (third or fourth year). This allowed the novice student either time in the clinic observing (most common) or occasionally undertaking minor treatment processes with peer support. A majority of the programs also reported having students work in pairs during initial practice and when the students started with real patients in the clinic setting.

Table 2.3-3 Motor practice arrangements for university programs

University	Take home	Allowed but not encouraged	Not allowed	University clinic – additional allowed	University clinic only
1	✓		✓		
2		✓			
3		✓	✓		
4		✓	✓		
5			✓	✓	
6				✓	✓
7	✓	✓		✓	
8	✓				

2.3.2. Assessment

Participants expressed strongly that the capability of students with respect to manual clinical skills needed to be assessed practically, which was difficult to do through only written or verbal means. For half of the programs (n = 4) this was achieved through the use of competency checklists (Table 2.3-4). For some programs this was achieved on an ongoing basis, where students were required to get a particular competency signed off by the supervising clinical educators one or more times throughout the specified clinical period. Three programs described once-only competency exams where students demonstrated particular techniques or skills at a set point in time during the subject. For many of these programs the competency checklist or exam was a required milestone which students needed to satisfactorily pass in order to progress to practice on the public. Finally, all programs used an Objective Structured Clinical Exam (OSCE) or patient examinations as a component of the assessment (Table 2.3-4). In the case of the patient exams this meant that examiners and students were often *"...at the mercy of what turns up at the time"* (Participant 11).

Assessment methods and ongoing clinical observation were recognised by participants to play an important role in identifying poor performers. An exception to this was one participant who felt that judging the particular point of competency was difficult and therefore not formally evaluated.

"...because the skill learning (sic) is developed over time it is hard to have a black and white point to say that they are competent and therefore there isn't a lot of formal assessment going on" (Participant 2).

Another participant (Participant 12) reported that they did not undertake any formal assessment until the end of semester, relying on *ad hoc* feedback and admitted that students who picked up a poor technique were occasionally 'missed' and not picked up until the examination stage.

In order to understand in more depth and detail the process of scalpel skill learning including the strategies and issues which needed to be overcome and to address research aim two of the study, participants were asked their opinion of what worked well or didn't work well within their program. Two categories resulted from the inductive coding process: the first was issues and successes with respect to teaching structure, and the second was the management of poor performers (Figure 2.3-1).

Table 2.3-4 Reported methods for assessing manual clinical skills (scalpel)

University	Competency checklist	Patient exam	OSCE	Ongoing clinical	Reflective journal/ logbook
1	✓		✓		✓
2	✓	✓	✓		
3	✓		✓	✓	
4	✓		✓	✓	
5		✓		✓	✓
6		✓		✓	
7			✓	✓	
8			✓	✓	

OSCE – Objective Structured Clinical Examination

2.3.3. Issues and successes

Within this category there were instances where similar aspects were identified but in opposing contexts. For example one participant may have identified an issue such as 'teaching scalpel skills being quite labour-intensive', whilst another may have identified a success as 'having low student to staff ratios'. Where possible these themes have been grouped accordingly and discussed in both contexts. Conversely, in some cases opposing opinions were expressed. For example, even within programs some participants felt that the use of inanimate objects was a particularly successful strategy, whilst others expressed that they felt inanimate objects were an inadequate replacement for practice on a real foot. However, this may simply represent the feeling that inanimate objects are better than nothing, but not as good as the real thing. The issues and successes identified for teaching manual clinical skills, in particular scalpel skills, to podiatry students were identified in two main category areas: teaching-related elements and student-related elements.

2.3.3.1. Teaching related

A number of teaching related issues were reported, including the labour-intensive nature of teaching scalpel skills, the need for teaching consistency, need for evidence-based competencies and safety (Table 2.3-5).

Issues

Teaching podiatric manual clinical skills was identified by many participants as a resource intensive process in comparison to other university programs or subjects. Scalpel use, particularly in early learning or instances of struggling students, was perceived to require high levels of supervision as identified by one participant,

"…although it is expensive you have to put really low student (to) staff ratios into those preclinical skills to get the students as competent as they can be early on rather than trying to correct things at a later stage" (Participant 7)

This was also highlighted as an issue directly influenced by the increasing number of students in programs as another participant explained,

"…there is always going to be issues around that (sic) the class sizes getting bigger…..so monitoring people is always going to be an issue" (Participant 16).

The podiatry programs in this study reported teacher to student ratios between approximately 1:4 and 1:7 for the relevant clinics.

The perceived need for teaching consistency was also an issue. It's *"better if one person can teach the skill to the students"* (Participant 14), however if this is not possible then *"consistency is really important…..with an agreed process between all members of staff"* (Participant 4). Yet it was identified that due to the uniqueness or different styles of tutors and educators there were likely to be differences in teaching and that this could cause confusion or difficulties for students, particularly students who were struggling. Differences in teaching were perceived to stem from differences in teaching styles, different emphases, differences in scalpel blade choice, individual differences in the technique of the staff, working in different environments or a difference in expectations (for example between a university-based clinic and external clinic placement). There were also issues around teaching scalpel skills to left-hand dominant students if the staff member was right-handed and presumably vice versa; where possible a like-handed tutor was preferred.

Some participants identified that podiatry lacked suitable evidence-based teaching models, outcome measures and competencies as illustrated by the following statements, there is:

"…no way of measuring their capabilities, (we) don't have lots of competencies like nursing, but maybe it's because we haven't structured it that way" (Participant 10)

"…not a suitable simulation model we can use… wax is hardly sufficient… I mean putting wax on a piece of moleskin is hardly a good model to use….. without them (simulation models) students practically go straight from virtually no experience to practising on live patients" (Participant 9)

*"…no such thing as an adequate practice dummy…and it doesn't matter how much effort we put in to allowing them (students) to carve up soap… I think it's a good introduction but nothing prepares them for a foot that moves...or... that's got a person attached" (*Participant 16)

"..nothing really which tells you how you should be removing callus, there is nothing evidence-based" (Participant 14).

Another issue identified by educators from one of the programs was that they had noticed that students were no longer gripping pens and pencils the same way as previous cohorts and that this was impacting on the teaching and development of their scalpel grip.

Achieving adequate clinical experience for teaching related to patient numbers and exposure was another challenging issue identified by participants,

"…if we had more patients we'd treat more and get more (experience)... manual skills would obviously improve at a quicker rate" (Participant 13)

"we are relying on the space we have, the rotation through of patients and the time we have to allow them to do it" (Participant 16)

In part, this was suggested to come from the limited time available for students to practice in the clinic or skills laboratories with or without patients, which in turn can be related to staffing issues as mentioned above and the time available to provide supervision. However, participants also related this issue to patient numbers and

available infrastructure. In one case, a participant reported having insufficient clinic rooms or space for student numbers which created a timetabling issue. This was further compounded by perceived inadequate exposure of students to, or availability of, some clinical conditions as they may only gain clinical experience in what presents *"on the patient, which may be ad hoc"* (Participant 12).

As outlined in the reporting for research aim one, many programs used wax, or wax impregnated materials for students to practice. Many participants highlighted that whilst wax models or similar may be useful for initial practice and technique development, it cannot completely replace real skin.

"practising on real skin works best and I don't know how you get around that … callus is completely different to fleecy web so try and get them onto real skin as soon as possible but depends if (it is) available on (their) partner" (Participant 12)

"one of the students this year said …they would prefer to have actually done (practised) on a patient, because the texture and everything (of the wax) is not the same" (Participant 5)

However, in order to practise on real skin requires live human participants which may have significant quality of teaching and safety implications. Safety was identified as an issue in the training of scalpel skills by three interviewees in the context of the need to ensure student safety, guarding against complacency and ensuring students possess the required ability. The following statements relate to this concern:

"it is dangerous... we did have a big scalpel injury in the past…so guarding against complacency (on behalf of students)" (Participant 11).

"we have had it happen twice where we put the wax impregnated fleecy web onto a student and the person doing the debridement has been more vigorous than they should have been" (Participant 15)

It was also acknowledged that scalpel use, particularly on patients, is inherently risky and therefore: *"...there is no such thing as safe practice; they have to work on a human"* (Participant 16).

A contrasting opinion regarding the use of models or alternatives to real skin is outlined under successes below.

Successes

Despite contrasting statements regarding the legitimacy of using inanimate objects as models for practice, many participants reported that the use of models was more time efficient, safer, less intimidating and able to better engage students.

"rubberised feet are really helping because when they used to sit there and do nothing for half the class they'd get bored, get disruptive but here with this you can really intensify a three hour session or how many hours session you have..." (Participant 1)

"practising on innate (sic) objects tends to work well to get students competent, a scalpel can be intimidating..." (Participant 2)

"the wax on felt works very well… and (we) find that the students are less apprehensive and less anxious if they are taught that way rather than straight onto a foot and the safety issues around that as well' (Participant 14)

Yet, it was also perceived by some participants that getting students into clinic and a real-life situation early on in the program was also beneficial. Therefore, as practice on real patients was inevitable, numerous successful strategies to mitigate the risk involved were identified. This included a targeted selection of low risk patients with less complex lesions for students to practise on early in student learning and low staff to student ratios.

Other teaching approaches reported as successful included the use of multimedia such as DVDs or online streaming for description and demonstration. Pairing students either for practice or in an observational role with other similarly staged students or with more experienced students was also reported to be greatly beneficial. Four programs reported using a mentoring system whereby students attend and observe clinics of more advanced students and most used a dyadic arrangement for ease of practice and available space. Four programs reported that the successful sequencing of teaching involved breaking the skill down into its components and to gradually build upon these.

2.3.3.2. Student related

Issues

A number of student-related issues which impact on the teaching of scalpel skills were identified. These included psychological factors, general dexterity and issues specific to international students (Table 2.3-5).

Scalpels and their potential to inflict harm were considered daunting for students. Psychological factors such as increased student anxiety or lowered confidence, particularly relating to the risk of harm to themselves or the patient were reported as having an impact on the students. For example, respondents commented:

"So when that (treating a patient) actually happens, when they do come across a patient with callus that needs to be debrided, they've usually got a peer alongside of them to help them because they're quite nervous …their anxiety and their fear of haemorrhaging a patient and that (it) seem(s) to be that their general feedback on their reflection is that they are all terrified of actually cutting someone" (Participant 14).

From a psychological perspective, lowered student motivation may also impact on learning. The lowered motivation may be for any number of reasons: *"...in some cases it's just that they really don't want to be there... and that can reflect in poor performance"* (Participant 15)

A lack of dexterity was also a common student-related issue identified, with one participant suggesting they should undertake prerequisite testing for the program prior to admission:

"It would be lovely if (we) could screen all new people coming in for their ability and if they have (good) manual dexterity skills…. I have been in places in the past where they do a dexterity test" (Participant 1)

However, another participant commented that they did not think screening was necessary. There was a spectrum of experiences reported relating to the issue of dexterity with some participants describing students presenting with poor dexterity impacting on their long-term prospects, whilst others felt that dexterity is something that could develop in all students over time and that they had never had a student who couldn't proceed in the program as a direct consequence of poor dexterity. The diversity of opinion on this issue is illustrated by the following participant statements:

"There is occasionally a student (who) has no clue, no idea and no skill so we would encourage that student as much as possible to develop those (skills) but if at the end of the day the student just couldn't get it, then there has been occasions when we said look, 'this isn't really for you'....some people just can't use a scalpel it doesn't matter how many times you break it down or change it…" (Participant 1)

"The classic is you have students who have done tech(nical) studies, a lot of craftwork or some sort of fairly complex fine motor skills, they tend to be hugely advantaged over students who have had very little or no exposure to those sorts of skills at all.." (Participant 15)

"It's very rarely (sic) that we get people come in to the course that don't have good hand dexterity, I think they understand pretty quickly that they need to have that.." (Participant 7)

"…I think it's pretty hard to do that at the end of first year, to tell somebody, 'right, you're not going to cut it, go and find something else to do', there are so many other factors… you know it's our job to make sure that the clinical skills improve over time… when I started out, my clinical skills, my manual skills, callus debridement, you know they just improved and improved every year and I'd say after 10 even; when I'd been at it for 10 years..." (Participant 13).

Table 2.3-5 Frequency of teaching or student related issues regarding teaching manual clinical skills

Issue	Count (n = 16)
Staffing/ Labour intensive	3
Dexterity	4
Psychological issues	
Confidence	5
Motivation	4
Anxiety	5
Clinical Experience	
Patient Availability	3
Clinical Exposure	6

International students were highlighted as a group who often experienced difficulty learning manual clinical skills. It was suggested by participants that this could be related to comprehension when English was a second language and not having the confidence to speak up, or that the dual task of talking (to the patient) and undertaking the manual clinical skill was more complex when English was not the student's first language.

2.3.4. Managing poor performers

The second category to emerge from the qualitative content analysis was specific to the strategies used in the management of poor performers or struggling students.

2.3.4.1. Strategies

A range of strategies were nominated for managing poor performers. These were increased teaching or practical exposure, increased positive feedback and moving students back a step on the teaching continuum to decrease complexity. An increase in teaching or practical exposure to scalpel skills included further demonstration, increased supervision or mentoring, the introduction of further competency checklist requirements, pairing up with stronger students or increasing the time students were exposed to patients. Increasing positive feedback (and avoiding negative feedback) was reported as another strategy to effectively manage poor performers. For example, one participant outlined that,

"...if you say anything negative to the student, that's going to put a block up and they won't perform well at all, ever" (Participant 5).

Five of the programs reported providing an increase in the regularity and amount of 'on the spot' feedback, both formal and informal, for poor performing students. Moving students back on the teaching continuum was achieved by having them practise scalpel techniques on inanimate objects in between clinics or to screen for patients with less complex lesions. Each of the university programs reported they employed one, or a combination of the outlined strategies.

2.4. Discussion

This study determined that the approach to teaching manual clinical skills, in particular scalpel skills, appears to be consistent between university programs in Australia and

New Zealand, utilising didactic-style content, demonstration, physical practice on inanimate objects and real skin, and often the use of supplementary audio-visual material. The main reported differences between programs were around the methods and processes of practice. The primary area of controversy was regarding the use of inanimate objects versus real skin, which was reflected in comments relating to both issues and successful strategies. Common issues elicited from the interviews included both student-related and teaching-specific issues. In the subsequent section, we will discuss the current teaching approaches relating to podiatric manual clinical skills and how this relates to the literature. This includes the influential role of practice, observational learning, feedback and autonomy can play. We will also further discuss issues which act as barriers to the successful learning of podiatric manual clinical skills, particular the issues around developing sufficient dexterity and strategies used to manage this.

Most podiatry programs followed a traditional teaching structure when teaching scalpel skills with a didactic-style lecture or talk outlining the theoretical and explicit information relevant to using a scalpel supplemented by skill demonstration, either in real-time, streaming media or via a recorded medium such as DVD or online video. This teaching approach is consistent with evidence that observational learning together with practice is more effective for motor learning than practice alone (Ashford, Bennett & Davids 2006). As outlined in the introduction, this is supported by objective transcranial magnetic stimulation (TMS) and neuroimaging studies, which show that similar areas of the brain activate whilst a student is observing a particular skill being performed as when they are undertaking that skill themselves (Decety et al. 1997; Fadiga et al. 1995; Iacoboni et al. 1999; Rizzolatti et al. 1996b).

The reported mentoring relationships and strategies of students working in pairs regularly provide an alternative avenue for observational learning. When working in pairs, students are able to watch someone else undertake a learning process, which is believed to facilitate adaptation when they are required to perform the same action (Mattar & Gribble 2005; McCullagh & Caird 1990; Shea, Wulf & Whitacre 1999; Shebilske et al. 1998; Shebilske et al. 1992; Wulf, Shea & Lewthwaite 2010). Such observational learning provides the opportunity for students to continue to maximise learning by engaging in alternative forms of processing, whilst having a break from the cognitive demands of the skilled task (Shea, Wulf & Whitacre 1999). Moreover, the

non-treating student can take the responsibility of engaging the patient, allowing the practising student to focus their cognitive resources and concentrate on learning and performing the skill. Working in pairs may also have an influence on the motivation and competitiveness students feel for the task, which can have a significant influence on learning outcomes and address psychological issues (Elliott et al. 2011; Shea, Wulf & Whitacre 1999; Shebilske et al. 1992; Wulf, Shea & Lewthwaite 2010).

The role of practice in teaching of manual clinical skills was highlighted by participants from all programs. Practice was often undertaken on inanimate objects and foot models, and perceived as a successful teaching strategy as it reportedly decreased students' relative anxiety, increased engagement and provided a safer alternative than a real-life patient. Half of the programs reported using specific inanimate objects followed by wax added to some sort of base such as tape or fleecy webbing. All except one program reported using wax on a base, with the remaining program using fleecy web only. In a majority of cases students were paired-up and the wax was attached to the foot of their partner, to enable more context specific practice. However, there are caveats on this and a contrast of opinions. Participants reported that it was good to have students put into a real-life situation early and identified that the wax does not sufficiently replicate real skin. It was felt that there is a lack of suitable models. This may be compounded by a lack of sufficient clinical exposure, particularly in the context of growing class sizes and the fact that students and teachers often rely on real patients attending the university podiatry clinic for practice exposure to a variety of conditions. It is for these reasons a combination of practice strategies were often utilised. Safety was also a concern that influenced the practice strategy used. Students' practising on real patients creates a paradoxical dilemma where the public are exposed to the risk of receiving treatment by inexperienced students, with students relying on this exposure in order to gain the required experience. Relating to this is controversy in the literature regarding open versus closed skill learning, with some authors promoting research which supports open skill learning, such as a real-life clinic with a variable environment. However, in contrast Knight (1998) argues that these studies don't take into consideration the effects of anxiety and arousal which are present particularly in learning many of the health-related clinical skills.

In some cases, practice of podiatry-related manual clinical skills, particularly scalpel skills occurred in a massed or blocked form, whilst other programs used practice

intermittently or spaced over an extended time. As previously outlined, whilst the early belief was that intermittent or spaced practice was the superior approach for simple motor tasks, more recent research suggests that outcome effect sizes decrease with increasing task complexity and cognitive demands thereby putting into question the benefits provided by spaced practice (Section 1.2.2.3) (Donovan & Radosevich 1999). A plethora of research designs and physical structures makes interpretation and synthesis of published data to inform the teaching process quite difficult.

The role of feedback, contextual interference and motivation can also have a strong influence (Section 1.2.2.3). Interpreting studies relating to motor skill acquisition should be undertaken with care, as findings based on simple skills do not take into account the greater cognitive demand and other aspects typical of complex motor skills. Furthermore, whilst there is an expectation that transfer of learning from laboratory practice to the real setting is automatic (Gomez & Gomez 1984), this may depend on the environmental context.

Issues relating to the practice setting and associated safety concerns were recognised by participants when discussing issues and successes in manual podiatric skills.

A variation in practice environments reported between programs, such as home, supervised clinic and unsupervised clinic has the potential to vary the type and timing of feedback regarding performance of a skill. For instance, the practice environment can influence whether the student receives extrinsic augmented feedback or feedback only via intrinsic mechanisms. As outlined in Section 1.2.2.3, intrinsic feedback occurs via the sensory system using kinaesthetic, visual, cutaneous and auditory input (Wierinck et al. 2005), whilst augmented feedback originates external to the operator and includes feedback such as knowledge of results or a knowledge of performance from a supervisor (Gomez & Gomez 1984; Oermann 1990). Mars et al. (2005) found that the part of the brain responsible for error detection and correction was activated by extrinsic feedback earlier in the learning process than intrinsic feedback. Furthermore, it is commonly thought that when augmented feedback is provided too frequently, the learner becomes dependent and no longer able to perform effectively when it is withdrawn (Wierinck et al. 2005). As previously mentioned, there is debate whether this applies to complex tasks as well as simple tasks (Wulf & Shea 2002). However, it still seems that the exact timing, frequency and type of feedback can have a significant

influence on task learning. Until further research is conducted on complex tasks relating to health professionals, the default process should be to provide augmented KP and KR feedback early during learning and at the discretion of the student (i.e. they have autonomy). Students should also have the opportunity to undertake observational learning and possibly even undertake mental rehearsal.

Learning may be encouraged through facilitating student autonomy. It is now recognised that when students are provided with autonomy over learning, when to practise and when to receive feedback, they display improved motor learning (Chiviacowsky & Wulf 2002, 2005; Post, Fairbrother & Barros 2011). It is believed that this may be related to motivation (Bandura 1991; Boekaerts 1996; McNevin, Wulf & Carlson 2000; Wulf, Shea & Lewthwaite 2010), specifically intrinsic motivation. One way this may be achieved is through the use of multimedia or enabling safe ways for students to practise independently. Many of the podiatry programs attempted to do this either intentionally or unintentionally.

One of the teaching-related issues in the study findings was the labour-intensive nature of teaching scalpel skills and fitting this within the university-driven workload model, potentially producing a mismatch between necessary supervision levels and the time availability and priorities of staff. The staff-student ratio specified by the Australian and New Zealand Podiatry Accreditation Council (ANZPAC)(*Accreditation Standards for Podiatry Programs for Australia and New Zealand v1.1* 2009) is 1:4 to 1:10 depending on associated risk. For example learning scalpel skills in a clinic environment involving novices should have a low ratio, which makes it both labour-intensive and consequently expensive. In addition to staffing ratios, the ANZPAC recommends that 1000 clinical hours need to have been achieved by students by completion of the program in order to be eligible for registration. Sixty percent of these hours should have been completed within internal clinical facilities putting further pressures on university staff and workload. However, these time requirements do not necessarily take into consideration the patient numbers treated, amount of pathology or variety of pathologies to which they are exposed, or the competency of a particular student. These factors will also impact on the motor skill capability related to scalpel skills of a particular student.

It is possible that the choice to enforce a clinical time requirement to ensure registration standards are met rather than using other measures may stem in-part from a lack of objective outcome indicators and established competencies within the teaching of manual podiatry skills. These were also identified as lacking by some of the interview participants. Bradshaw (1998) reported from a number of nursing-based articles that without clearly defined competencies and prescribed assessment standards, graduating students were concerned about their practical skill competence. One participant in this study identified that professions such as nursing have attempted to rectify this issue. A simple comparison of two separate searches on PubMed database for 'competencies' AND 'Nursing', or 'competencies' AND 'podiatry' shows an almost 500-times greater return for nursing specific articles investigating the teaching of manual clinical skills (undertaken 31st January 2014). ANZPAC has developed a collection of competencies for the purpose of evaluating foreign podiatrists seeking registration in Australia, which at least one interviewee reported modifying for use in the undergraduate educational setting. However, it seems that further work in developing relevant competencies may be beneficial.

An important issue identified by participants was the need for consistency regarding either how or by whom manual scalpel skills are taught. It was identified by the interviewees themselves and what they report from student feedback, that students get frustrated by inconsistencies which may exist between tutors and educators with respect to teaching and performance expectations. One way to ensure a more consistent approach would be for only one educator to teach scalpel skills. Where this is not possible then efforts should be made to ensure consistency in teaching, supervision and feedback regarding the specific details of skill requirements. This would also be aided by the existence of well-defined competencies and task definitions.

Despite the lack of developed skill competencies outlined by some participants, the most commonly employed assessment method reported was through the use of student competencies, usually as an ongoing checklist. This may be in the form of an examination or via ongoing assessment requiring students to be signed-off on particular aspects, rather than as formal examination assessment. Ongoing assessment was more commonly reported to be associated with evaluating a minimum skill threshold rather than grading performance. This potentially has the added benefit of invoking less anxiety in the students, thereby facilitating greater safety for both the students and

patients concerned. Also, through the use of an ongoing competency checklist, poor performers can be identified easier and earlier, providing a greater opportunity for remedial strategies to be used.

Motivational states are influential to the learning of complex skills (Wulf, Shea & Lewthwaite 2010) and were identified as a student-related issue in this study. The defining feature of intrinsic motivation is that it needs to be driven by the individual themselves, not just by the educators or other external mechanisms. There are also other student-related psychological aspects which may impact on motor learning, including high levels of anxiety and decreased confidence or self-efficacy. Evidence consistently demonstrates a high correlation between an individual's self-efficacy, motivation and subsequent performance (Bandura & Locke 2003). Self-efficacy has been linked with motivation (Bandura & Locke 2003; Colquitt, LePine & Noe 2000; Gist & Mitchell 1992) and anxiety (Bandura & Locke 2003; Chen et al. 2000; Colquitt, LePine & Noe 2000; Gist & Mitchell 1992; Martocchio 1994), itself affecting performance. A number of participants outlined the need to avoid negative comments and instead provide positive comments in an attempt to positively reinforce or increase a student's self-efficacy. Self-efficacy may mediate anxiety and the effect it has on performance (Bandura 1997; Chen et al. 2000). A number of reported experiments found that self-efficacy was the major predictor of anxiety, even more than the individual's susceptibility to anxiety (Bandura, 1997). There are consistent findings that managing perceived self-efficacy is of greater benefit than merely managing anticipatory anxiety in avoidance behaviour (Bandura 1997), and therefore may be a more suitable method of managing students learning scalpel use. Artificially manipulating self-efficacy has a positive effect on performance and this can be achieved at both an individual and group level (Bandura & Locke 2003). This was not directly identified by the interview participants (although building confidence was mentioned) but provides a potential strategy for educators to improve performance in skill acquisition for students which should receive greater attention within programs and is an area for further research.

A student's ability to reach a sufficient level of dexterity was identified as an issue by participants with the suggestion that a screening test would possibly be useful, similar to that used by dental programs in North America (Gansky et al. 2004; Lundergan & Lyon 2007). However, the importance of screening was not universally agreed by

participants. One participant suggested that maybe students self-select prior to commencing the program or even transfer themselves out of the program if they do not feel they have the ability. Research undertaken on a number of pre-entry skill aptitude tests for study programs have been shown to have poor correlation or non-significant outcomes between the test and success in the program, associated learning, or subsequent performance (Gansky et al. 2004; Lundergan & Lyon 2007; Lundergan, Soderstrom & Chambers 2007; Oudshoorn 2003; Ranney, Wilson & Bennett 2005; Raybould, Raggard & Norton 1983; Weinstein et al. 1979). This is clearly an area for future research, including consideration of the student perspective.

A number of remedial strategies were discussed to manage poorly performing students, which were targeted at increasing practice and improving dexterity. Participants reported strategies of increasing practice time, increasing exposure to relevant conditions, increasing educator input and feedback, providing reassurance or building the confidence of the student or by pairing struggling students with a stronger student to utilise the benefits of observational learning discussed earlier. Dexterity is considered a skill which may be learnt over time rather than being entirely innate. There has been little research into the best ways to improve dexterity, particularly in health professionals, and therefore does not address the dilemma where students have a need for increased exposure and practice which may increase the risk to the patients or students. This is also an area which would clearly benefit from further research and serves as the impetus for the aims of this thesis.

There are limitations in the use of semi-structured interviews to investigate the teaching approach in podiatry programs. Despite an overall feeling that a particular point is relevant or important, participants may not think of it at the time of the interview or may prioritise other points. Therefore, the findings from this study cannot be considered to be a ranking of issues nor an exhaustive indication of the breadth of all relevant issues. Furthermore, participants are likely to be influenced by their most recent exposures or experiences and therefore have a specific bias.

On occasion, there were small inconsistencies reported between participants from the same university, for example with the motor practice arrangements as shown in Table 2.3-3. All views were reported, however this may reflect the lack of standardised rules regarding scalpel skill teaching within some programs.

Finally, whilst an additional coder was involved to limit error, the presence of errors in coding data is still possible, related to fatigue, personal bias, and perception (Downe-Wamboldt 1992, p.319) and therefore needs to be considered when interpreting findings. Information should ideally be replicated by further research into the issue of teaching manual clinical skills to podiatrists.

2.5. Conclusion

Teaching manual clinical skills, particularly scalpel use, is a complex process which may be affected by a number of influencing factors. Despite a lack of research and literature surrounding this topic, particularly in podiatry, the approach to teaching is relatively consistent between programs with the greatest disparity being the arrangements around practice structure and duration.

From the perspective of podiatry program teachers, key issues in teaching podiatry related manual clinical skills were students' clinical exposure, motivation, levels of anxiety and dexterity. These areas deserve greater attention and research to ensure ongoing improvement in service provision and safety for the public and students.

The findings highlight the particular importance that dexterity and clinical exposure play in the development of scalpel skills, and as such, it is vital for a safer evidence-based approach to be determined, particularly in the instance struggling students are identified.

3. Which tools are commonly used to evaluate health professionals and their psychometric properties

The following chapter is presented with the identical content and structure in which it was published but has been modified to match the formatting of the rest of the thesis. The original paper can be found in:

Causby, RS, Reed, L, McDonnell, MN & Hillier, S 2014, 'Use of objective psychomotor tests in health professionals', *Perceptual and Motor Skills* vol. 118, no. 3, pp. 765-804.

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http://www.amsciepub.com/doi/abs/10.2466/25.27.PMS.118k27w2

The authorship form for a published paper is provided in Appendix F.

THE USE OF OBJECTIVE PSYCHOMOTOR TESTS ON THE HEALTH PROFESSIONAL POPULATION

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3.1. Abstract

Evaluation of psychomotor skills is undertaken in a number of broad contexts. This includes testing of health professional populations as a measure of innate ability, to evaluate skill acquisition, or to compare professions. However, the use of psychomotor tests is frequently confounded by a lack of understanding of a particular tool's psychometric properties, strengths and weaknesses. Thus, the purpose of this paper was to identify and appraise the most commonly used tests on health professional populations. A total of 86 articles were reviewed and the top nine tests identified. There has been a significant increase in the reporting of the use of these tests over the last 20 years. However, few tests have had sufficient validity or reliability testing on health professionals. Based on the evidence available, use of the Grooved Pegboard Test (GPT), PP or Finger Tapping Test (FTT) is recommended for the evaluation of dexterity in a health professional population, however this choice may be dependent on the task/s for which findings need to be generalised. A more rigorous evaluation of their validity and other psychometric properties is required.

Keywords: Psychomotor testing, Dexterity testing, Health professional, Validity, Reliability

3.2. Introduction

To safely and effectively perform clinical procedures it is essential that health professionals in dentistry, surgery, nursing and podiatry have highly developed cognitive and psychomotor skills. Dexterity is an important part of psychomotor ability and is defined as a "manual ability that requires rapid coordination of gross or fine voluntary movements, based on a certain number of capacities, which are developed through 'learning, training and experience" (Poirier 1988, p.71) and there is often a need to evaluate this ability.

Evaluation of psychomotor skills is undertaken in a number of broad contexts for various purposes. Traditionally, psychomotor testing has been used in an occupational context to evaluate aptitude, brain impairment or hand function after physical injury, with many validation studies focussing on these populations. More recently psychomotor testing has been used in the health professional populations. For example dexterity assessment has been utilised as a measure of innate ability (Boyle & Santelli 1986; Gansky et al. 2004; Giuliani et al. 2007), consequently leading to its use as an entry requirement to some programs of study such as dentistry or surgery (Gallagher, Leonard & Traynor 2009; Lundergan & Lyon 2007; Wanzel, Ward & Reznick 2002). Dexterity testing has also been used as a comparative tool to evaluate skill acquisition (Lauf & LeCompte 1982; Luck, Reitemeier & Scheuch 2000) i.e. evaluation of a particular teaching method (Akram et al. 2008), training effect (Bitter, Hillier & Civetta 2011; Brogårdh et al. 2010; Manjunath & Telles 1999; Yadav & O'Regan 2010) or to validate the acquisition of manual skills. Furthermore, dexterity testing has been used to compare experts with novices (Munz et al. 2004b), one profession of interest with another profession (Wanzel et al. 2003) or even to compare the abilities of one population group with normative values for the population as a whole (Hellebrandt & Houtz 1955).

The use of psychomotor tests, particularly in health professional populations, is frequently confounded by a lack of understanding of a particular tool's psychometric properties, strengths and weaknesses. The choice of tool is often based on historic reasons or familiarity, rather than a thorough evaluation of its psychometric properties. Additionally, there is a large quantity and diversity of tests available, used for a

multitude of purposes making the choice difficult for any researcher or clinician who wishes to use psychomotor tests.

An ideal assessment tool should be valid, reliable, objective, sensitive, relatively cost effective and easy to administer. Within the literature relating to health professionals and dexterity, there are a number of tests which mimic professional tasks. Whilst this allows for an assessment, which may be representative of the requirements of that role, it is frequently subjective in nature, requiring a peer, colleague or researcher to rate the performance. An example of this would be the 'chalk carving test' used as a pre-admissions test for dental students in North America (Gansky et al. 2004; Lundergan & Lyon 2007). Such tests often struggle to correlate with other more objective measures or lack reliability. An alternative to this, an objective 'standardised' test with higher reliability may not always face these issues, but may produce results which cannot be as easily generalised or related to the task of interest. For example, varieties of pegboard tests provide objective measures of dexterity, but it is questionable if the ability to place pegs correlates with a surgeon's ability to perform a procedure.

The purpose of this review was to systematically identify the tests that have been most commonly used to evaluate the dexterity or psychomotor skills of health professionals and appraise these tests. Within this, we hoped to identify any trends in the use of psychometric testing on health professionals. It is hoped that this will inform researchers when choosing the most appropriate tool for their own research, dependent on study needs. Further, it may enable clinicians to interpret research findings more appropriately and choose the most appropriate test for skill or occupational evaluation purposes.

3.3. Methods

3.3.1. Search strategy

A comprehensive systematic search of the literature was undertaken in October 2011 based on the PICOS (Population, Intervention, Comparison, Outcome and Study design) method. This included searching for any health profession where an objective dexterity test was used in a randomised controlled trial, controlled trial or observational study. Databases included Medline (1948 – 1st week of October 2011), Embase (1974 – October 17th 2011), AMED (1985- October 2011), Cinahl, Scopus and Google Scholar.

Where possible, 'Medical Subject Headings (MeSH)' and 'Emtree', search terms specific to 'Medline' and 'Embase' databases were utilised. Where this was not possible a Boolean search strategy was used, which combines search terms using a combination of 'and', 'or' and 'not' operators to make the search more specific.

3.3.2. Inclusion and exclusion

Articles identified by the search strategy were screened based on the title and abstract. Articles clearly not relevant were removed and the remainder were imported to EndNote® citation manager for further screening. Articles were included if they were available in English, included psychomotor tests which were administered to health professionals or health professional students and only if tests contained objective measures. Duplicates were removed. Other articles previously known to the authors, or discovered via hand searching were added if they were within the inclusion criteria.

3.3.3. Test appraisal and description of tests

The nine most commonly reported psychomotor tests were identified from the included articles. The articles were then scrutinised for psychometric properties of tests. A data extraction sheet (Appendix G) was utilised to consider elements that contribute to the validity, reliability, confounding effects and application of the test. In order to confirm each of these elements, a further search of the test name and any aliases, together with the search terms reliability or validity were used through the OVID database services and on Google with relevant studies obtained. Where other articles were identified pertaining to validity or reliability data these articles were also retrieved and included in the appraisal. Extracted data including relevant statistics were added to the data sheets for evaluation by a second reviewer (SH).

3.3.3.1. Reliability

The inter-rater and intra-rater reliability of the tools were assessed. This included test-retest reliability and both correlations and intraclass correlation coefficients.

3.3.3.2. Validity

The Face validity of the tests was not considered rigorous enough for the purposes of this paper and therefore not reported. An evaluation of the criterion-related validity is the ideal form of validity testing, by comparing the test of concern with a gold standard, where one exists. Criterion-related validity is more relevant for clinical populations as

it confirms the measure has relevance in relation to an accepted reference or criteria. In the absence of a gold standard, often construct validity is considered, relating to the construct of the test of concern. An instrument is said to be a valid measure of a construct when its measurements support the underlying theoretical assumptions used to define a particular condition or concept (Portney & Watkins 2009). For example, if dexterity is considered to contain elements of speed and accuracy relating to fine motor skill, then a valid test should contain elements of precision over a specific period. A number of methods may be used to evaluate if the tests support a particular construct. These include: known-groups, convergence, factor-analysis, hypothesis testing and criterion validation.

3.4. Results

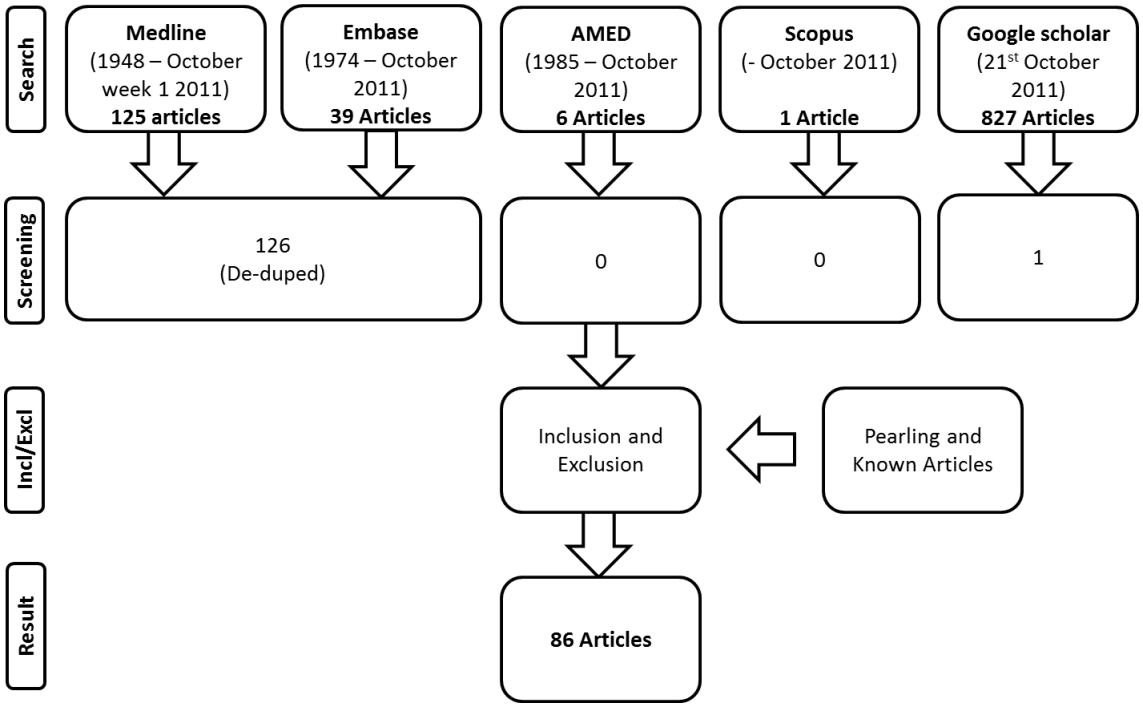


Figure 3.4-1 Flow diagram of search results

A total of 86 articles (Figure 3.4-1) were reviewed, from which a wide variety of tests were identified. 'Standardised' tests, which could be applied to multiple professions and used in a number of studies, were identified as well as 'novel' tests, which were created specifically for a particular task, profession or study. The evolution of more complex surgical procedures requiring the use of tools and working in a 'closed' environment has spurred the development of virtual trainers with objective methods of evaluating discipline specific task performance. Articles containing task specific

trainers (e.g. LapSIM®, Mist-VR®) were included in the original systematic search but as they were not considered to be tests generalisable across professions they were omitted from the full appraisal and review process.

The studies spanned a wide date range, from 1934 to 2012. The frequency of these publications by year can be seen in Figure 3.4-2. From these, in excess of 35 standardised tests were identified. The top nine standardised tests (Appendix H) identified were: the Purdue Pegboard (PP), O'Connor Tweezers dexterity test (O'Con (Tw)), Grooved Pegboard Test (GPT), Crawford Small Parts Dexterity Test (CSPDT), Gibson Spiral Maze (GSM), MacQuarrie Test for manual dexterity (MacQ), O'Connor Finger Dexterity test (O'Con (F)), Finger tapping or Finger Oscillation test (FTT) and the Minnesota Manual Dexterity test (MMDT), also known as the Minnesota Rate of Manipulation Test (MRMT) (Figure 3.4-3). An overview of the tests, their origins, the professions for which they were used and outcomes can be found in Table 3.4-1. A majority of these tests utilise time as the outcome variable, thereby potentially evaluating speed more than accuracy.

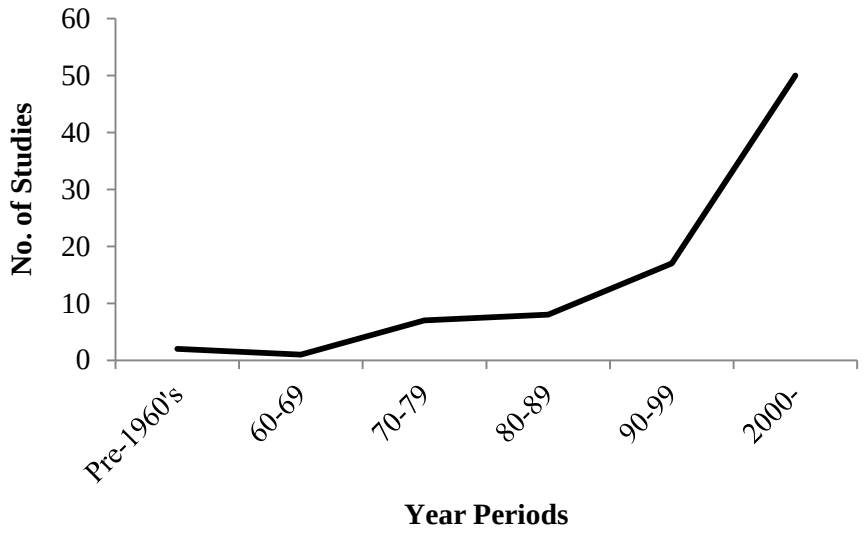
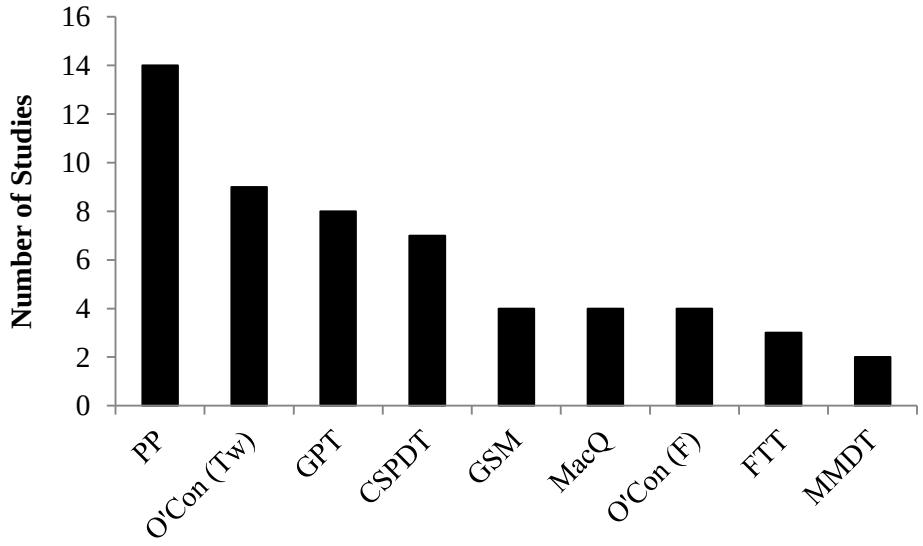


Figure 3.4-2 Number of articles with health professional Generalised Dexterity Tests (GDTs) by date



PP- Purdue Pegboard; O'Con (Tw) – O'Connor Tweezers Dexterity Test; GPT - Grooved Pegboard Test; CSPDT – Crawford Small Parts Dexterity Test; GSM – Gibson Spiral Maze; MacQ – MacQuarrie Test; O'Con (F) – O'Connor Finger Dexterity Test; FTT – Finger Tapping Test; MMDT – Minnesota Manual Dexterity Test.

Figure 3.4-3 Most common standardised tests of dexterity and their frequency of use

Table 3.4-1 Overview of tests identified

	Inventor/s	Professions	Protocol*	Outcomes
PP	Tiffin and Asher (1948)	Dentistry, Podiatry, Surgery, Medicine, Nursing, Renal Technician	*No. of pins placed in 30 seconds (right; left and both) &1 minute (assembly); Time taken to complete all 30 pegs.*	Integer (ratio) – discrete (mostly) & continuous
O'Con (Tw)	O'Connor (1925)	Dentistry, Medicine, Ophthalmology	*Time to completion. Pins inserted to board using tweezers.*	Integer (ratio) – continuous
GPT	Kløve (1963)	Surgery, Dental Hygiene, Medicine, Anaesthesiology, Nursing.	*No. of pegs inserted in 30 seconds; Time to completion. Time for removal (used less frequently)*	Integer (ratio) – discrete & continuous
CSPDT	Crawford and Crawford (1956)	Dentistry, Surgery, Psychiatry, Medicine, Radiology, Urology Cardiology, Pulmonology, Anaesthesiology	*No. of screws or pins inserted in 5 minutes (screw) or 3 minutes (pin); Time to completion*	Integer (ratio) – discrete & continuous
GSM	Gibson (1964)	Surgery, Psychiatry, Anaesthesiology, Medicine	*Time to complete maze and number of errors from touching the edges*	Integer (ratio) – discrete & continuous
MacQ	MacQuarrie (1925)	Dentistry, Nursing, Occupational Therapists	*Tracing – no. of gaps lines not touched; Tapping – no. of completed circles* *Dotting – no. of circles completed without error*	Integer (ratio) - discrete
O'Con (F)	O'Connor (1925)	Dentistry, Ophthalmology	*Time to completion. Pins in board.*	Integer (ratio) - continuous
FTT	(Halstead 1947)	Dentistry, Surgery, Nursing	*No. of taps in 10 seconds, and number of taps in 10 seconds average of 5 attempts within 5 taps of one another*	Integer (ratio) - discrete
MMDT (MRMT)	Educational Test Bureau (*Minnesota Rate of Manipulation Test* 1931)	Dentistry, Surgery, Medicine	*Time to completion, discs placed in board, repeated 5 times, first trial discarded*	Integer (ratio) - continuous

*This represents the protocol reported in the health professional literature reviewed. Where this was not stated or not clear, the most commonly reported protocol in the broader literature is reported.

3.4.1. Validity and reliability

With the exception of a factor analysis study (Zullo 1971), none of the identified health professional literature primarily investigated validity or reliability of the psychomotor tests. Only two studies reported reliability (Simon & Chambers 1992; Wilson, Waldman & MacDonald 1991).

3.4.1.1. Reliability

Two articles in the health professional specific literature reported on reliability; Wilson, Waldman and MacDonald (1991) found that the GPT and O'Con (Tw) tests demonstrated moderate test-retest reliability ($r = 0.64$ and 0.50 respectively, $p < 0.001$) and Simon and Chambers (1992) who reported split half reliability of $r = 0.93$ and $r = 0.86$ for the O'Con(Tw) and O'Con(F) respectively. The PP scores had very poor reliability, with a non-significant correlation of only $r = 0.04$. Consequently, they removed the PP from the remainder of their study together with other psychomotor tests not reported here. However, this is inconsistent with other results reported below.

Outside of the health professional literature, test-retest reliability was more frequently evaluated. Relevant reliability data for the most common tests have been provided in Table 3.4-2. The PP showed the most extensive test-retest reliability reporting by correlation (Barnsley & Rabinovitch 1970; Bass & Stucki 1951; Bear-Lehman & Abreu 1989; Bosshardt 1988; Buddenberg & Davis 2000; Desrosiers et al. 1995; Doyen & Carlier 2002; Fleishman & Hempel 1954; Lezak, Loring & Howieson 2004; Reddon et al. 1988; Sterne 1969; Tiffin 1968; Tiffin & Asher 1948; Wilson et al. 1982) and Intraclass Correlation Coefficients (ICC's) (Buddenberg & Davis 2000; Desrosiers et al. 1995; Jones et al. 1991; Muller et al. 2011). Generally test-retest correlations for the PP varied between $r = 0.35$ and $r = 0.93$, but average scores were between $r = 0.63$ and $r = 0.81$ (Lezak, Loring & Howieson 2004). Haward and Griffin (2002) also found significant correlations over a number of weeks of repeated administration with correlations between $r = 0.59$ and $r = 0.83$, with the exception of one of the time periods (week 1 to 3) using the non-dominant hand. The reliability for a three trial administration, where the average score is used for analysis is superior to the one trial method (Buddenberg & Davis 2000).

The other test for which extensive test-retest data were available was the FTT. The FTT test shows good test-retest reliability with correlations ranging between $r = 0.71$ and $r =$

0.99 (Barnsley & Rabinovitch 1970; Bornstein, Baker & Douglass 1987; Dikmen et al. 1999; Eckardt & Matarazzo 1981; Gill et al. 1986; Matarazzo et al. 1974; McCaffrey, Duff & Westervelt 2000; McCaffrey, Ortega & Haase 1993; Morrison, Gregory & Paul 1979; Ruff & Parker 1993; Sakong et al. 2007).

In addition to the study outlined above, evidence of sufficient GPT reliability was provided by a number of articles (Barnsley & Rabinovitch 1970; Dikmen et al. 1999; Levine et al. 2004; Ruff & Parker 1993; Wilson, Waldman & MacDonald 1991) with correlations varying between $r = 0.64$ and $r = 0.86$.

The MRMT has had test-retest reliability testing, with correlations ranging from $r = 0.87$ to $r = 0.97$ (Barnsley & Rabinovitch 1970; Bosshardt 1988; Clark & King 1960; Fleishman & Hempel 1954; Maiden & Dyson 1997) and including ICC's between $r = 0.79$ and $r = 0.87$ (Desrosiers et al. 1997).

An older report by Bosshardt (1988), reported on the reliability of the PP, CSPDT, MRMT and O'Con (F), collating data from many of the original manuals which were not easily available and in most instances not replicated in scholarly journals. The following reliabilities were reported: PP - test-retest of $r = 0.68$, corrected split-half of $r = 0.83$ and 'other' reliability results of $r = 0.9$; CSPDT - corrected split-half reliability of $r = 0.89$ and 'other' reliability of $r = 0.9$; MRMT - 'other' reliability of $r = 0.89$; O'Con (F) - test-retest of $r = 0.87$, corrected split half of $r = 0.92$ and 'other' reliability of $r = 0.76$. A clear description of what 'other' reliability entailed was not provided.

Inter-rater reliability was only available for the FTT which was $r = 0.78$ for the dominant hand and $r = 0.76$ for the non-dominant hand, comparing just two raters (Morrison, Gregory & Paul 1979). Likewise, Arceneaux et al. (1997) compared only two raters and found reliability scores of $r = 0.67$ and $r = 0.73$ for both the right and left hands respectively.

Table 3.4-2 Reported reliability ranges for evaluated tests

	Intra-rater reliability				Inter-rater reliability	
	No.	*Correlation (r or r_s)*	*No.*	*ICC's*	*No.*	*Correlation (r)*
PP	14	0.22 – 0.92	4	0.37 – 0.90		
O'Con(Tw)	1	0.93				
GPT	5	0.64 – 0.86				
CSPDT	4	0.56 – 0.9				
GSM	1	$X^2 = 34.99$; d.f. = 9				
MacQ	1	0.63 – 0.9				
O'Con(F)	4	0.76 – 0.92				
FTT	9	0.71 – 0.99			2	0.67 – 0.78
MMDT/MRMT	6	0.87 – 0.97	1	0.79 – 0.87		

No. = No. of studies used to calculate range; r = Correlation; rs = Spearman rank correlation; ICC = Intraclass correlation coefficient; X^2 = Chi squared; d.f. = Degrees of freedom

3.4.1.2. Construct validity

A summary of the identified studies, their population of interest, study characteristics, effect sizes and the construct validity offered are presented in Table 3.4-3 and those which were hypothesis testing only are presented in Table 3.4-4. For the most commonly used test (PP) there was only one study to show a clearly significant correlation with a criterion (Van Herzeele et al. 2010) and two studies which correlated with some but not all evaluated criterion (Masud, Undre & Darzi 2012; Strenge, Niederberger & Seelhorst 2002); there were seven unsuccessful attempts to use the test to correlate with a chosen criterion or discriminate known subject groups. The most successful test was the GPT, which correlated successfully with a chosen criterion in three separate studies (Anderson et al. 1989; Stefanidis et al. 2006; Van Herzeele et al. 2010) and unsuccessfully in two (Waldman, Macdonald & Wilson 1995; Wilson, Waldman & MacDonald 1991). Both of these tests were also successfully used for hypothesis testing in a number of studies.

Table 3.4-3 Health Professionals' studies and reported construct validity

	Study	Validation	Population	N	Comparison	Age/ Sex (M:F)/ Handed (R:L)	Effect Sizes
PURDUE PEGBOARD	Zullo (1971)	Factor Analysis	Dental students	100	N/A	Unavailable	N/A
	Raybould, Raggard and Norton (1983)	Criterion	Dental students	20	Pre-dental GPA Performance on admission tests	Unavailable	r = 0.02 – 0.23
	Schueneman et al. (1984)	Criterion	Surgical Residents	120	Surgical Performance	Mean Age 26.9 Handed 107:13	Simple regression = 0.15 Multiple regression = 0.75 R^2=0.58
	Squire et al. (1989)	Known Groups	Physicians and Surgeons; Residents and Staff	57	Residents vs Staff and Surgical vs Medical	Mean Age, medical residents 28, medical Staff 42, Surgical residents 29, Surgical Staff 46	Unable to calculate
	Wilson, Waldman and MacDonald (1991)	Criterion/ Convergent	Dental Students	111	Maturational, fine motor and skill examination tests	Unavailable	Unable to calculate
	Casanova et al. (1993)	Known Groups/ Hypothesis testing	Hospital staff (mainly nursing)	34	Needlestick injury vs control	Mean age Case 34.5, Control 36.6. Sex 0:34	Unable to calculate
	Strenge, Niederberger and Seelhorst (2002)	Criterion	Medical Students	49	Tests of attention (alertness and divided attention)	Median Age 23 (range 19-30) Sex 23:26 Handed 49:0	r = 0.05 – 0.19 (right) r = 0.05 – 0.39 (all tests)
	Stefanidis et al. (2006)	Criterion	Surgical residents	20	Virtual trainer outcomes	Median Age 28 Sex 14:6 Hand 18:2	r = 0.02 – 0.38

	Study	Validation	Population	N	Comparison	Age/ Sex (M:F)/ Handed (R:L)	Effect Sizes
	Van Herzeele et al. (2010)	Criterion	Medical Students	20	Endovascular surgery simulator tasks and generic rating	Median Age 22 (range 20-26) Sex 8:12 Handed 19:1	r = 0.48 – 0.67
	Lee et al. (2012)	Known Groups	Medical Students	58	Surgical vs Non-surgical	Data for larger cohort only provided: Sex 58:42 Handed 91:9	d = 0.03 (right), 0.11 (left) and 0.77 (combined)
	Masud, Undre and Darzi (2012)	Criterion	Senior medical students	36	Anastomosis training grades, suture no. and accuracy	Unavailable	r = 0.082 – 0.58 grades r = 0.04 – 0.13 no. sutures r = -0.33 – 1.86 accuracy
O'CONNOR TWEEZERS DEXTERITY TEST	Zullo (1971)	Factor Analysis	Dental students	100	N/A	Unavailable	N/A
	Kirby (1979)	Criterion & Hypothesis testing	Ophthalmology residents	17	Teacher ranking	Unavailable	Spearman rank r_s = 0.22
	Weinstein et al. (1979)	Criterion & Known Groups	Dental practitioners	74	Experience Tooth restorative quality scores	Unavailable	r = 0.21 (all restorations) r = -0.02 – 0.48
	Wilson, Waldman and MacDonald (1991)	Criterion/ Convergent	Dental Students	111	Maturational, fine motor and skill examination tests	Unavailable	Unable to calculate
	Waldman, Macdonald and Wilson (1995)	Criterion	Dental Hygiene students	45	Early learning skills tests	Unavailable	r = 0.05 – 0.01

	Study	Validation	Population	N	Comparison	Age/ Sex (M:F)/ Handed (R:L)	Effect Sizes
	De Andrés et al. (2004)	Criterion (?Known groups)	Dental Students	306	Low, Medium and High academic ability	Age < 25 Sex 84:222 Handed 288:18	Unable to calculate
	Goldberg et al. (2008)	Criterion	Medical students	113	Personal assessment of dexterity; Licensing exam scores & class rank	Median age 27 (range 24-41)	r = 0.04 – 0.08
	Suksudaj et al. (2012)	Criterion	Dental Students	121	Cognitive, perceptual speed and psychomotor ability tests; Cavity preparation; Motivation	Sex 58:68	r = 0.02 – 0.19
GROOVED PEGBOARD TEST	Anderson et al. (1989)	Criterion	Medical residents	10	Diagnostic ability score	Unavailable	$r^2 = 0.432$
	Wilson, Waldman and MacDonald (1991)	Criterion/ Convergent	Dental Students	111	Maturational, fine motor and skill examination tests	Unavailable	Unable to calculate
	Waldman, Macdonald and Wilson (1995)	Criterion	Dental Hygiene students	45	Early learning skills tests	Unavailable	r = -0.09 – 0.13
	Strenge, Niederberger and Seelhorst (2002)	Criterion	Medical Students	49	Tests of attention (alertness and divided attention)	Median Age 23 (range 19-30) Sex 23:26 Handed 49:0	r = 0.03 – 0.3 (right) r = 0.03 – 0.50 (all)
	Stefanidis et al. (2006)	Criterion	Surgical residents	20	Virtual trainer outcomes	Median Age 28 Sex 14:6 Handed 18:2	r = 0.13 – 0.67
	Van Herzeele et al. (2010)	Criterion	Medical Students	20	Endovascular surgery simulator tasks and generic rating	Median Age 22 (range 20-26) Sex 8:12 Handed 19:1	r = 0.29 – 0.56

	Study	Validation	Population	N	Comparison	Age/ Sex (M:F)/ Handed (R:L)	Effect Sizes
CRAWFORD SMALL PARTS DEXTERITY TEST	Zullo (1971)	Factor Analysis	Dental students	100	N/A	Unavailable	N/A
	Boyle and Santelli (1986)	Criterion	Dental students	71	Grades; Admission test scores	Sex 55:16	Pins: r = 0.11 – 0.24 Screws: 0.07 – 0.32
	Steele, Walder and Herbert (1992)	Criterion	Surgical trainees	10	Anastomosis trial scores	Mean Age 26.5 (range 25-29) Sex 9:1	Pins: Spearman rank: $r_s = 0.03 – 0.37$ Screws: Spearman rank: $r_s = 0.69 – 0.67$
	Harris, Herbert and Steele (1994)	Known Groups	Surgical, Psychiatric, Anaesthetic and Medical trainees	48	Surgical vs psychiatry vs Anaesthesia vs Medical trainees	Mean age (per group): 28.2 (2.4), 28.3 (3.9), 28.3 (2.2), 28.6 (3.0) Sex (per group): 13:1, 7:6, 7:4, 6:4 Handed (per group): 12:2, 9:4, 9:2, 10:0	Pins: d = -0.09 – 0.52 Screws: d = 0.06 – 0.42
	Francis et al. (2001)	Known Groups	Surgeons and Medical students	40	Surgeons vs students	Median age (per group): 47 (range 38-57), 21 (range 18-28)	Unable to calculate
	Wanzel et al. (2003)	Criterion	Surgeons, Surgical residents and Dental students	47	Expert rating of performance Efficiency of hand motion on bench model task	Unavailable	r = 0.03 – 0.46
	Schijven, Jakimowicz and Carter (2004)	Criterion & Convergent	Residents and Interns	33	Ranking on virtual trainer Aptitude tests correlation matrix Gibson Spiral maze Abstract reasoning Space relations	Mean age: 28 (range 21-35) Sex 18:15 (sic) Handed 19:2 (2 ambidextrous)	r = 0.00 – 0.23

	Study	Validation	Population	N	Comparison	Age/ Sex (M:F)/ Handed (R:L)	Effect Sizes
GIBSON SPIRAL MAZE	Steele, Walder and Herbert (1992)	Criterion	Surgical trainees	10	Anastomosis trial scores	Mean Age 26.5 (range 25-29) Sex 9:1	Time (spearman rank) $r_s = 0.07 – 0.48$ Errors (spearman rank) $r_s = 0.01 – 0.57$
	Harris, Herbert and Steele (1994)	Known Groups	Surgical, Psychiatric, Anaesthetic and Medical trainees	48	Surgical vs psychiatry vs Anaesthesia vs Medical trainees	Mean age (per group): 28.2 (2.4), 28.3 (3.9), 28.3 (2.2), 28.6 (3.0) Sex (per group): 13:1, 7:6, 7:4, 6:4 Handed (per group): 12:2, 9:4, 9:2, 10:0	Time: d = -0.4 – 0.88 Errors d = 0.93 – 0.99
	Francis et al. (2001)	Known Groups	Surgeons and Medical students	40	Surgeons vs students	Median age (per group): 47 (range 38-57), 21 (range 18-28)	Unable to calculate
	Schijven, Jakimowicz and Carter (2004)	Criterion	Residents and Interns	33	Ranking on virtual trainer Aptitude tests correlation matrix Crawford Small parts Abstract reasoning Space relations	Mean age: 28 (range 21-35) Sex 18:15 (sic) Handed 19:2 (2 ambidextrous)	r = 0.07 – 0.31
MACQUARRIE TEST	Burr (1934)	Criterion	Nursing students	61 - 241	Alpha examination Nursing grades	Unavailable	r = 0.27 – 0.58
	De Andrés et al. (2004)	Criterion (?Known groups)	Dental students	306	Low, Medium and High academic ability	Age < 25 Sex 84:222 Handed 288:18	Unable to calculate
	Suksudaj et al. (2012)	Criterion	Dental students	121	Cognitive, perceptual speed and psychomotor ability tests; cavity preparation; motivation	Sex 58:68	Unable to calculate

	Study	Validation	Population	N	Comparison	Age/ Sex (M:F)/ Handed (R:L)	Effect Sizes
O'CONNOR FINGER DEXTERITY TESTS	Zullo (1971)	Factor Analysis	Dental students	100	N/A	Unavailable	N/A
	Gluskinos and Brennan (1971)	Criterion	Nurses and technicians	40	Supervisors score on factors elicited from 42-item criterion checklist	Mean age 28.4 (range 19-54) Sex 2:38	r = 0.09 – 0.32
	Kirby (1979)	Criterion & Hypothesis testing	Ophthalmology residents	17	Teacher ranking	Unavailable	Spearman rank: $r_s = 0.29$
FINGER TAPPING TEST	Stefanidis et al. (2006)	Criterion	Surgical residents	20	Virtual trainer outcomes	Median Age 28 Sex 14:6 Hand 18:2	r = 0.1 – 0.60
MMDT	Zullo (1971)	Factor Analysis	Dental students	100	N/A	Unavailable	N/A
	Squire et al. (1989)	Known Groups	Physicians and Surgeons; Residents and Staff	57	Residents vs Staff and Surgical vs Medical	Mean Age, medical residents 28, medical Staff 42, Surgical residents 29, Surgical Staff 46	Unable to calculate

MMDT – Minnesota Manual Dexterity Test

Table 3.4-4 Hypothesis Testing Health Professionals' studies

Test	Study
Purdue Pegboard	Lauf and LeCompte (1982)
	Casanova et al. (1993)
	Ayalon and Friedman (2008)
	Mucksavage, Kerbl and Lee (2011)
O'Connor Tweezers Dexterity Test	Kirby (1979)
	Simon and Chambers (1992)
	Lundergan, Soderstrom and Chambers (2007)
Grooved Pegboard Test	Buffington, MacMurdo and Ryan (2006)
	Drabek, Boucek and Buffington (2010)
Macquarrie Test	Hellebrandt and Houtz (1955)
O'Connor Finger Dexterity	Kirby (1979)
	Simon and Chambers (1992)
Finger Tapping Test	Korttila et al. (1978)
	Bittner Jr et al. (1998)

3.4.1.3. Factor analysis

Of the studies identified in the systematic search only one was a factor analysis (Zullo 1971). The psychomotor tests subjected to factor analysis were two sub-tests of the PP, CSPDT, the O'Con (F) and O'Con (T) tests and two sub-tests of the MRMT. Factor loadings were representative of the elements that, at face value, one would expect to underlie the tests. The subtests of the PP and the O'Con (F) dexterity test loaded highest for the 'Finger Dexterity Factor', the subtests of the MRMT loaded for the 'Manual Dexterity Factor' and the CSPDT and O'Con (T) test loaded highest for the 'Small Instruments Dexterity Factor'. A broader search of the literature identified factor analyses that were undertaken for the tests on healthy non-health professional populations (Aftanas & Royce 1969; Barnsley & Rabinovitch 1970; Bourassa & Guion 1959; Chapman 1948; Clark & King 1960; Fleishman & Ellison 1962; Fleishman & Hempel 1954; Goodman 1947; Harrell 1940; Lansdell & Donnelly 1977). Whilst not

all articles used similar terminology, ‘manual dexterity-like’ and ‘finger dexterity-like’ terms were grouped and subsequent loadings are reported in Table 3.4-5.

3.4.1.4. Convergent validity

Convergent validity between tests was occasionally reported as outlined in Table 3.4-6. The PP and MMDT both showed convergent validity with the O’Con (F) Dexterity test (Rogers & Noddin 1984). The MMDT showed convergent validity with the PP and Box and Block test (Desrosiers et al. 1997), and more specifically to the PP with correlations ranging between r = 0.92 and r = 0.95 for various subtests (Maiden & Dyson 1997). Furthermore the MacQ test was found to correlate with the Stenquist Manual ability test (Stein 1927), a test not reported amongst the top nine tests. The GPT showed convergent validity correlating with grip, pinch grip and 1st dorsal interossei strength tests and correlating with pinch and index finger steadiness tests (Marmon et al. 2011). Intercorrelation testing undertaken on the MacQ test of manual ability subtests showed poor correlation, varying from r = 0.29 to r = 0.55 (Goodman 1946). In contrast, the correlations in a group of 14 year olds ranged from r = 0.15 to r = 0.70 (Babcock & Emerson 1938). Wilson and colleagues (1991) found a significant correlation between test results of the O’Con (Tw) dexterity test and the GPT, however correlations between the PP and GPT, and between the O’Con (Tw) and PP failed to reach significance. The CSPDT error score only was significantly correlated with the GSM (r = 0.48) but not time to completion (Schijven, Jakimowicz & Carter 2004).

Table 3.4-5 Factor loadings for identified tests on manual and dexterity-like factors

	Manual dexterity factor	Finger dexterity factor
PP	Assembly (0.32), non-preferred and both hands (0.68, 0.63)	Preferred (0.57 – 0.73) and non-preferred (0.70), left hands (0.62), both hands (0.61), assembly (0.57) and right hands (0.46)
GPT	(0.51 – 0.63)	Preferred (0.37)
CSPDT	Preferred hand (.62)	Non-preferred (0.36)
MMDT (MRMT)	Placing (0.42, 0.52, 0.73) and turning (0.49, 0.53, 0.61), non-preferred (-0.56 – -0.66) and preferred (-0.48)	Placing (0.37) and turning (0.34 and 0.39), preferred (-0.45)
O'Con (F)	(0.50)	
MacQ	Dotting test (0.5), tapping, dotting, tracing, location, pursuit and copying (0.58, 0.51, 0.49), location and dotting (0.33 & 0.27)	

NB: Factor loadings are not comparable between studies. Values are provided to indicate the strength of association within the identified factor within a particular study.

Specific references can be provided upon request. All references are included in reference list.

Table 3.4-6 Convergent validation of identified tests

r =	PP	O'C (Tw)	GPT	CSPDT	GSM	MacQ	O'C (F)	FTT	MMDT
PP									
O'Con (Tw)	0.15								
GPT	0.22	0.33, 0.32, -0.25							
CSPDT									
GSM				Time 0.1 Error 0.48					
MacQ		Trace -0.02, Tap -0.31, Dot -0.11							
O'Con (F)	0.16								
FTT			-0.35, 0.53, -0.47						
MMDT	-0.63 – -0.67						0.6		

Specific references can be provided upon request. All references are included in reference list.

3.4.1.5. Criterion validity

From the remaining studies identified in the systematic search, a number of the tests were compared with another criterion, which was frequently subjective, to determine the tests' suitability or ability in predicting or evaluating dexterity.

The PP did not correlate with dental admissions tests or skill of dental students as evaluated by educators (Raybould, Raggard & Norton 1983), nor did it predict laparoscopic trainer ability (Stefanidis et al. 2006) or surgical skill, although the inter-rater reliability of the raters was extremely poor (Schueneman et al. 1984). However, times to complete the PP did correlate with initial endovascular skill and fine motor dexterity (Van Herzeele et al. 2010) and for surgical trainees, anastomosis grade for the first four out of eight sessions (Masud, Undre & Darzi 2012).

Time taken to complete the GPT correlated with 'diagnostic ability' in surgical registrars (Anderson et al. 1989), training duration and repetition on a trainer (Stefanidis et al. 2006) and as with the PP, GPT times correlated with initial endovascular skill on a virtual reality trainer (Van Herzeele et al. 2010). However, the GPT did not correlate with a periodontal skills test (Wilson, Waldman & MacDonald 1991) or dental hygiene instrumentation tests (Waldman, Macdonald & Wilson 1995).

The CSPDT outcomes also showed some important correlations, including correlating with the Dental Admissions Test (DAT) and preclinical technique (Boyle & Santelli 1986) but did not correlate with improvement in an anastomosis task (Steele, Walder & Herbert 1992), nor VR trainer performance (Schijven, Jakimowicz & Carter 2004). In fact, Steele, Walder and Herbert (1992) found a negative correlation whereby those who performed the CSPDT the quickest showed the least improvement. This has implications regarding the possible ceiling effect of the test.

Weinstein et al. (1979) found a similar result from the O'Con (Tw) test and dental practitioners whereby those practitioners who took longer to complete the O'Con (Tw) test achieved significantly higher quality scores. The study by Wilson and colleagues (1991), as with the GPT, found the O'Con (Tw) test did not correlate with periodontal skills. Whilst the O'Con (Tw) test did correlate with some personal variables there were no significant correlations with academic scores of dental students (De Andrés et al. 2004) or with class rank or licensing exam scores in medical students (Goldberg et

al. 2008). Most recently, Suksudaj et al. (2012) also found that psychomotor ability using the O'Con (Tw) showed only weak positive correlations with dental performance on cavity preparation exercises. Similar findings were found for the Ophthalmology profession, whereby the O'Con (Tw) and O'Con (F) tests did not significantly correlate with student grades or teacher ratings (Kirby 1979). In an operating room setting the O'Con (F) significantly correlated negatively with attention to detail but did not correlate with general technical knowledge, patient awareness or social interaction (Gluskinos & Brennan 1971).

The MacQ test did not correlate with a subjective measure of nursing ward performance; however, it did correlate with a preliminary nursing grade, although this did not carry over to the intermediate grades (Burr 1934). The MacQ test also did not show any positive correlations with criteria in two studies already mentioned (De Andrés et al. 2004; Suksudaj et al. 2012). The GSM did not correlate with anastomoses surgical ability (Steele, et al., 1992) or performance on a virtual reality trainer (Schijven, Jakimowicz & Carter 2004). The research by Stefanidis et al. (2006) evaluating the predictive ability of psychomotor tests on virtual trainer performance and mentioned above for its correlation with the GPT also showed a correlation with one aspect of the virtual trainer use but not another, consequently providing equivocal results.

3.4.1.6. Known groups discrimination validity

Within the remaining studies identified, many attempted to use the psychomotor tests to discriminate between known groups of health professionals. Harris, Herbert and Steele (1994) found no differences between registrars and senior professionals from the surgical, psychiatric, anaesthetic and general medicine disciplines on the CSPDT or GSM. Using these same psychomotor tests Francis et al. (2001) was unable to discriminate between medical students and surgeons with the CSPDT; however, the GSM showed decreased errors for master surgeons. The CSPDT was also unable to differentiate between surgeons, surgical residents and dental students (Wanzel et al. 2003). Finally, Squire et al. (1989) found no significant differences between medical and surgical residents on the MRMT. Whilst not a true example of discrimination of 'known-groups', the MacQ test was used in one study to evaluate the manual abilities of Occupational Therapy students, and found that the students surpassed equivalent normative values (Hellebrandt & Houtz 1955).

3.4.2. Confounding effects

Table 3.4-7 outlines common confounding effects and calculated effect size ranges on the tests of interest. Common confounders include age, sex and handedness. In some instances education or intellect were also evaluated. Education usually represented years in study or level of accomplishment whereas intellect was usually evaluated using an objective test.

3.4.2.1. Purdue Pegboard (PP)

Reddon et al. (1988) found that practice effects existed only for the right and left hand tasks but not for the 'both' hand subtest or the 'assembly' subtest on the PP and that these effects were only in men and not women; consequently, this is an equivocal finding. Furthermore, Bartels et al. (2010) found an effect size of d = 0.52 existed when the assembly sub-test was regularly applied over a three month period. However, a clear age and sex effect was reported for the PP in favour of females and younger adults (Agnew et al. 1988; Brito & Santos-Morales 2002; Desrosiers et al. 1995; Mathiowetz et al. 1986; McCurry et al. 2001; Sattler 1982; Sterne 1969; Wilson et al. 1982; Yeudall et al. 1986). Haward and Griffin (2002) however, found no effect of age or sex.

3.4.2.2. Grooved Pegboard Test (GPT)

The GPT test was one of the more extensively studied tests, with 19 studies investigating age and sex effects alone. Whilst effect size ranges are broad there seems to be clear evidence of practice effects (Dikmen et al. 1999; Levine et al. 2004; Lezak, Loring & Howieson 2004; McCaffrey, Ortega & Haase 1993; Schmidt et al. 2000), age effects (Bornstein 1985; Bryden & Roy 2005b; Levine et al. 2004; Lezak, Loring & Howieson 2004; Marmon et al. 2011; Mitrushina, Boone & Razani 2005; Ruff & Parker 1993; Schmidt et al. 2000; Selnes et al. 1991), and sex influences (Bornstein 1985; Bryden & Roy 2005a; Lezak, Loring & Howieson 2004; Mitrushina, Boone & Razani 2005; Ruff & Parker 1993; Schmidt et al. 2000) in favour of females, although the sex difference was not supported by Mitrushina et al. (1995). The GPT showed improving performance with age in a paediatric and adolescent population; this then reversed in the adult population with decreasing performance with increasing age, particularly in older cohorts. Equivocal findings were reported for handedness on the remove task (Bryden & Roy 2005a), and a trial-handedness interaction (Schmidt et al. 2000), but no reports of a clear effect of handedness by itself were found. The effect of level of education on

the GPT is also not clear with research findings supporting the affirmative (Bornstein 1985; Ruff & Parker 1993; Selnes et al. 1991) and negative (Bornstein & Suga 1988; Heaton, Grant & Matthews 1991; Levine et al. 2004).

3.4.2.3. Finger Tapping Test (FTT)

For the FTT, the effect of confounders is somewhat equivocal. Gill et al. (1986) found that overall there were no practice effects, sex effects or handedness effects. However, a detailed look at sub-groups found that there was a significant improvement for males on both preferred and non-preferred hands suggesting a practice effect. Dodrill and Troupin (1975) also found that correlations increased after the first two trials going from $r = 0.77$ up to $r = 0.90$, suggesting a practice effect. Dikmen et al. (1999) also confirmed a practice effect but only in the dominant hand and felt it was less pronounced with a mean change of only 0.85 taps (SD 4.31, $p < 0.001$). A number of authors report sex effects (Bornstein 1986; Elias et al. 1990; Fromm-Auch & Yeudall 1983; Mitrushina, Boone & Razani 2005; Morrison, Gregory & Paul 1979; Shimoyama, Ninchoji & Uemura 1990) with males outperforming females, but this was not always supported (Gill et al. 1986; Mitrushina et al. 1995). The effect of age on the FTT is less clear, Ruff and Parker (1993) report no age effect with men, only with women. However, other authors found an effect of age (Mitrushina, Boone & Razani 2005) either by correlation (Bornstein 1985, 1986; Vega & Parsons 1967) or by group stratification (Bak & Greene 1980; Goldstein & Braun 1974; Heaton, Grant & Matthews 1991; McCurry et al. 2001; Mitrushina et al. 1995; Shimoyama, Ninchoji & Uemura 1990) from which a consistent age of performance decline could not be determined, although Shimoyama, Ninchoji and Uemura (1990) found this to be over 40 years of age, which was supported by Fromm-Auch and Yeudall (1983) and Villardita et al. (1985). Not all authors found such a pronounced effect with Yeudall et al. (1987) showing combined sample correlations of only $r = 0.20$ to $r = 0.22$ albeit in a population between 15 and 40 years of age, Heaton, Grant and Matthews (1986) found an attributable variance of between 5 and 10%, and Elias et al. (1993) found only a marginal decline. Elias et al. (1990) found no significant effects of age whatsoever.

3.4.2.4. O'Connor Finger Dexterity test

For the O'Con (F), Corlett, Salvendy and Seymour (1971) found a significant practice effect, recording mean times 17% faster on a subsequent trial.

Table 3.4-7 Confounding effects for identified tests

	No.	Practice Effects (d)	No.	Age (d)	No.	Sex (d)	No.	Hand (d)	No.	Education (d)	No.	Intelligence (d)
PP	2	0.07 – 1.04	6	0.03 – 2.07	7	0.08 – 1.34	2	0.14 – 0.22				
(Child)			3	0.00 – 4.52								
O'Con(Tw)												
GPT	4	0.01 – 0.4	11	0.36 – 2.72	8	0.04 – 1.29	3	0.01 – 0.71	6	0.02 – 0.58	2	0.1 – 0.43
(Child)			2	0.54 – 1.59								
CSPDT												
GSM			2	0.1 – 2.46								
MacQ	1	0.51 (Tapping)	1	0.82	2	0.01 – 0.95			1	0.6	1	1.58
O'Con (F)	1	0.14 – 1.01										
FTT	1	0.07 – 0.13	19	0.02 – 1.8	21	0.02 – 1.62	4	0.01 – 0.97	8	0.12 – 0.69	2	0.03 – 0.53
MMDT	1	0.16 – 0.48	1	0.67 – 1.69	1	0.02 – 0.6						

No. = No. of studies used to calculate range, Hand = Handedness, Educ = Education, d = Effect sizes (Cohen's d) calculated from means and standard deviations, F-scores and correlations where appropriate. Specific contributing references may be provided on request. All references are included in reference list. Articles that did not provide sufficient information for effect size calculation were excluded.

3.4.3. Test feasibility and utility

As seen in Table 3.4-8, tests were similar with respect to elements of test applicability. This included consideration of: ease of use, knowledge requirements of the assessor or the cost and availability of the instrument of concern. With the exception of the FTT test, all other tests needed to be purchased from a specific supplier; however, the CSPDT has been discontinued as of April 2010.

Table 3.4-8 Feasibility and utility of identified tests

	Equipment requirements & Availability	Knowledge requirements	Ease of application
PP	Moderate	Easy	Easy
O'Con (Tw)	Moderate	Easy	Easy
GPT	Moderate	Easy	Easy
CSPDT	Difficult	Easy	Easy
GSM	Moderate	Easy	Easy
MacQ	Moderate	Easy	Easy
O'Con (F)	Moderate	Easy	Easy
FTT	Easy	Easy	Easy
MMDT (MRMT)	Moderate	Easy	Easy

3.5. Discussion

Based on the literature reviewed, the most extensively used test on the health professional population was the PP followed closely by the O'Con (Tw) and GPT. Seemingly, the most valid of these would be the GPT, showing convergent validation with other tests of dexterity including the O'Con (Tw) dexterity test and FTT, in addition to significant correlations with a number of other dexterity-related criteria in the identified studies. However, it is also evident that this is very dependent on the elements to be investigated and the associated criterion and hypothesis. Interestingly, convergent validation shows that the PP and GPT are not correlated, nor is the PP and O'Con (Tw), but the O'Con (Tw) and GPT are. This may represent the finer elements of manipulation required by these two tests or simply that the studies were underpowered. The lack of evaluation of convergent validation of these tests is indicative of how little we know about them and the interactions they may provide.

The tests which have undergone the most extensive reliability testing were the PP and FTT. The PP was evaluated in 14 different studies. However, the reliability range provided from these studies was quite broad, ranging from poor to excellent. The reliability of these measures should display a minimum correlation of r = 0.7 to be acceptable (Cook & Beckman 2006; Warr & Downing 2000). The test-retest reliability of the FTT was evaluated in nine studies, many of which evaluated the Halstead-Reitan test battery as a whole. The reliability range reported for the FTT was narrower, ranging from moderate to excellent. The only tests that had been evaluated using intraclass correlation coefficient statistics were the PP and MMDT. Whilst both ranges extended into a good reliability range the PP had a much broader range with the lower limit showing quite poor reliability, whereas the MMDT had only been evaluated once (Desrosiers et al. 1997).

As would be expected, tests that are sensitive to differences in a healthy population may often also be influenced by other common population variances. The most comprehensive information on these confounders exists for the PP, GPT and FTT; however, results were in some parts contradictory.

Test utility across all the tests was quite similar, with most tests being relatively easy to administer.

With the exception of one factor analysis, no specific psychomotor test validation studies had been undertaken on the health professional population, which may originate in part from the age of the tests or from the lack of a criterion standard for dexterity or psychomotor testing. The trend for factor analyses was evident in the early literature with a number of studies incorporating many of the tests identified in addition to a multitude of others which were undertaken but unavailable, located within the United States military (Fleishman 1953). Of particular interest Zullo (1971) undertook a factor analysis on a health professional population incorporating the PP, CSPDT, O'Con (F) and (Tw) test and MRMT. This study suggests that the PP and O'Con (F) consist of considerable elements of finger dexterity, to be interpreted as 'fine motor' dexterity, and the MRMT consists of elements of manual dexterity, to be interpreted as 'gross motor' dexterity. These findings may be important when selecting an appropriate test to match the underlying elements of the task or profession to be evaluated. For example, the

slow precise fine movements underlying neurosurgery may differ from rapid repetitive movements used in podiatric callus debridement.

There was a distinct lack of data on the test-retest reliability of tests other than the PP and FTT. This, however, may be the result of publication or research bias. Some tests had been evaluated for test-retest reliability but not for practice effects, consequently making interpretation of the results more complicated. From the available data, test-retest reliability seemed to reach adequate levels, however in some cases reported ranges were very broad, suggesting inconsistencies with methodologies or test administration, such as the time periods between testing. This also means that test selection should only be made after a detailed review of a study similarly structured to the planned research. Inter-rater reliability data were only available for the FTT, which showed moderate reliability. No data were available for the remaining tests, which may be reflective of the methodology of the studies reviewed, predominantly using only one assessor.

As outlined above, test utility was similar between tests; the only exception to this was the CSPDT, which is no longer available for purchase from the supplier as of April 2010. The FTT is the most flexible test with respect to equipment needs. A purpose-specific 'tapper' may be purchased or an easily accessible calculator can also make a suitable substitute, however this may affect reliability of the test and should be considered. Arceneaux et al. (1997) found that a calculator was a suitable substitute to the tapper with score correlations of $r = 0.85$ and $r = 0.80$ for the right and left hands respectively. In terms of administration time, it would be reasonable to assume that the greater number of sub-tests the longer it would take. Particularly if the sub-tests load similarly in factor analyses i.e. they examine similar elements, then the test with the shortest administration time would be the obvious choice. Likewise, for the pegboard-like tests, provided the required elements are being tested, the quickest (least amount of pegs) test is preferable. In some tests the administration protocol is to record the number of pegs inserted or removed during a specified period of time. This decreases the administration time, however, results in discrete rather than continuous data, which could potentially decrease the precision of the results and consequently the sensitivity of the test.

For this study, 86 articles concerning health professionals, across a broad date range and incorporating a broad range of tests were identified. Publications utilising such tests have increased two-fold in the last ten years. Interestingly, a majority of the tests (excluding the discipline specific trainers, omitted as outlined above) were developed many years ago, as far back as 1925 (O'Connor 1925). The nine most predominantly used 'standardised psychomotor tests' are reported here. However, the most frequently utilised test, the PP, was used in only 14 of the identified studies and the least used tests of the top nine were used in only two or three studies leading to limitations in interpreting their external validity in a health professional population. The origin of these tests is quite diverse, ranging from tests of delinquency (Gibson, 1964) to personnel selection for industry (Ghiselli 1973; MacQuarrie 1927). Consequently, literature pertaining to a normal or healthy population was not always easy to identify. The predominant use of psychomotor testing in health professionals was for aptitude testing, particularly in the dental profession where there is a history of testing as a selection process for dental school (Coy, McDougall & Sneed 2003; Deubert et al. 1975; Spratley 1990).

Choosing the most appropriate psychomotor test to use for the health professional population is difficult; it depends on the underlying purpose for which the test is to be used, and in addition, suitable validity or reliability needs to be considered. It is important that a chosen test is both reliable and valid for the purpose it is being used, whilst being generalisable to multiple professions and tasks purported to reflect the attribute in question, such as fine-motor or gross-motor dexterity. There is a long history of a lack of suitable validity and reliability for hand assessment tests (Bear-Lehman & Abreu 1989; Fess 1986). With respect to the psychomotor tests identified in this review this is particularly hard to establish given the age of many of the tests and that original data are historical and not always freely available. Often the original data released on the test may have been provided in a manual only rather than in peer-reviewed journals.

In the absence of specific 'validation' studies, or the existence of a gold standard, we need to consider 'criterion-related' correlation or the ability of the tests to discriminate two or more 'known-groups' in the health professional or healthy population literature as an indication of their validity for a certain task. However, relying on 'criterion-related' validation or 'known-groups' discrimination does have limitations. For

example, care should be taken that the criterion against which the test is being compared is sufficiently valid itself and not subjective in nature. Furthermore, it is possible that the underlying psychometric properties of the GDT chosen for the study do not match those of the task being evaluated in that particular study. Furthermore, normative values for health professions need to be established on the commonly used tests to allow for appropriate benchmarks in evaluation or rehabilitation. Future research in this area should consider a large study directly comparing the psychometric properties of the commonly used psychomotor tests on a number of the health professions in which they are commonly used.

Finally, this paper focused on appraising the tests themselves and presenting the evidence available. However, the quality of each of the articles was not evaluated. Considering the age of some of the articles it is quite likely that they provide poor quality evidence which should be evaluated.

3.6. Conclusion

This paper has demonstrated that a wide range of psychomotor tests have been used to assess manual dexterity of health professionals. There has been an increase in reported use of these tests, over the last 20 years, with a two-fold increase in the last 10 years. However, this research has identified that of these tests few have had sufficient reliability testing and the majority have either not had their validity evaluated or have been shown to be valid for only some components of clinical skills required by health professionals. Therefore, caution should be applied regarding test selection and interpretation of findings. Based on the evidence available, the GPT, PP and FTT are recommended as they have been the most extensively studied and provide us with the greatest insight to their validity, reliability and the effects of confounding population characteristics; although more rigorous evaluation of their validity is required. Furthermore, choice should be made dependent on the specifics of the task/s to which the outcomes must be generalised. For example, each of these tests is weighted towards the evaluation of speed rather than accuracy. The FTT is the more reliable of these tests and seems the most resilient to confounders, however it severely lacks validation on a health professional population. A number of the other tests show potential; however, a scarcity of data makes them less desirable choices at this stage.

4. A comparison of novice podiatry students and experienced podiatrists using selected dexterity tests (study two)

4.1. Introduction

The ability to undertake fine and gross motor activities is an important component of podiatry practice. The ability to adequately perform these activities relates to the dexterity of the practitioner. A task analysis of podiatric management in the primary care setting, undertaken by Levy and Lepow in 1979, determined 65% to be dexterity-related (Lauf & LeCompte 1982). This was also identified in Chapter 2, Section 2.3.3.1, by interviewees as an important issue in the learning of manual clinical skills, particularly novice podiatry students learning scalpel skills.

Numerous methods of evaluating dexterity have been proposed and used for a wide variety of purposes, but only a limited number of these tests have been used to evaluate a health profession population (Chapter 3). Only one study has addressed the evaluation of dexterity in a podiatric population, using the PP in this instance (Lauf & LeCompte 1982). To date there is no 'gold-standard' for the evaluation of dexterity, either generally or specifically for the health professional or podiatric population. This makes appropriate test selection when designing a dexterity-related study convoluted. One reason for the lack of consensus regarding appropriate tests for measuring dexterity may be the sheer number of psychomotor elements which may contribute to a dexterous performance. For example, when using a scalpel, in addition to the co-ordination of muscle groups to effectively and appropriately facilitate scalpel movement, numerous afferent and cognitive processes are required. These include visualisation, proprioception and tactile sensation; predictive processes determine the appropriate amount of force and approach required and cognitive processes to integrate and interpret this input in order to successfully coordinate and implement a suitable motor plan. Task requirements in all of these foundational areas can vary from slow, precise, fine

movements in a surgical nail bed resection through to the rapid, repetitive movements required for callus debridement. Tests of dexterity target different components which contribute to a dexterous performance and consequently may suit one particular task or profession better than another.

Thus, the primary aim of this study was to determine which objective GDTs are best suited to evaluating scalpel skills in a podiatry (health professional) population through the differentiation of experience. In order to do this a number of GDTs were selected from the review undertaken in Chapter 3 (Causby et al. 2014), the study which acted as the impetus for pursuing this area of research (Bitter, Hillier & Civetta 2011), and through discussions with a number of local researchers well published in evaluating dexterity (Cirillo, Todd & Semmler 2011; Flavel et al. 2012; Flavel, White & Todd 2013; McDonnell & Ridding 2006; McDonnell et al. 2005; Rogasch & Todd 2013; Todd et al. 2009). Tests were selected which targeted different elements important for dexterity. A secondary aim was to identify differences in psychological factors, which may influence motor learning, as outlined in Section 1.2.2.3, due to differences in experience. The GDTs and psychological inventory would be used to evaluate and compare novice and experienced podiatry students and experienced podiatrists; grouped as novice, intermediate and experienced participants. The intended outcomes were two-fold; firstly, to determine which test outcomes or psychological factors were able to discriminate between the novice students and experienced podiatrists and secondly, to determine which of these contributed the most to group classification, allowing us to identify which elements may be most relevant to Podiatric experience.

4.2. Methods

Ethics approval was obtained from the University of South Australia Human Research Ethics Committee (Protocol no. 0000025462) and Queensland University of Technology University Research Ethics Committee (Protocol no. 1100001362) (Appendix I). A cohort of podiatry students were recruited from the University of South Australia (UniSA) and the Queensland University of Technology (QUT) (Novice and Intermediate group) (Appendix J). However, the intermediate group was dropped early in recruitment after an equipment delay resulting in missing a whole student cohort and it was clear that insufficient participants would be obtained. The Experienced group participants were recruited from the podiatry workforce, with data

collection conducted at both universities. Participants were required to be between 18 and 40 years of age, not perform as a professional musician, or have a condition or require medication, which could affect hand function. Novice participants were first or second year students who had not used a scalpel previously. Experienced participants needed to have greater than two years of podiatric clinical experience working greater than 0.5 full-time equivalent.

Consent was obtained (Appendix K) before demographic data, including height, age, sex, medical history, working history, hobbies and podiatric experience were recorded for each participant. Participants who identified as having played computer games or musical instruments as a hobby were required to provide an estimate of time dedicated to the task in order to further explore the effects on test variables if necessary. This was achieved through the selection of a grouped category, being: 'nil', 'less than five hours', 'between five and ten hours' and 'greater than ten hours' per week. Participants from the Experienced group also made an estimation of their overall patient experience by making a year-by-year evaluation of the approximate number of patients seen, to be used if further within-group discrimination was required. Each participant's hand dominance was determined using the Edinburgh handedness inventory (EHI) (Oldfield 1971), implemented prior to testing. The benefit of the EHI is that it provides a quantitative value, a laterality quotient, indicating the degree of handedness. The EHI has been shown to be a valid measure of handedness (Demura et al. 2006) , with a test-retest reliability of $r = 0.97$ ($p < 0.01$) (McMeekan & Lishman 1975; Triggs et al. 2000).

Participants were required to perform a battery of objective psychomotor tests (see Table 4.2-1). As outlined previously, the test battery was chosen to represent a diverse combination of elements and complexity considered to underpin dexterity, from pure motor tests such as grip strength, or maximal voluntary contraction (G-MVC) to more complex visuomotor interpretation in the form of a computerised visuomotor tracking test (VTT). The order of testing was selected by a researcher (MM) experienced in use of the tests to minimise fatigue and allow a logical flow to testing. Tests were completed in a single 60 minute session. Participants were requested not to consume caffeine or other stimulants for four hours prior to testing, or undertake any vigorous exercise one hour preceding testing. Caffeine, as a stimulant, has been shown to affect psychomotor performance (Jacobson & Thurman-Lacey 1992; Jacobson, Winter-Roberts & Gemmell 1991) including an increased rate on the FTT (Fagan, Swift &

Tiplady 1988; Rees, Allen & Lader 1999). Whilst Waldron & Anton (1995) found no effect of exercise on dexterity using the GPT, the physiological effects of exercise and subsequent adrenaline release and temperature changes are well-known and have been shown to cause a delayed increase in physiological tremor (5-10 mins) and decrease tetanic tension within a muscle (maximal motor unit stimulation) at 10 and 20 Hz (Davies, Mecrow & White 1982; Lakie 2010). Testing was undertaken with participants sitting at a desk adjusted to an ergonomically appropriate height to avoid any potential confounding from working in a compromised position (Buffington, MacMurdo & Ryan 2006). Participants sat on a movable operators chair consistent with use in podiatric practice and to avoid compromising the participants test position. The dominant hand was tested first, followed by the non-dominant hand. In participants who were identified as ambidextrous by the EHI (laterality quotient between -40 and +40), the writing-hand was tested first.

Participants were also required to fill out an Intrinsic Motivational Inventory (IMI) (Ryan, 1982) regarding how they felt about using a scalpel in the podiatric context. The IMI, described below, was used to evaluate the domains of 'Perceived Competence', 'Effort/ Importance' and 'Pressure/ Tension', representing their self-efficacy, motivation and anxiety respectively, associated with scalpel use.

4.2.1. Dexterity tests

The test battery comprised of the following non-task specific tests of dexterity, presented in order of testing, and summarised in Table 4.2-1.

Table 4.2-1 Outcome variables for each of the tests within the battery

Test (in order of testing)	Outcome Variables
Tremor	Peak power in acceleration spectrum (g^2) Frequency of Peak Power (Hz)
Visuomotor tracking test (VTT)	Absolute error value (deg), Maximum cross-correlation value (ρ), lag (ms)
Finger Tapping Test (FTT)	Maximum taps (n), Coefficient of variation
Maximum Pinch Grip (P-MVC)	Maximum force (N)
Grip-lift Task	Preload duration (ms), Minimum Load (N), Maximum grip force (N), Grip force to Lift force ratio, Maximum Cross-Correlation (ρ), Timeshift (ms), Average Grip (N), Standard Deviation of grip, Hold ratio, Lift Duration (ms)
Grooved Pegboard Test (GPT)	Time to complete (s)
Grip Strength (G-MVC)	Maximum Force (Kgs)
AsTEX® Sensory test	Texture Discrimination Index (mm)

4.2.1.1. Tremor

Tremor was measured using methods similar to that of Flavel et al. (2012). A small accelerometer (Precision ±2 g dual axis, PWM Output accelerometer, ADXL212, Analogue devices, Norwood, Massachusetts) was glued to the fingernail of the dominant index finger. Acceleration was sampled at 400 Hz and filtered (low-pass 100 Hz) using a custom amplifier, a CED Micro1401-3 (Cambridge Electronic Design, Cambridge, UK) data acquisition unit and Spike2 v.7 software (Cambridge Electronic Design, Cambridge, UK). Resting tremor was measured with the hand resting on the table in a self-selected comfortable position. Tremor during an externally paced (metronome at 1 Hz) flexion and extension movement of the index finger was then performed with the participant's hand off the table in front of them in a comfortable position with the arm unsupported, shoulder in a neutral position, the elbow flexed and forearm pronated. A minimum period of 30 s of data was recorded for both conditions.

Tremor test data analysis was similar to the methods of Flavel et al. (2012). For analysis, 30 s of data was selected and the direct current (DC) offset removed (time constant 0.25 s) from the raw acceleration trace, followed by Fast Fourier

Transformation (FFT; size 1024, resolution 0.4 Hz, Hanning window) to construct a power spectral density. The resultant data were exported to Microsoft Excel™ (Microsoft Corporation, 2010). As physiological tremor occurs between 8-12 Hz in healthy people (Hallett 1998), the peak power and frequency within a 7-13 Hz range were extracted. The mean power for the same range was also determined for comparison between trials. Mean and peak power are an index of tremor amplitude in the specified frequency range (Flavel et al. 2012)

4.2.1.2. Visuomotor Tracking Task (VTT)

The VTT used a device and methods similar to that described by Todd et al. (2009). The VTT requires participants to manipulate a waveform graph on a computer screen via an electrogoniometer attached to the index finger to match a target wave (Figure 4.2-1). In order to manipulate the cursor, the index finger must be abducted and adducted at the metacarpophalangeal joint which facilitates onscreen movement of the cursor to the top or bottom of the screen. The target path is created by 18 individual epochs of 10 s duration, in which the line moves from horizontal up and down up to the equivalent of ± 10˚on the goniometer in an unpredictable pattern (Figure 4.2-1). The tracking path is directed by the goniometer, with between ± 10˚of excursion by finger abduction and adduction. The onscreen scale was kept consistent between participants. Participants were instructed to follow the path as closely as possible, moving the finger when the target path moved from being a horizontal line. An acclimatisation period was not provided. The signal was amplified (x 3000), digitised online at 2 KHz (Cirillo, Todd & Semmler 2011) and recorded using the CED Micro1401-3 data acquisition unit (Cambridge Electronic Design, Cambridge, UK) together with Signal v.4 software (Cambridge Electronic Design, Cambridge, UK).

Data analysis, as outlined in Todd et al. (2009), involved the extraction of target and goniometer data points to Microsoft Excel™ (Microsoft Corporation, 2010) so that the absolute error (the distance between the target and tracking path at each time point) could be calculated; the average for each epoch was calculated. The remaining outcomes required the transfer of each specified time period to SPSS v.21 (IBM Corporation, Armonk, NY, USA) for a cross-correlation analysis of target versus tracking values. Cross-correlation was set to ± 200 lags (ms); the maximum cross-correlation value and lag point at which this occurred were exported for statistical group comparisons.

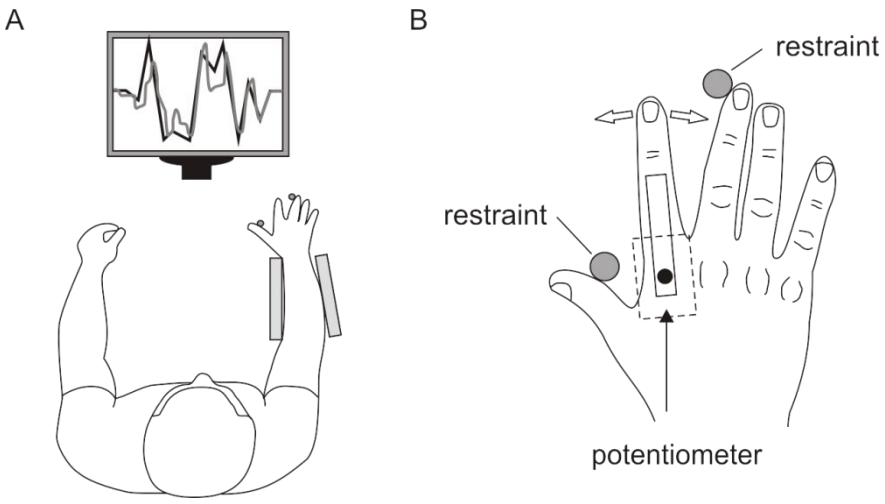


Figure 4.2-1: Visuomotor tracking task (VTT) apparatus

4.2.1.3. Grip-lift Task

The Grip-lift task uses a manipulandum similar to that used by Westling and Johansson (1984) (Figure 4.2-2). The manipulandum is a device for measuring grip force and lift force whilst a small object is gripped and lifted off the supporting surface. Two linear strain gauges (model MLP-100; Transducer Techniques, Temecula, CA, USA) detect the grip force (horizontal force) applied to the object whilst simultaneously recording lift forces (vertical) as the device is lifted to a pre-determined height (100 mm). Two brass pads are positioned at the top of the device and sit approximately 35 mm apart. Below the second force gauge there is a metal strip which provides a ledge upon which a variety of weights may be placed to alter the overall weight of the device. This weight is indeterminable to the participant to prevent visual based prediction of weight whereby they could establish an anticipatory strategy for lifting the manipulandum. The weight of the manipulandum was 127 g without the weight. A 117 g weight in the form of a small black plastic box was used for this study. Therefore, the total weight of the apparatus combined was 244 g. To lift the device, participants used a pincer-style grip also known as a precision grip (Johansson & Westling 1984; McDonnell et al. 2005; Westling & Johansson 1984), similar to the thumb and forefinger grip commonly used to hold a scalpel handle. Participants were required to wash their hands to remove sweat and oily substances as required for the Grip-lift task (Gölge et al. 2003; Westling & Johansson 1984). Methods employed were similar to those reported by McDonnell et al. (2007) and Todd et al. (2009). Briefly, the participant was required to gently lift (lift

phase), hold (hold phase) and replace the manipulandum on the table. Instructions given to the participant were as follows: 'Lift the device off the table to the height indicated (100 mm). Hold the device at this height for three seconds and then replace it on the table'. This process was repeated for three trials on each hand with a rest period of approximately 10 s between trials to allow adequate data separation for analysis. The output signal was amplified (1000x) using a custom amplifier, and filtered (low-pass 100 Hz) and recorded using CED data acquisition hardware 1401 and using Spike2 v.7 software (Cambridge Electronic Design, Cambridge, UK). The outcomes of interest are described below, and illustrated in Figure 4.2-3:

- **Preload duration (PDn)** (ms) (Figure 4.2-3: T_1-T_2): time between onset of Grip Force (GF) and onset of positive Lift Force (LF). This may be preceded by a negative LF if the manipulandum is pushed into the supporting surface. A longer period corresponds with a clumsy lift strategy.

- **Minimum load (LFmin)** (N): maximum downwards force applied during PDn if the object was pushed into the surface as part of the lift phase. The greater the force the poorer the technique when attempting to grip and lift the manipulandum.

- **Maximum grip force (GFmax)** (N): peak GF reached during the lift phase. Optimum GF is the lowest force applied without slippage occurring and is made up of the force required to overcome LF plus a margin of error. Therefore, the higher the GF applied the greater the margin of error, and considered a poorer performance.

- **Grip force to Lift force ratio (GF:LF)**: ratio of GF to LF at GFmax during the lift phase. A low ratio suggests a better scaling of required force and therefore a better grip-lift strategy.

- **Maximal cross-correlation:** the maximum correlation coefficient obtained when the rate of change of GF over time (dGF/dt) and rate of change of LF over time (dLF/dt) were cross-correlated using time-shifts of 2.5 ms (Duque et al. 2003). A cross-correlation value of one indicates a perfect response of the participant's grip force regulation synchronous to the increase in lift force.

- **Time-shift** (ms): the incremental shift required for maximum cross-correlation of dGF/dt and dLF/dt. This is calculated using 2.5 ms increments as outlined above until maximum cross-correlation is obtained. The time-shift is an indicator of whether the grip was primarily anticipatory or reactive. A positive time-shift indicates an anticipatory strategy and conversely a negative time-shift indicates a reactive strategy.

- **Lift Duration (LFDn)** (Figure 4.2-3 – T_2-T_3): The time from which LF onset occurs until the force reaches within 98% of maximum LF. Previous studies have found poorer strategies to be associated with a longer lifting duration (Duque et al. 2003).

- **Average grip force (GFavg)** (N): The average GF during the hold phase. A higher average force is indicative of poor scaling of force relative to the weight and therefore poorer lift strategy.

- **Standard Deviation of Grip Force (GFsd)**: The standard deviation of the GF during hold phase, i.e. how much the GF varies whilst trying to maintain the manipulandum at the required height (Gölge et al. 2004). Less change in force over this time results in lower standard deviations, indicating better control.

- **Hold ratio**: The average ratio of GF to LF as the object is held stationary during the hold phase. If the participant uses greater force to hold the manipulandum stationary, suggesting a less efficient technique, then the ratio increases.

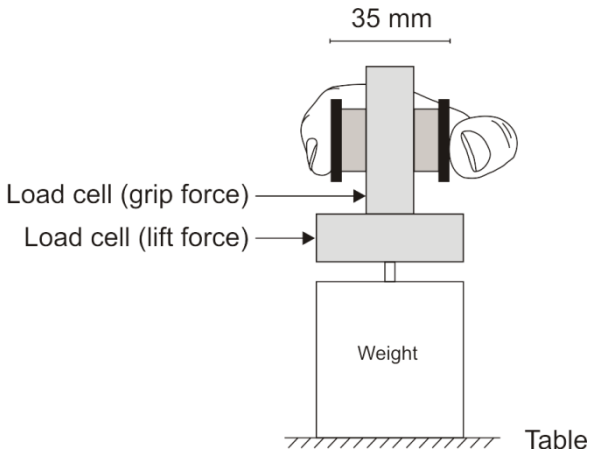


Figure 4.2-2: Grip Lift Manipulandum

For analysis, each of the files were printed and visually inspected by the principal researcher (RC) and another team member (MM) for any notable fumbled or failed attempts, which were then removed from further analysis. Although a fumble can be indicative in itself of poor technique or strategy, the procedure used to analyse the data would result in the reporting of false values for some of the variables. For example, GFmax may be identified as being at the point of the fumble (downturn in force reading) rather than at the true peak. A total of 19 lifts for the dominant hand (11 Experienced and 8 Novice) and 14 (6 Experienced and 8 Novice) lifts for the non-dominant hand were removed and the remaining data for each lift were converted to an individual text (.txt) file. Text files were imported into a customised program created in LabVIEW (National Instruments, Austin, TX, USA) for analysis. The following operational definitions based on the methods of McDonnell et al. (2005) and Duque et al. (2003) were used for analysis:

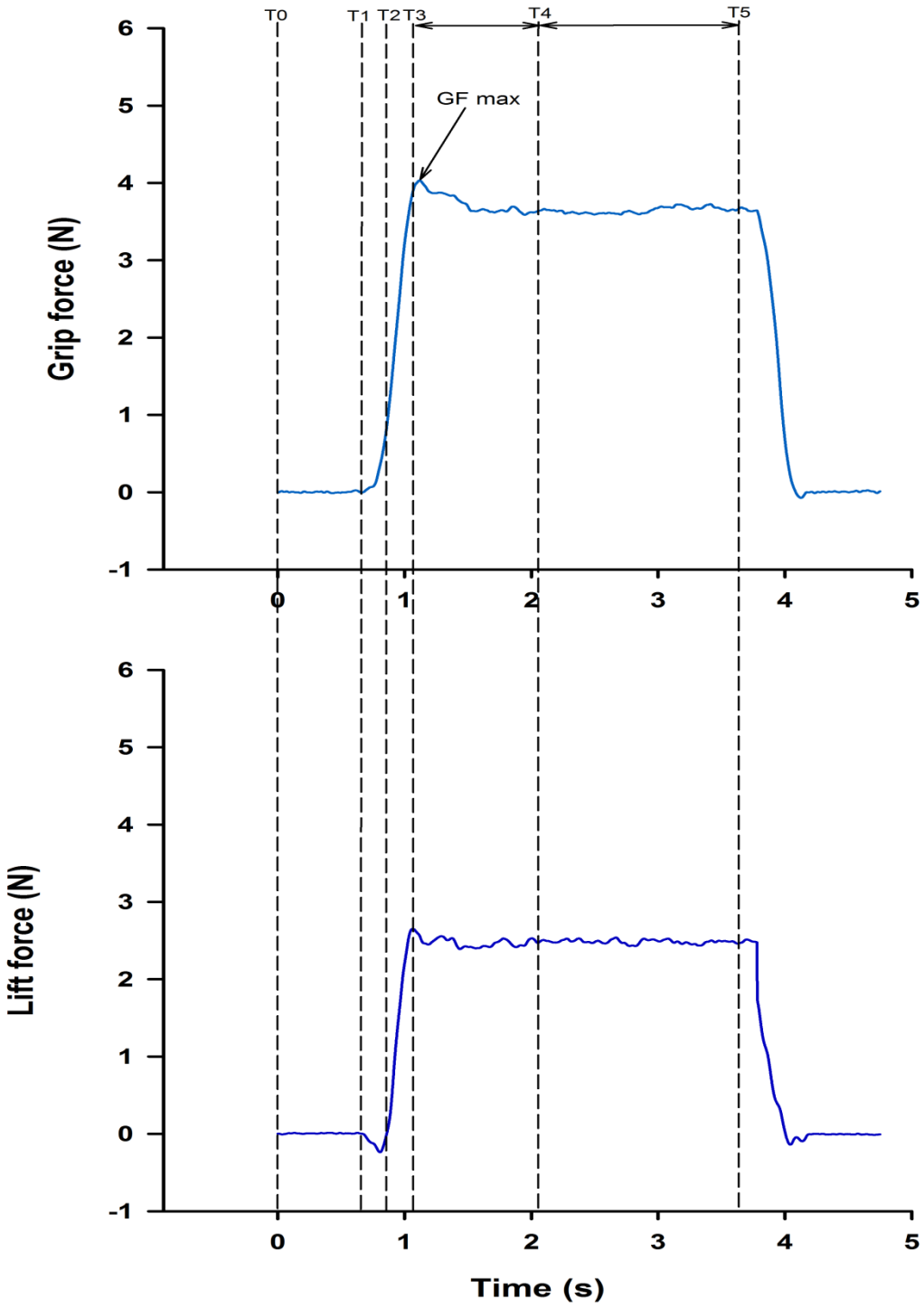
- Pre-lift phase comprises the 0.5 s prior to grip onset as determined below (Figure 4.2-3 – T_0-T_1) and is used to calculate the baseline values for GF and LF channels

- Grip onset occurs at the last point when the grip lift signal derivative (slope) is at zero prior to the signal reaching 30% of maximum force (Figure 4.2-3 – T_1)

- Lift onset occurs when the lift force becomes positive prior to the signal reaching 50% of maximum force (Figure 4.2-3 – T_2)

- Lift phase incorporates up to 2.5 s prior to maximum grip force (Figure 4.2-3 – T_0-T_3)

- Hold phase incorporates a 1.5 s period starting 1 s after maximum grip force is reached (Figure 4.2-3 – T_4-T_5)



$T_0 – T_1$ = Pre-lift Phase (Baseline calculation)
$T_1 – T_2$ = Preload Duration (PDn)
$T_1 – T_3$ = Lift Duration (LFDn)
$T_0 – T_3$ = Lift Phase
$T_4 – T_5$ = Hold Phase

Figure 4.2-3: Actual example of a lift with indicative time points used for variable calculation (based on a diagram by Duque et al., (2003))

An average of the values for each of the lifts was calculated. Due to the large number of first lifts removed because of fumbles and the potential skewing of the data it was decided to use the average of the second and third lifts. These values were subsequently exported for statistical analysis.

4.2.1.4. Finger Tapping Test (FTT)

The FTT (Halstead 1947) is a measure of motor speed and coordination control (Mitrushina, Boone & Razani 2005). The method of administration used was similar to Todd et al. (2009). Participants were instructed to tap the linear strain gauge (MLP-100; Transducer Techniques, Temecula, CA, USA) associated with the manipulandum (Figure 4.2-2) at the maximum rate possible for 10 s. To do this the manipulandum was placed on its side with a 150 mm thickness piece of Ethyl Vinyl Acetate (EVA) density 450 kg/m^3 wedge to keep it level. The heel of the hand was required to maintain contact with the bench top to avoid participants using their whole arm. The test was repeated three times. A 30 s rest period was provided between trials. The signal was amplified (1000x), filtered (DC-100 Hz) and sampled at 400 Hz using CED data acquisition hardware using Spike2 v.7 software (Cambridge Electronic Design, Cambridge, UK).

The Spike2 v.7 (Cambridge Electronic Design, Cambridge, UK) data files (.smr) acquired for each trial were copied and exported to a text (.txt) file. This file was imported into a customised program created in LabVIEW (National Instruments, Austin, TX, USA) for analysis. The following criteria were defined for calculation of 'number of taps', 'inter-tap interval' and 'coefficient of variation (for the taps)' variables for each of the trials:

- a three second pre-tap period was used from which the baseline was calculated
- a threshold of three standard deviations above baseline was used to indicate a tap
- tap onset occurred at the point at which the GF slope (signal derivative) was at zero prior to the indication of a tap
- a period of greater than five seconds between taps indicated a separate trial.

Values for each of the variables were calculated from a 10 s period after tap onset.

4.2.1.5. Pinch Grip Strength – Pinch Maximum Voluntary Contraction (P-MVC)

The Pinch Maximum Voluntary Contraction (P-MVC) is similar to the well-known grip strength test, a measure of motor output; but requires an alternative arrangement of intrinsic and extrinsic muscles (Kozin et al. 1999). The pinch grip employed may also be termed the tip pinch (Mathiowetz et al. 1985) or precision grip (McDonnell et al. 2005). P-MVC involves gripping the manipulandum, with the hand supinated, between the tips of the thumb and index finger and is measured using the pressure transducers from the linear strain gauge (model MLP-100; Transducer Techniques, Temecula, CA, USA) of the manipulandum (Figure 4.2-2). Participants were required to pinch the transducer as hard as possible between the thumb and index finger, without recruiting adjacent digits. The elbow was positioned on the bench in a comfortable position and did not move during the trial. Participants were provided with verbal encouragement but not visual feedback whilst performing the contraction. Three trials were performed with a 30 s rest period in between trials. The output signal was amplified (1000x) using a custom amplifier, and filtered (low-pass 100 Hz) and recorded using CED data acquisition hardware using Spike2 v.7 software (Cambridge Electronic Design, Cambridge, UK).

4.2.1.6. Grooved Pegboard Test (GPT)

The GPT (Figure 4.2-4) (Kløve 1963) (model 32025, Lafayette Instrument, Lafayette, IN, USA) has 25 keyhole style slots of varying orientation throughout (Trites 1977). Attached to the pegboard is a dish which contains matching pins of key-like presentation which must be aligned to the holes and inserted accurately. The GPT is purported to test psychomotor speed, fine motor control, and rapid visual-motor coordination (Mitrushina, Boone & Razani 2005). It is likely that greater sensory feedback is required to sense the orientation of the groove on the pin prior to placement and that greater coordination is required than the PP (Lezak, Loring & Howieson 2004). Research has found that the GPT is less affected by handedness (Bornstein 1985; Bryden & Roy 2005a; Ruff & Parker 1993) making it more suitable than other pegboard style tests. Implementation was undertaken as follows: Participants had the test described to them explicitly and partly demonstrated before undertaking three timed tests for each hand. The participant began with the test board positioned centrally in front of them and the tested hand flat on the table next to the pegboard. The timer was

started and the participant began each trial after the tester counted '1, 2, 3... Go…', and ended when the last peg was successfully inserted into the board. The time taken to complete the board was recorded for analysis. A 30 s rest period was provided between trials to allow the pegboard to be re-set and prevent participant fatigue.

The fastest time recorded for the participant to place all 25 pegs for each hand was used for data analysis. This was chosen to address the limitation which exists from averaging values and the possibility of a practice effect, as suggested in other pegboard trials (Desrosiers et al. 1995).

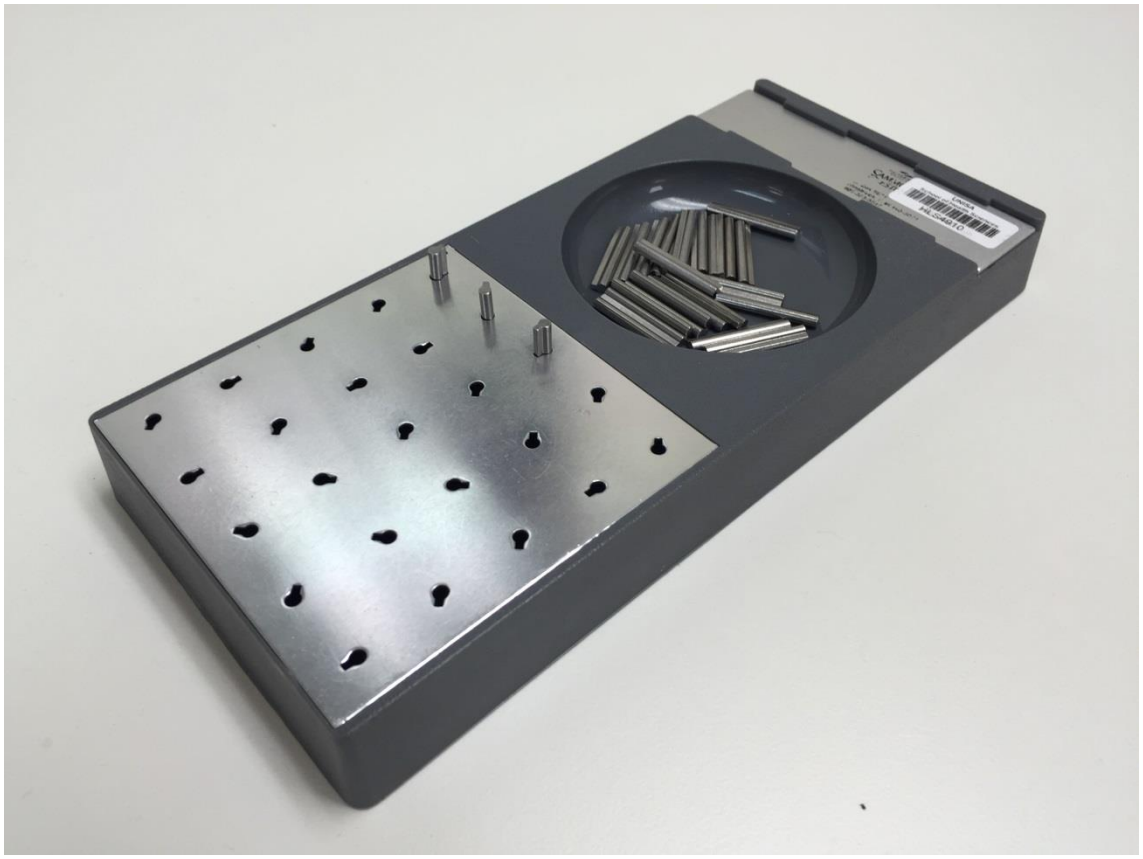


Figure 4.2-4 Picture of Grooved Pegboard Test (GPT)
(model 32025, Lafayette Instrument, Lafayette, IN, USA)

4.2.1.7. Grip Strength – Grip Maximum Voluntary Contraction (G-MVC)

The Grip Maximum Voluntary Contraction (G-MVC) is a measure of efferent output which was captured with a hand-held dynamometer (Jamar Dynamometer - Sammons Preston Rolyan, Bolingbrook, IL, USA). It is an outcome of pure motor ability, through the measure of strength (Mitrushina, Boone & Razani 2005). To perform this test a dynamometer was held by the participant with the shoulder in adduction and neutral humeral rotation, the elbow flexed to 90˚and the forearm and wrist in mid-pronation

(Bear-Lehman & Abreu 1989). Participants then squeezed the handgrip as hard as possible in a rapid, maximum contraction. Participants were verbally encouraged during each trial. Three trials were performed with each hand, with a 30 s rest period between trials to reduce fatigue.

The greatest value in kilograms from three trials on each of the dominant and non-dominant hands was retained for analysis.

4.2.1.8. Sensory Testing

Digital fine-touch sensation was determined using the AsTex® (Australian Patent No.2008229741) screening tactile assessment tool (Miller 2008)(Figure 4.2-5). The AsTex® is an acrylic board approximately 390 mm long and 100 mm wide, printed with parallel vertical ridges and grooves that logarithmically decline in width from 2.5 mm to 0.2 mm along its length (Miller et al. 2009). Participants are requested to run their index finger across the grooves in the direction from widest to narrowest with their eyes shut, stopping when they can no longer perceive individual grooves. The point at which the participant stopped was recorded and the value transformed into a texture discrimination index (TDI) (Miller 2008), representing the actual distance between the grooves at that point, as provided in the user manual (Miller 2008). This was repeated for a total of three trials for each hand and the smallest TDI value for each participant was retained for statistical analysis.

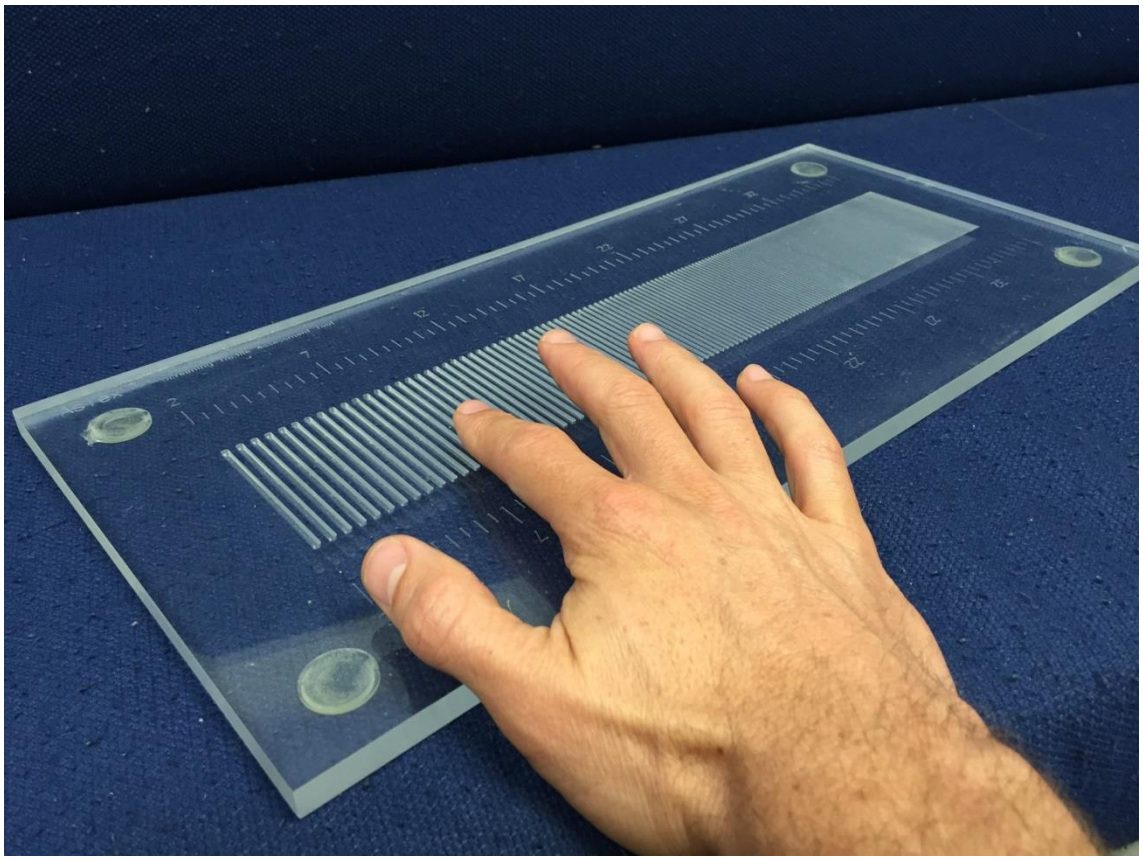


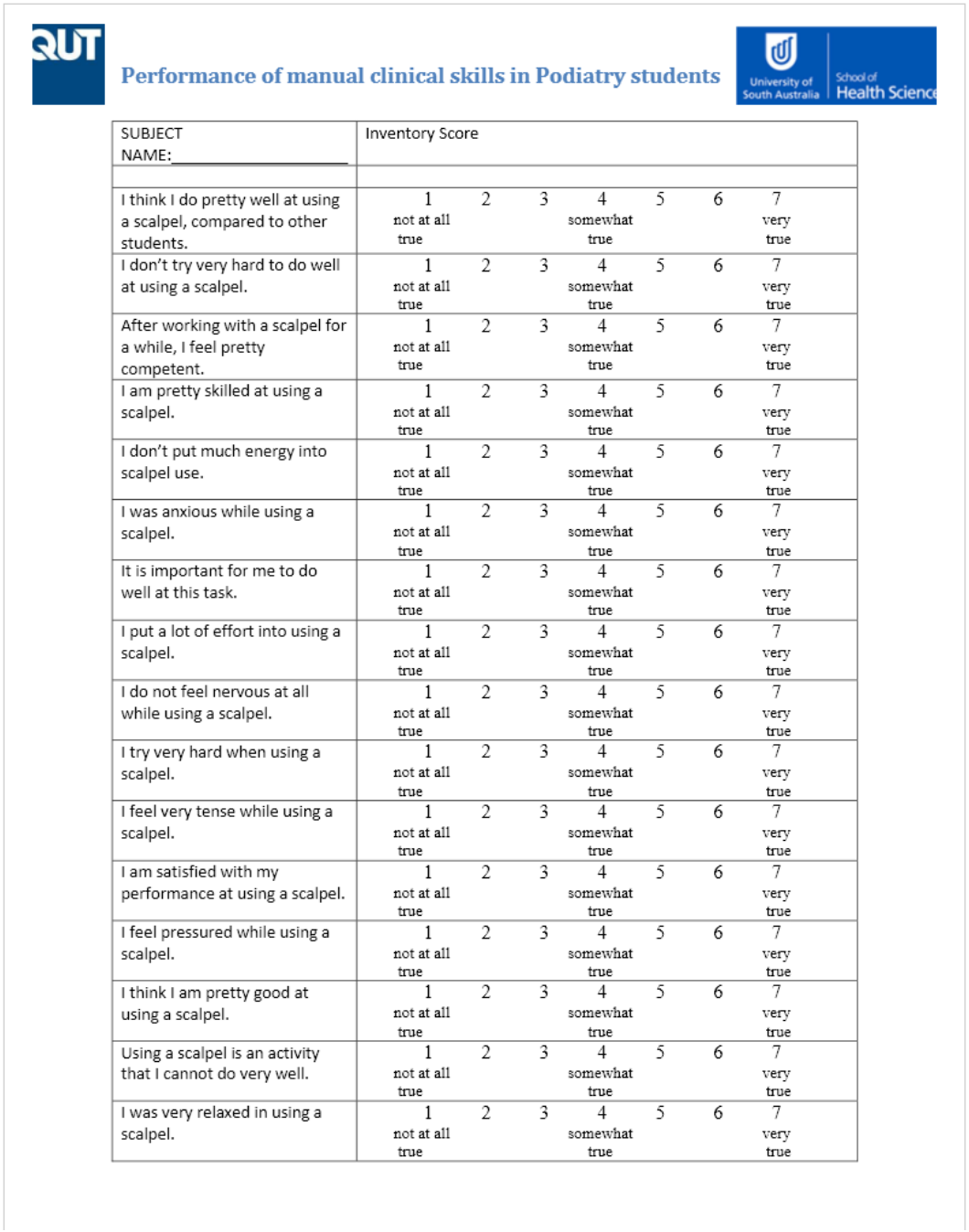
Figure 4.2-5 Picture of AsTex® tactile discrimination tool

4.2.2. Intrinsic Motivation Inventory (IMI)

The creation of the IMI is credited to Ryan (1982), however this is controversial and the true origins are somewhat uncertain (Markland & Hardy 1997). McAuley Duncan & Tammen (1989) report four original validated sub-scales ('Interest/ Enjoyment', 'Perceived Competence', 'Effort/ Importance' and 'Pressure/ Tension') and one yet to be validated sub-scale ('Perceived Choice'), however the 'Self-determination theory' website (Selfdeterminationtheory.org 2014) on which the IMI resides now reports six validated sub-scales ('Value/ Usefulness' additional) with another sub-scale (Relatedness) which is yet to be validated. McAuley, et al. (1989) evaluated the internal consistency of the various sub-scales in a sports setting and reported a Cronbach's alpha coefficient of the 'Perceived Competence' scale as $\alpha = 0.80$, indicating high reliability. Furthermore it has been reported that the IMI can be used with the inclusion or exclusion of any one factor and in a shortened form without an adverse effect on the psychometrics of the inventory (McAuley, Duncan & Tammen 1989). Responses to each of the questions are reported on a Likert-style scale from 1 (not at all true) to 7 (very true). The 'Self-determination Theory' group report that 'Interest/ Enjoyment'

subscale is directly related to self-reported intrinsic motivation and that 'Perceived Choice' and 'Perceived Competence' subscales are positive predictors of both self-report and behavioural measures, whilst 'Pressure/ Tension' have a negative influence. However, as outlined by Waterman (2005), many activities may meet the criteria of interest, pleasure and enjoyment for motivation but may vary considerably in the required effort. Waterman (2005) went on to show that true intrinsic motivation can be further distinguished from hedonic motivation based on the effort employed for a certain task. Consequently, we employed the subscale of 'Effort/ Importance' to distinguish behaviour as it relates to intrinsic motivation rather than investigating participants' 'Interest/ Enjoyment'.

The IMI was modified to represent scalpel use (Figure 4.2-6). Scores for each of the factors of Perceived Competence, Effort/ Importance and Pressure/ Tension were calculated by adding the scores for the contributing questions (Table 4.2-2). For a reversed question, such as question 5, 'I don't put much energy into scalpel use', in the effort-importance category, the reported value is subtracted from eight to determine a true score for addition.



Performance of manual clinical skills in Podiatry students

SUBJECT NAME:_____	Inventory Score						
I think I do pretty well at using a scalpel, compared to other students.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I don't try very hard to do well at using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
After working with a scalpel for a while, I feel pretty competent.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I am pretty skilled at using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I don't put much energy into scalpel use.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I was anxious while using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
It is important for me to do well at this task.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I put a lot of effort into using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I do not feel nervous at all while using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I try very hard when using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I feel very tense while using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I am satisfied with my performance at using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I feel pressured while using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I think I am pretty good at using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
Using a scalpel is an activity that I cannot do very well.	1 not at all true	2	3	4 somewhat true	5	6	7 very true
I was very relaxed in using a scalpel.	1 not at all true	2	3	4 somewhat true	5	6	7 very true

Figure 4.2-6 The modified 'Intrinsic Motivation Inventory' (IMI)

Table 4.2-2 IMI Index calculations

Evaluated Factor	Question	Total Score
Perceived Competence	1, 3, 4, 12, 14, 15 (R*)	42
Effort/ Importance	2, 5 (R*), 7, 8, 10	35
Pressure/ Tension	6, 9, 11, 13, 16 (R*)	35

*R indicates a reversed question whereby the number must be subtracted from eight for the true score

4.2.3. Statistical analysis

In the absence of any precedent in the literature an *a priori* power analysis was performed for a medium effect size based on Cohen's f ($f = 0.25$) for 80% power and 5% significance level for the three original groups. A total of 53 participants were required for each group.

All data were extracted to a Microsoft Excel™ (Microsoft Corporation, 2010) spreadsheet and visually checked for errors. Data were imported to SPSS v. 21 (IBM corporation, Armonk, NY, USA) for statistical analysis. Outliers were identified from the data for each of the test outcomes and visually checked in the dataset to ensure transcription errors had not occurred. Continuous data were checked for normality using the Kolmogorov-Smirnov statistic. The demographic and other group characteristics were compared using non-parametric (categorical and non-normally distributed continuous data) and parametric tests (normally distributed continuous data). A chi square test was used to compare categorical group characteristics (group composition per locality, sex, handedness, musical history and video-gaming history). A general linear model univariate analysis was used to test for differences in normally distributed continuous demographic characteristics and test outcome variables. The Mann-Whitney U test was used for non-normally distributed data. Where indicated, sex was included in the statistical model as a covariate. Differences on the IMI were calculated using the Mann-Whitney U test to account for the non-normal distribution to the data. Statistical significance was set at $p \leq 0.05$.

Age has been identified as a significant confounder for some psychomotor function tests (Causby et al. 2014; Mitrushina, Boone & Razani 2005). Thus, to ensure that within-group variability was not due to variation in age or experience levels, correlations were calculated (Pearson's or Spearman's Rho as appropriate) with the dependent test variables and age and patient experience for the Experienced group. Furthermore, to investigate if there was any influence or association with other potential confounders of musical instrument use and playing computer games, correlations were calculated with each of these categorical variables and dependent test outcomes.

Finally, binomial logistic regression was used to directly compare significant outcomes from group comparisons in order to determine which tests contributed most to group categorisation. Group membership (Novice and Experienced) was the dependent

variable with each of the test variables entered into the model as factors. Prior to establishing the regression model, the independent variables were checked for multicollinearity using a correlation matrix and Pearson's correlation and correlation coefficients. Multicollinearity was suspected if correlation values were greater than $r = 0.80$ at which point predictors were removed from the model based on the p-value, where the correlated variable with the highest p-value after running the model was dropped. After the correlated variables were removed the binary logistic regression model was determined using a backward conditional approach with $p \leq 0.05$ as the condition for inclusion and $p \geq 0.10$ as the condition for immediate removal.

4.3. Results

A total of 108 participants were recruited and provided consent, with 54 participants in each of the Novice and Experienced groups. As previously outlined the Intermediate group was removed due to a delay in equipment availability and insufficient participant interest from the remaining study population (only six were recruited prior to removal). A total of 85 participants were tested at UniSA and 23 at QUT.

4.3.1. Group characteristics

Group characteristics can be found in Table 4.3-1. There were significant differences between the compositions of the groups for location with a significantly greater proportion of Experienced group participants tested in South Australia at UniSA ($p < 0.001$). As expected, there were significant age differences between the Novice and Experienced groups ($p < 0.001$), with the Experienced participants being significantly older. Finally, there were also a significantly greater proportion of participants with a history of musical instrument use in the Experienced group ($p = 0.031$).

Table 4.3-1 Comparison of Novice and Experienced group characteristics

	Novice (n = 54)	Experienced (n = 54)	Between group differences p values
Location			
UniSA	35 (64.8%)	50 (92.6%)	< **0.001**^
QUT	19 (35.2%)	4 (7.4%)	
Sex			
Men	21 (38.9%)	16 (29.6%)	0.311^
Women	33 (61.1%)	38 (70.4%)	
Age (SD)	22.5 (5.1)	30.7 (4.7)	< **0.001**††
Handedness			
Right	41 (75.9%)	46 (85.2%)	
Left	5 (9.3%)	5 (9.3%)	0.278^
Ambidextrous	8 (14.8%)	3 (5.6%)	
Height (cm) (SD)	171.1 (8.9)	171.7 (10.2)	0.771†
Musical History			
Yes	16 (29.6%)	27 (50%)	**0.031**^
No	38 (70.4%)	27 (50%)	
Video Gaming History			
Yes	23 (42.6%)	16 (29.6%)	0.161^
No	31 (57.4%)	38 (70.4%)	

†† Mann U Whitney test. † Univariate analysis. ^ Chi square analysis

4.3.2. Which dependent test outcomes significantly differentiate the experience between groups?

To determine whether any of the test variables were able to significantly differentiate experience levels (between-group) the dependent outcomes were compared. Only five of the eight tests (Table 4.3-2 and 4.3-3), the GPT, the Grip-lift task, P-MVC, G-MVC and AsTex® sensory test showed a significant difference between the two experience groups. The strength tests (P-MVC and G-MVC) were only significantly different between experience groups if sex was considered as a factor in the univariate analysis.

For the Grip-lift task, seven dependent variables showed significant differences: PDn, Maximum cross-correlation, GFmax (Non-dominant hand only), GFavge, GFsd, LFDn and Hold Ratio (Table 4.3-3). In almost all of these measures, the Novice group outperformed the Experienced group. The Novice group displayed lower means and therefore superior grip-lift technique for the variables: PDn, GFmax, GFAvge, LFDn and Hold Ratio. The Novice group also demonstrated a greater mean and therefore superior strategy for the maximum cross-correlation of grip force to lift force variable. The only exception to this trend was on the GFsd variable where the Experienced group showed lower means and less within-group variation than the Novice group. From the remaining GDTs the GPT 'time to completion' (Dominant & Non-dominant hand) variables and TDI (Dominant hand only) also showed a significant difference in means between the groups. The Experienced group showed quicker completion times and therefore better performance on the GPT. However, the Novice group once again outperformed the Experienced group on the AsTex® sensory test (Table 4.3-2).

Strength was measured in two ways, P-MVC and G-MVC. Outcomes were only significant if sex was considered as a factor. The Novice group consistently demonstrated lower and therefore weaker values than the Experienced group (Table 4.3-2). Overall performance on the P-MVC test was similar for the dominant and non-dominant hands. The mean force (N) for the Novice group dominant hand 69.27 N (19.95) was significantly less than the Experienced group 72.81 N (17.74), $p = 0.039$ and for the non-dominant hand the Novice group 65.68 N (17.13) was significantly less than the Experienced group 69.33 N (18.46), $p = 0.005$. The non-dominant hand on the P-MVC test also showed a significant sex by experience group interaction, $p = 0.037$. Post-hoc comparisons of the sex sub-groups within the two experience groups suggest that it was the male sub-group driving the significant difference; however, neither of the sex sub-groups reached significance for the dominant hand. For the non-dominant hand, the male Novice group 77.34 (16.41) had significantly lower mean forces than the Experienced group 90.84 (14.80), $p = 0.014$. For the grip strength test (G-MVC) there were also significant differences between groups with the dominant and non-dominant hands performing similarly overall. Mean force (Kgs) for the Novice group 36.76 Kgs (11.00) was significantly lower than for the Experienced group 38.59 Kgs (11.18), $p = 0.005$ on the dominant hand; the non-dominant hand mean forces were also significantly different with the following respective values Novice 33.59 Kgs (10.78) and

Experienced 34.98 Kgs (10.60), p = 0.009. Post-hoc tests differed between sex with a significant difference only for the female group on the dominant hand with the Novice group 29.70 Kgs (4.90) significantly weaker than the Experienced group 32.79 Kgs (5.40), p = 0.014.

Variables which were normally distributed were analysed using parametric tests with and without outliers removed. Removing outliers did not change the significance of any of the variables and therefore were not considered to be errors in the data or detrimental and were consequently retained for the final analysis.

Table 4.3-2 Means and standard deviations or medians and interquartile ratios, and p-values for Tremor, VTT, FTT, P-MVC, GPT, G-MVC and AsTex® sensory GDTs variables

Test	Outcome	**Novice (n=54)** *Mean (SD) or Median (IQR)*	**Experienced (n=54)** *Mean (SD) or Median (IQR)*	**P-value**
Tremor	**Maximum frequency** (Hz)			
	Resting	$2.60e^{-8}$ ($3.89e^{-8}$)	3.23e-8 ($4.03e^{-8}$)	0.509
	Self-paced	$2.12e^{-3}$ ($2.62e^{-3}$)	1.58e-3 ($1.82e^{-3}$)	0.088
	Time of maximum (ms)			
	Resting	10.94 (1.56)	10.94 (4.30)	0.464
	Self-paced	9.57 (2.34)	9.38 (1.95)	0.829
	Mean Frequency (Hz)			
	Resting	$1.37e^{-8}$ ($1.50e^{-8}$)	$1.31e^{-8}$ ($1.37e^{-8}$)	0.945
	Self-paced	$1.16e^{-3}$ ($1.53e^{-3}$)	$8.71e^{-4}$ ($1.53e^{-3}$)	0.143
Visuomotor tracking	**Absolute Error** (deg)			
	Epoch 1	4.19 (1.36)	3.80 (1.48)	0.151
	Epoch 2	3.78 (1.50)	3.93 (1.24)	0.701
	Epoch 3	3.66 (0.91)	3.70 (1.06)	0.626
	Maximum correlation value (ρ)			
	Epoch 1-3	0.30 (0.15)	0.33 (0.16)	0.312†
	Epoch 4-6	0.41 (0.20)	0.46 (0.20)	0.287†
	Epoch 7-12	0.55 (0.20)	0.54 (0.20)	0.850†
	Time lag (s)			
	Epoch 1-3	-0.30 (0.31)	-0.34 (0.25)	0.729
	Epoch 4-6	-0.25 (0.16)	-0.27 (0.13)	0.982
	Epoch 7-12	-0.25 (0.91)	-0.26 (0.09)	0.797

Tests continued	Outcome	Novice (n=54) *Mean (SD) or Median (IQR)*	Experienced (n=54) *Mean (SD) or Median (IQR)*	P-value
Finger-tapping	**Maximum taps 10 seconds** (n)			
	Dominant	62.25 (5.33)	62.02 (6.40)	0.839†
	Non-dominant	56.53 (5.90)	54.92 (5.53)	0.149†
	Coefficient variation (%)			
	Dominant	0.09 (0.09)	0.12 (0.12)	0.206
	Non-dominant	0.11 (0.12)	0.14 (0.12)	0.251
Maximum Pinch Grip	**Force** (N)			
	Dominant-			
	Male	81.47 (18.28)	91.17 (14.20)	**0.039**
	Female	61.51 (17.05)	65.07 (12.73)	
	Non-dominant-			
	Male	77.34 (16.42)	90.84 (14.80)	**0.005**
	Female	58.26 (13.11)	60.28 (10.74)	
Grooved Pegboard Test	**Time** (s)			
	Dominant	53.77 (6.01)	51.06 (5.33)	**0.015**†
	Non-dominant	60.39 (8.07)	56.94 (6.24)	**0.014**†
Grip Strength	**Force** (Kgs)			
	Dominant-			
	Male	47.86 (8.39)	52.38 (9.04)	**0.005**
	Female	29.70 (4.90)	32.79 (5.40)	
	Non-dominant-			
	Male	44.19 (8.18)	48.56 (6.89)	**0.009**
	Female	26.85 (5.48)	29.26 (5.33)	
AsTex® sensory test	**TDI** (mm)			
	Dominant	0.53 (0.41)	0.57 (0.45)	**0.048**
	Non-dominant	0.52 (0.34)	0.54 (0.46)	0.728

† indicates one-way ANOVA, all other calculations utilised Mann-Whitney U non-parametric tests for non-normally distributed data. †† Indicates a two-way ANOVA was used with Sex included as a factor.

Table 4.3-3 Means and standard deviations or medians and interquartile ratios, and p-values for the Grip-lift task variables

Test	Outcome	Novice (n=54) *Mean (SD) or Median (IQR)*	Experienced (n=54) *Mean (SD) or Median (IQR)*	P-value
Grip-lift task	**Preload duration** (ms)			
	Dominant	97.5 (166.25)	286.25 (375.63)	< **0.001**
	Non-dominant	108.75 (88.13)	138.75 (359.69)	**0.030**
	Minimum Load (N)			
	Dominant	-0.21 (0.17)	-0.19 (0.16)	0.252
	Non-dominant	-0.24 (0.20)	-0.19 (0.16)	0.079
	Maximum grip force (N)			
	Dominant	5.20 (2.97)	6.02 (3.30)	0.167
	Non-dominant	5.24 (3.54)	6.75 (4.14)	**0.033**
	GF:LF			
	Dominant	2.27 (1.65)	2.44 (1.34)	0.422
	Non-dominant	2.13 (1.27)	2.65 (1.72)	0.085
	Maximum correlation (ρ)			
	Dominant	0.74 (0.14)	0.71 (0.15)	**0.012**
	Non-dominant	0.77 (0.08)	0.72 (0.11)	**0.029**†
	Timeshift (ms)			
	Dominant	-8.75 (26.88)	-10.63 (40.94)	0.660
	Non-dominant	-5.00 (26.88)	-5.00 (36.88)	0.918
	Lift Duration (ms)			
	Dominant	292.50 (247.50)	433.75 (827.19)	< **0.001**
	Non-dominant	247.50 (208.75)	295.63 (413.75)	**0.049**
	Average Grip (N)			
	Dominant	3.69 (2.61)	4.96 (2.83)	**0.007**
	Non-dominant	3.82 (2.79)	4.94 (2.46)	**0.012**
	SD Grip			
	Dominant	0.24 (0.11)	0.15 (0.07)	< **0.001**
	Non-dominant	0.23 (0.09)	0.15 (0.07)	< **0.001**
	Hold Ratio			
	Dominant	1.72 (1.28)	2.04 (1.05)	**0.042**
	Non-dominant	1.61 (1.22)	1.99 (1.20)	**0.038**

† indicates one way ANOVA, all other calculations utilised Mann-Whitney U non-parametric tests for non-normally distributed data

4.3.3. Which outcome measures best categorise participants appropriately into experience groups?

To determine which tests best predicted group categorisation, a binary logistical regression procedure was undertaken using the independent variables which had demonstrated significant group differences in the previous parametric and non-parametric analyses. Previous 'musical instrument' use was also included as this was a significant demographic difference between the groups. The final regression model (Table 4.3-5), after highly correlated (Table 4.3-4) and non-significant variables were progressively removed, contained six independent variables including outcomes for both the dominant hand (TDI from the AsTex® sensory test and GFavge, GFsd and LFDn from the Grip-lift task) and non-dominant hand (LFdn from the Grip-lift task). The full model containing predictors was significant X^2 (6, N = 107) = 49.259, $p < .001$. The model as a whole explained between 36.9% (Cox and Snell R square) and 49.2% (Nagelkerke R Square) of the variance in group classification and correctly classified 79.4% of cases. As shown in Table 4.3-5, three of the independent variables made a unique statistically significant contribution to the model. The strongest predictor for classification into the Experienced group was the AsTex® dominant hand with a coefficient value (OR) of 4.73, indicating that participants who scored well (smaller value) were almost five times more likely to belong to the experienced group when the other variables are held constant.

Table 4.3-4 Correlated predictor variables (for binary logistic regression)

	Dominant ***(r)***	**Non-dominant** ***(r)***
Average grip – Hold ratio	0.95**	0.96**
Average grip – Maximum Grip	0.93**	0.96**
Hold ratio – Maximum Grip	0.89**	0.92**

** Significant to $p < 0.001$

Table 4.3-5 Final logistic regression model calculated for predicted experience group classification

								95% C.I.	
		B	**S.E.**	**Wald**	**df**	**p**	**Odds Ratio**	**Lower**	**Upper**
Grip-lift task									
Average Grip	Dominant	0.332	0.115	8.288	1	**0.004**	1.394	1.112	1.747
SD Grip	Dominant	-8.042	4.545	3.131	1	0.077	0.000	0.000	2.376
	Non-Dominant	-11.062	4.946	5.002	1	**0.025**	0.000	0.000	0.255
Load Duration	Dominant	0.001	0.001	5.210	1	**0.022**	1.001	1.000	1.003
AsTex®									
TDI	Dominant	1.553	0.908	2.926	1	0.087	4.727	0.797	28.021
Musical Instrument		1.009	0.535	3.563	1	0.059	2.743	0.962	7.819
Constant		-0.772	1.193	0.419	1	0.518	0.462		

4.3.4. Were there any within-group confounders for test variables based on actual level of experience in the experienced group?

4.3.4.1. Experienced group confounders

Correlations were calculated to ensure that possible within-group variability of the Experienced group from 'age' and 'experience' were not detrimentally impacting on the dependent test variables. No significant correlations were present between an estimate of the overall number of patients seen to date by the Experienced group participants and any of the dependent variables (Table 4.3-6 and 4.3-7). The patient estimate however did correlate with age $r = 0.618$, $p < 0.001$. Age only correlated with one dependent variable: the time at which the cross-correlation was at its maximum for epoch one to three seconds for the VTT (Lag 1-3, $r = -0.298$, $p = 0.030$). Correlations were also calculated for age and experience with strength measures (P-MVC and G-MVC) stratified by sex but these were not significant.

Table 4.3-6 Correlations of Estimated patients and age with VTT, P-MVC, FTT, GPT, G-MVC and AsTEX® sensory test variables for the Experienced Group

		Estimated patients		Age	
		Correlation	*P-value*	*Correlation*	*P-value*
Estimated patients				**0.62**	**<0.001**
VTT					
Error 1†		-0.06	0.67	-0.17	0.23
Error 2†		0.04	0.79	-0.07	0.60
Error 3†		0.03	0.86	-0.16	0.26
Max r 1-3		-0.02	0.90	0.13	0.34
Max r 4-6		-0.03	0.84	0.04	0.78
Max r 7-12		-0.07	0.63	0.13	0.36
lag 1-3†		-0.10	0.47	**-0.30**	**0.03**
lag 4-6†		-0.12	0.42	-0.02	0.92
lag 7-12†		0.01	0.96	0.08	0.56
lag 13-18†		0.04	0.77	0.01	0.95
P-MVC					
	Dominant	-0.05	0.72	0.05	0.74
	Non-Dominant	0.06	0.66	0.08	0.57
FTT					
No. of taps	Dominant	0.05	0.73	0.05	0.70
	Non-dominant	0.08	0.57	0.14	0.31
CV	Dominant†	0.02	0.91	0.16	0.26
	Non-dominant†	0.03	0.85	-0.13	0.37
GPT					
Time to	Dominant	0.15	0.28	0.04	0.75
completion	Non-dominant	-0.15	0.30	-0.09	0.50
G-MVC					
	Dominant	0.13	0.34	0.05	0.71
	Non-dominant	0.12	0.41	0.07	0.62
AsTex®					
sensory test	Dominant†	0.08	0.56	0.00	0.97
	Non-dominant†	0.02	0.91	0.18	0.19

†Indicates Spearman's Rho correlation coefficient, all other calculations are Pearson's correlation. r = Correlation. CV = Coefficient of variation

Table 4.3-7 Correlations of Estimated patients and age with Grip-lift test variables for the Experienced Group

Grip-lift Task		Estimated patients		Age	
		Correlation	*P-value*	*Correlation*	*P-value*
PDn	Dominant†	0.10	0.49	0.20	0.15
	Non-dominant†	-0.02	0.89	-0.10	0.47
GFmin	Dominant†	0.03	0.83	0.11	0.43
	Non-dominant†	0.02	0.88	0.08	0.59
GFmax	Dominant†	-0.02	0.90	-0.13	0.35
	Non-dominant†	-0.08	0.58	0.04	0.78
GF:LF	Dominant†	-0.01	0.92	-0.15	0.27
	Non-dominant†	-0.08	0.59	0.06	0.69
Maximum Correlation	Dominant†	-0.10	0.49	-0.05	0.72
	Non-dominant†	-0.05	0.75	-0.05	0.74
Timeshift	Dominant†	0.13	0.35	-0.03	0.83
	Non-dominant†	-0.21	0.14	-0.05	0.71
LFDn	Dominant†	-0.09	0.50	-0.04	0.80
	Non-dominant†	0.14	0.31	0.16	0.25
GFavge	Dominant†	-0.03	0.82	-0.07	0.61
	Non-dominant†	-0.06	0.68	0.07	0.60
GFsd	Dominant†	0.08	0.59	0.00	0.98
	Non-dominant†	-0.17	0.23	-0.13	0.37
Hold Ratio	Dominant†	-0.01	0.97	-0.08	0.57
	Non-dominant†	-0.03	0.82	0.08	0.58

†Indicates Spearman's Rho correlation coefficient, all other calculations are Pearson's correlation.

4.3.5. Psychological outcomes

There were statistically significant differences ($p < 0.001$) between both experience groups on all three domains of the IMI, representing self-efficacy, motivation and anxiety (Table 4.3-8). The largest difference was for the 'Pressure/ Tension' domain representing anxiety with a difference in medians of 22 points ($p < 0.001$).

Table 4.3-8 Medians, inter-quartile ratios and p-values for the Intrinsic Motivation Inventory (IMI)

	Novice *Median (IQR)*	**Experienced** *Median (IQR)*	**Difference**	**P-value**
Perceived competence	23.5 (9.0)	37.5 (5.0)	+14.0	**<0.001**
Effort/ Importance	30.0 (6.0)	24.0 (12.0)	-6.0	**<0.001**
Pressure/ Tension	22.0 (8.0)	7.0 (6.0)	-15.0	**<0.001**

4.3.6. Power Analysis

Post-hoc power calculations showed sufficient power for the logistic regression analysis ($\alpha = 0.81$). P-MVC was strongly powered ($\alpha = 0.86$) and the GPT and G-MVC moderately powered ($\alpha = 0.70$ and 0.77 respectively). The remaining tests did not reach adequate power.

4.4. Discussion

Five of the eight tests used in the test battery were able to successfully discriminate dexterous ability of participants in the Novice and Experienced groups. These included the Grip-lift task, GPT, P-MVC, G-MVC and the AsTex® sensory discrimination test. These tests comprised a total of 11 significant dependent variables, including both the dominant and non-dominant hand for all but the Grip-lift task 'maximum grip' and the AsTex® sensory discrimination test (which were significant only for the non-dominant and dominant hands respectively). P-MVC and G-MVC test variables were only significantly different between the groups if sex was considered. A binary logistic regression test incorporating the significant dependent variables was able to successfully predict 79.4% of the Novice and Experienced group membership and explained between 36.9 and 49.2% of the tests' variance overall. The TDI from the AsTex® outcome for the dominant hand contributed the most to Experienced group membership.

There were also significant differences between the two experience groups on the self-reported psychological measures relating to how they felt about using a scalpel. The Novice group reported much higher levels of anxiety and lower levels of self-efficacy about performing with a scalpel. There was less of a divide between the groups on the domain relating to the importance of the task; however, this was still significant, with the Novice group attributing greater importance to the task than the experienced practitioners.

Despite the significant differences between the groups on 11 of the test variables, in some instances the data outcomes were different than anticipated. On most of the Grip-lift task measures, the Novice group outperformed the Experienced group. This included all significant variables for the Grip-lift task except GFsd. For the force measurements (GFmax, GFavge, GFsd) a lower value suggests a superior performance, for temporal measures (PDn, LFDn) lower values indicate a superior performance and finally for ratio measures (Hold ratio) values closest to one suggest a superior performance. For all of the significant variables from the remaining tests (P-MVC, G-MVC, GPT) except the AsTex® sensory test, the opposite occurred, whereby the Experienced group outperformed the Novice group. For maximum voluntary contraction outcomes (P-MVC, G-MVC) higher force values indicate a superior performance and for the timed pegboard test (GPT) a smaller value indicates a superior performance. The superior haptic threshold performance by the Experienced group was consistent with findings by Mueller et al. (2014) who also found improved performance in physiotherapists and advanced manual therapists compared with a control group. They also found a decreased haptic threshold in physiotherapy students compared to control, similar to our findings; however, our novice podiatry students had not started any clinical training and therefore may act more like the control group from Mueller's study. Mueller et al. (2014) also found a large variance in individual performance within the groups, which they attributed to individual differences in everyday tactile perceptual learning and reliance on touch (Wong, Peters & Goldreich 2013). Interestingly, Mueller et al. (2014) did not find a significant difference in tactile acuity between therapists and control groups measured with grating domes. The question remains as to whether improved haptic threshold translates to improved manual dexterity.

The Grip-lift task evaluates reaching and manipulating of an object of an unknown weight. It has been determined that the GF applied is dependent on four main things: a predetermined motor plan based on prior experience, the weight of the object, the coefficient of friction of the object and the safety margin employed (Johansson & Cole 1992; Johansson & Westling 1984; Westling & Johansson 1984). In healthy participants a scaling of GF occurs to allow the object to be lifted (LF to overcome gravity) without being too excessive so as to damage the object or hand, give rise to increased muscle fatigue or affect the manipulation of that object (Johansson & Westling 1984). Insufficient force will result in slippage or potentially dropping the object. It is initially the role of glabrous skin receptors (Meissner Corpuscles) to detect friction representations prior to the lift occurring and then further tactile afferents detect the tiny frictional slips whilst the lift is occurring, so that the force applied may be adjusted accordingly (Johansson & Cole 1992). Consequently, the importance of afferent feedback in providing a dexterous performance needs to be considered.

Thus, assuming the test was performed appropriately, the higher grip forces (GFmax and GFavge) applied by the Experienced group, suggestive of poor performance, may relate to a variation in the predetermined motor plan, the safety margin adopted or as a result of diminished or poor afferent feedback. Significantly poorer performance of the Experienced group on other Grip-lift task variables (maximum cross-correlation, LFdn, Hold ratio) suggest it could be related to the predetermined motor plan (PDn) or poor afferent feedback rather than just a sub-conscious choice to adopt a greater safety margin. There was a small but significant difference on the AsTex® sensory test (dominant hand only), which would support this theory. However, we would also expect that if this were the case then we should also see increased variability and therefore larger GFsd, which we did not. Instead, the experienced group displayed a more stable hold, either as a result of sub-optimal afferent feedback or as a result of the higher GFavge and higher safety margin.

There may be a number of plausible reasons for the group differences on the Grip-lift task. It may be that the experienced practitioners have chosen to forgo lower forces to enable greater stability and have determined strategies for maintaining the ability for object manipulation; or are used to an increased safety margin as a result of regular glove usage, practice requirements or similar. Early studies have shown diminished sensory performance with glove usage (Neiburger 1992; Phillips, Birch & Ribbans

1997). It may be that experienced podiatrists, at least subconsciously, are less concerned with the issue of fatigue related to these higher forces due to an increased endurance capacity. This could also account for the greater force performance on the other strength measures for this group in the test battery. It has also been consistently found that older adults use a higher level and fluctuation in grip force during both movement and a static hold (Cole 1991; Cole, Rotella & Harper 1999; Gilles & Wing 2003; Kinoshita & Francis 1996), suggesting age may potentially play a part in explaining the findings. However, Gilles and Wing (2003) found that coordination, as measured by the ratio of the GF to the LF (GF:LF), was quite similar between young and old participants. This is consistent with our findings. Whilst we did not measure the stability of GF during lifting, the GFsd during hold phase was reduced in the Experienced group compared to the Novice group. This is in contrast with the findings by Kinoshita and Francis (1996) but not with findings by Cole and Beck (1994) who found no difference in stability when the higher GFs were controlled for. One of the theories as to why older participants require greater force is due to the function of skin. If the hydration of skin is reduced then there is also a reduction in the coefficient of friction independent of the surface texture of the object (Cole, Rotella & Harper 1999). However, Cole (1991) found that the safety margin (difference between the grip force applied and the minimum force required to avoid the manipulandum slipping) employed by older participants was much greater, greater than what would be predicted due to increased slipperiness from the reduced coefficient of friction. Instead they propose that there is also a decrease in the cutaneous afferent signals (sensory) crucial to hand dexterity (Cole 1991; Johansson & Westling 1984, 1987; Moberg 1962). These age-related mechanisms are reported to be influential in populations 50 years old and above (Cole, Rotella & Harper 1999), so it seems unlikely that they would influence outcomes in our study given there was such a small difference in the mean age of our population, and a group mean of only 30.7 (4.7) years old for the oldest group. However, it should be noted that this age difference was significant and may be something which requires further investigation.

It appears that the Experienced group approached the Grip-lift task and initiated the lift (PDn) with a lot less precision and potentially less care. There was much greater variability (more than twice as much) within this group than in the Novice group. There was not a significant correlation between this measure and the age of participants in the

Experienced group, however there may be other within-group differences to explain this variance. One possible difference is the motivation felt for the task. Motivation was the dependent variable (Effort/ Importance) which showed the greatest variance in the Experienced group compared with the Novice group on the IMI (double the variance) when describing scalpel use. It may be that in a study relating to scalpel use, the novice students felt higher levels of motivation to perform well at the tasks than the experienced podiatrists, particularly when the principal researcher was someone involved in their teaching. Some of the experienced podiatrists may have been overconfident and consequently more blasé about the task.

Finally, Gilles and Wing (2003) found that grip-lift trials of less than 4.7ms^{-2} vertical acceleration were associated with quite variable GF measures and subsequently excluded these trials from their analysis. We were unable to measure the velocity of the lift accurately; however, there was a significantly slower LFdn mean for the Experienced group, particularly for the dominant hand, which could have influenced measures. Kinoshita and Francis (1996) noted that for their older cohort this was due to a prolonged PDn. Preload duration was similarly prolonged for the Experienced group, particularly for the dominant hand, in this study.

The conflicting results between the Grip-lift task, AsTex® sensory test and other tests could relate to the psychometric properties of the specific test and the skill-set required for podiatric tasks. The GPT clinimetric properties (Chapter 3) suggest that the test requires psychomotor speed, good fine motor control and rapid visual-motor coordination (Mitrushina, Boone & Razani 2005). Therefore the GPT measures more complex motor abilities than the FTT or G-MVC and would be regarded as a cognitive-motor task (Mitrushina, Boone & Razani 2005). Bezdicek et al. (2014) found it correlated more closely with other cognitive measures, albeit on a population with Parkinson's disease. The strength measures are considered to represent primarily motor function (Lezak, Loring & Howieson 2004; Mitrushina, Boone & Razani 2005). This would suggest that the Experienced group displayed superior ability on these elements. However, as outlined, the Experienced group performed more poorly than the Novice group on the Grip-lift task measures (except GFsd) and the AsTex® sensory test, which conversely suggests that the Novice group have more precise and therefore more skilled grip-lift strategies. Interestingly, the GPT has been found to correlate with grip strength, pinch grip strength and pinch steadiness tests (Causby et al. 2014; Marmon et

al. 2011). This is supported by the fact that the GPT, P-MVC and G-MVC and Grip-lift task (GFsd variable) were also tests on which the Experienced group consistently outperformed the Novice group.

Considering the psychometric properties of the tests at face value, these results suggest that the Novice group performed better on the tests which require high levels of sensory elements and subsequent adaptation, whereas the Experienced group performed better on tests which required the combination of speed, strength and precision. Could this mean that with respect to podiatric tasks, novices rely more heavily on the sensory feedback, which experienced practitioners do not need due to their experience and judgement? Anecdotally this would make sense as experienced practitioners would have much greater visual interpretation experience and therefore rely less on kinaesthetic feedback. The grip adopted for the Grip-lift task is sufficiently similar to grip used for podiatric scalpel that suitable inferences could be made. Therefore, it may be appropriate to extrapolate the findings regarding speed and precision to their vocational tasks as a podiatrist. The scalpel technique of a podiatrist compared to other professions requires greater elements of speed together with precision. A direct comparison with other health professions would be required to interpret results further.

However, there may be numerous reasons that many of the tests failed to show a significant difference between the groups or a relationship contrary to what was expected. The first possibility is that the Novice group performed better than would normally be expected. This could be due to the test population being more dexterous than the normal population. The most prolific normative data are provided for tests which fall within the Halstead-Reitan test battery including the FTT, G-MVC and GPT. A comparison of these results and published normative values suggest that this could be the case (Strauss, Sherman & Spreen 2006) (See Table 4.4-1). Bornstein (1985) reports a normative value for the number of taps on the FTT as low as 47.2 (6.5) for the dominant hand and 43.5 (5.4) for the non-dominant hand, which is much lower than our values. The values provided by the metasynthesis undertaken by Mitrushina, Boone and Razani (2005) are higher but still do not reach values as high as ours (Table 4.4-1). Similarly with the GPT, Ruff and Parker (1993) report slower completion times in their sample than demonstrated in this study. Mitrushina's (2005) group reported decreased number of dropped pins but still slower test completion than our sample (Table 4.4-1). G-MVC values were similar between the published normative data and our sample;

however, the metasynthesis provided (Table 4.4-1) shows values for the male cohort lower than in our sample.

Table 4.4-1 Comparison of test outcomes and metasynthesis of normative values (Mitrushina, Boone and Razani 2005)

Test	This study (n=54)	Metasynthesis	No. of studies	Total Participants
FTT (No.)				
Dominant	62.25 (5.33)	Male 54.41 (4.60)	8	963
		Female 50.07 (4.66)	4	560
Non-dominant	56.53 (5.90)	Male 50.00 (4.84)	7	933
		Female 50.07 (4.66)	3	530
GPT (s)				
Dominant	53.77 (6.01)	57.97 (8.32)	6	2382
Non-dominant	60.39 (8.07)	63.64 (9.40)		
G-MVC (Kg)				
Dominant	Male 47.86 (8.39)	Male 54.41 (4.60)	9	713
	Female 29.70 (4.90)	Female 50.07 (4.66)	5	454
Non-dominant	Male 44.19 (8.18)	Male 50.00 (4.84)	7	641
	Female 26.85 (5.48)	Female 50.07 (4.66)	4	407

NB: GPT outcome is in seconds (therefore smaller is better).

This may have been a chance occurrence in the sampling and can be a limitation of the cross-sectional design of the study. Alternatively, as suggested in Chapter 2, Section 2.3.3.2 by one of the interviewees, applicants to the program may already have insight to the dexterous needs of the profession and therefore only apply if they believe they possess sufficient ability; failing this, they may leave early in the program when this is realised. This would lead to self-selection and cause a selection bias for the study. There has been limited research into dexterity specific to the podiatry profession, particularly in the Australian context; however, studies looking at other health professions have had equivocal findings regarding dexterity levels between professions or comparative to normative levels. Unfortunately we did not ask participants to reflect on their own levels of general dexterity, and can only extrapolate from the self-report of

their perceived ability (self-efficacy) with respect to scalpel related tasks on the IMI. The novice podiatry students reported significantly lower levels of self-efficacy compared with the experienced practitioners. No further comparison is available due to a lack of information within the literature.

A second possibility relates to an underperformance of the Experienced group on some of the test items. It may be that they are not more dexterous than the normal population, or by extension the Novice group, in the general sense but simply better at a few isolated tasks due to practice and repetition. In order to test this we would need to compare task specific tests (i.e. scalpel use) between the novice and experienced groups.

Other reasons that the Experienced group may not have performed as well on a number of the tests include the possibility that the tests are sensitive to the effects of age as previously identified. Many psychomotor tests have been reported to be affected by age (Causby et al. 2014); for example Shimoyama, Ninchoji and Uemura (1990) were able to demonstrate age-related changes in a normal population of mean age 42.3 years on the FTT. Despite restricting recruitment to participants less than 40 years of age, there was a mean difference of eight years between the two groups, which was statistically significant. It may be that the age difference, even one as small as this could have a detrimental effect on the test outcomes counteracting the effect of experience.

Another possible reason that the Experienced group did not perform as well on the tests is that they simply felt less pressure to perform and were less motivated than the Novice group, resulting in a blasé approach to the tests. The fact that it was a member of faculty who was undertaking the testing may have increased motivation or performance pressure within the novice group. In particular, this was evident on some of the tests which participants may not have felt challenged, for example the Grip-lift task.

Despite these findings logic suggests it is still unlikely that the Experienced group would have inherently worse podiatry-related hand skills than the Novice group or the general public. Therefore, the lack of differentiation between the groups on the test battery may not be due to the performance of participants at all; rather the tests being used to evaluate the differences were inappropriate for this purpose. A broad range of elements may contribute to dexterity including fine motor, gross motor, hand-eye coordination, precision, speed, agility and many more. It may be that the tests were too generalised or did not contain the required combination of elements to represent the

specific task-related dexterity required for debridement and other real-life tasks of a podiatrist and are therefore unsuitable. This has been discussed in the literature whereby various medical and surgical professions such as those using endoscopy have recently found success using virtual reality (VR) trainers to train and evaluate manual clinical skills (Clevin & Grantcharov 2008; Grantcharov et al. 2003; Munz et al. 2004a; Torkington et al. 2001). The VR trainers are more task specific than GDTs. Despite this, GDTs are still regularly used to evaluate psychomotor performance, increasingly used to evaluate the dexterity of the health professional population and considered to be valid (predominantly only face-validity), for this purpose. Consequently, we can only suppose that further work needs to be undertaken in this area to establish either clearer protocols or appropriateness of the assortment of tests currently available.

As outlined in chapter three, the GPT and FTT have acceptable intrarater reliability. The GPT is classified as having a moderate to good correlation and the FTT a moderate to excellent relationship, depending on the study (Portney & Watkins 2009). Consequently, we have reasonable confidence that this would not have a substantial impact on the overall results of the study.

Other aspects of the study that should be considered are as follows: in most cases, the best value from three performances was used in the analysis. This has the benefit of limiting individual variability that may occur within trials due to the effects of fatigue or error. However, this may be an overly conservative approach, which could mask a learning effect or subtle differences observed within performance on simplistic tasks. For example, over the three trials there may be a similar endpoint due to a rapid rate of learning, but there may have actually been vastly different starting points and different rates of learning between the groups. The data obtained from the Grip-lift task was an exception to this, with the average of the second and third trials used. The first trial was excluded for participants in order to maintain better consistency for the high number of first lifts which needed to be excluded as a consequence of fumbled lifts.

As outlined, there were significant differences on all three domains for the IMI. This result was predicted, as you would not expect that experienced practitioners should find using a scalpel anxiety provoking. Furthermore, as a commonplace task, we would also expect experienced practitioners to find the task quite menial and not place much

importance or effort into it. This provides a degree of confidence that the IMI is appropriate for measuring these psychological domains in this context.

Both groups had a greater proportion of females than males, which is reflective of the Australian podiatry profession, with approximately 60% females and 40% males (*Podiatry registrant data* 2014). The significantly higher proportion of participants with a musical history in the Experienced group would be expected to increase dexterity, potentially increasing performance on the GDTs. We did not observe this.

The power calculation was based on 'Cohen's f' for a medium effect due to the unavailability of any previously undertaken studies. As identified by the post-hoc power analysis there is the possibility that insufficient numbers were obtained and consequently a type II error occurred. Further to this, we need to keep in mind the large number of measures which were being undertaken.

Overall, our results suggest that only a limited number of the test outcomes were useful at differentiating the experience groups. In some instances performance outcomes were the inverse to what would be expected, with the Novice group outperforming the Experienced group. A number of reasons have been proposed as to why this may have been the case. It seems that at face value these GDTs are not ideal for evaluating podiatrists or novice students in isolation in order to infer ability on clinical tasks, which is therefore a weakness in this cross-sectional study. However, some of these tests can differentiate the dexterous capability of the two groups and therefore may be useful in a longitudinal study to evaluate skill acquisition or change over time, such as would occur with usual learning or even in relation to an intervention. The overall purpose of the binomial logistic regression is to evaluate the capability of a test/test variable to determine group membership for the tests, not for scalpel skills specifically. Thus, we are making the assumption that the Experienced group have better skills which may be a hypothetical issue with the study design. Based on the Binomial Logistic Regression which was undertaken on the significant variables, in order of preference, the most useful measures which may be considered for this purpose are: TDI (Dominant hand) outcome from the AsTex®, and the GFavg (Dominant hand), LFdn (Dominant hand) and the GFsd (Dominant and Non-dominant hand) outcomes from the Grip-lift task.

4.5. Conclusion

Five physical tests, comprising 11 outcomes were able to sufficiently differentiate the experience levels of the two groups. These outcomes were able to predict 79.4% of the group membership overall. The Experienced group displayed superior performance in strength and speed on the relevant GDTs; however, the Novice group showed superior coordination on the Grip-lift task and the dominant hand on the AsTex® Sensory test. The strength tests were affected by the sex of participants and therefore test results need to be interpreted in relation to an individual's sex. Future dexterity testing on this population should use the GPT, Grip-lift task, G-MVC and P-MVC test. We would not recommend that this be extrapolated to compare their specific ability as a podiatrist, but instead be used to evaluate dexterous change relating to an intervention. The IMI was able to suitably differentiate groups on self-reported psychological domains relating to scalpel use. However, more research in this area is required.

5. Changes in self-efficacy, motivation and anxiety in novice podiatry students learning scalpel skills

5.1. Introduction

As outlined in previous Section 1.2.2.3, feedforward, and self-regulatory mechanisms will influence performance and learning through cognitive, motivational, affective and decisional processes (Bandura 1997; Bandura & Locke 2003). This includes the learning of psychomotor skills. Thus, some factors which may contribute to the learning of psychomotor skills include intrinsic motivation and self-efficacy at one end of the spectrum and anxiety at the other. As a consequence, these variables were evaluated as a part of the study comparing novice podiatry students and experienced podiatrists previously outlined (Chapter 4).

This cross-sectional study showed a significant difference between the novice podiatry students group and experienced podiatrists' group on all measures, including Perceived Competence, Effort/ Importance and Pressure/ Tension, representing Self-Efficacy, Motivation and Anxiety respectively. The greatest differences were between the variables of Perceived Competence and Pressure/ Tension.

The cross-sectional design is more convenient than a prospective longitudinal study, as data can be collected at a single point in time and making inferences with respect to the effect of experience on the variables. However, a longitudinal design is a much more robust method for determining change. Consequently, the intent of this sub-study was to re-administer the IMI to participants from the novice podiatry students' group after a period of scalpel learning to determine what change, if any, will occur in their feelings of self-efficacy, motivation or anxiety.

5.2. Methods

Ethics approval was obtained from the University of South Australia as an amendment to the previous study whence the IMI was originally implemented (protocol no. 0000025462) and Queensland University of Technology (protocol no. 1100001362) ethics committees.

5.2.1. Procedure

Students were initially requested to provide written informed consent and then complete the IMI in paper form. Students then undertook scalpel skills training and subsequent public clinics in line with standard teaching within their respective university programs. After a minimum of three clinics involving members of the public, students were sent an e-mail with a link to an online version of the IMI previously administered.

5.2.1.1. Intrinsic Motivation Inventory

The modified IMI (Figure 4.2-6) (Ryan 1982) previously described in Section 4.2.2, was used to evaluate the domains of 'Perceived Competence', 'Effort/ Importance' and 'Pressure/ Tension', representing self-efficacy, motivation and anxiety respectively, associated with the scalpel skill learning of novice students.

Scores for each of the factors of Perceived Competence, Effort/ Importance and Pressure/ Tension were calculated by adding the scores for the contributing questions (Table 4.2-2). For a reversed question, such as question 5, 'I don't put much energy into scalpel use', in the effort-importance category, the reported value is subtracted from eight to determine a true score for addition (Table 4.2-2).

5.2.2. Statistical analysis

Participant group characteristics were collected and reported. Means and standard deviations were calculated for each of the evaluated factors. A dependent samples t-test was used to compare these pre- and post-teaching. The period between inventory implementation was also calculated.

5.3. Results

A total of 27 students completed both stages of the IMI, including eight males and 19 females. The mean age of the cohort was 21.4 ± 2.98 years old. None of the students had used a scalpel previously. Due to missing data on a single contributing question

(i.e. participant skipped or did not respond), the 'Perceived Competence' factors for two participants were excluded from analysis.

A mean period of 109 ± 54 days was held between inventory implementation with students completing unspecified levels of self-practice and approximately three public clinics at both UniSA and QUT.

Results indicated a significant increase in the 'Perceived Competence' variable of the IMI after initial scalpel teaching and period of trial. Concurrent with this, a significant decrease in 'Pressure/ Tension' was observed. There was a small decrease in the 'Effort/ Importance' factor, but this was not significant. Table 5.3-1 provides statistical data.

Table 5.3-1 Pre and post comparison of IMI values (medians and interquartile ranges)

Medians (IQR)	**Pre-**	**Post-**	**Difference**	**P-value**	**ES**
Perceived Competence	24.0 (9.0)	30.0 (8.0)	+6.0	**.001**	-0.56
Effort/ Importance	31.0 (4.0)	30.0 (10.0)	-1.0	.198	0.25
Pressure/ Tension	24.0 (9.0)	20.0 (6.0)	-4.0	**.002**	0.63

ES = Effect size (d)

5.4. Discussion

In teaching a psychomotor task, particularly a clinical skill such as scalpel use, it is important to understand some of the psychological factors which may affect performance. In order to effectively understand the students' self-efficacy, motivation and anxiety associated with scalpel use, the IMI was used before and after teaching to measure each student's response for the domains of Perceived Competence, Effort/ Importance and Pressure/ Tension. Compared with experienced clinicians, the students had initially shown relatively low levels of self-efficacy and high levels of motivation and anxiety for using a scalpel (Chapter 4). Subsequent to teaching and practice, students showed a significant improvement in Perceived Competence and a decrease in the Pressure/ Tension they felt after a minimum of three undergraduate practicums and clinics. There was not a significant difference in the effort or importance they placed on the task. Thus, by our definitions students had an increase in post-learning self-efficacy and a decrease in anxiety attached to scalpel use.

Whilst these values did show significant change over the period observed they did not reach the values reported by experienced practitioners in the earlier chapter (see Section 4.3.5). This is not a surprise given the relatively short period observed and provides further confidence in the validity of the domains evaluated by the IMI. This also provides further support for the teaching methods reported by interviewees in Chapter 2 and shows that self-efficacy and anxiety levels can be influenced in a relatively short period.

These findings are consistent with the literature; self-efficacy has been shown to interact with motivation, affective processes, fear and anxiety and therefore subsequent behaviour (Bandura 1997; Prat-Sala & Redford 2010). For example, students with greater self-efficacy are more likely to be intrinsically motivated, show perseverance and feel less stressed (Prat-Sala & Redford 2010) and we would expect self-efficacy to change as a result of learning, experience and feedback (Gist & Mitchell 1992). We would presume their self-efficacy to increase and anxiety to decrease matching this mediatory effect.

There are consistent findings that managing perceived self-efficacy is of greater benefit than merely managing anticipatory anxiety in avoidance behaviour (Bandura 1997) and therefore may be a more suitable method of managing students learning scalpel use. Stevens et al. (2012) found that practice on an easier version of a stick balancing task improved self-efficacy and transfer of learning from pre- to post-testing, with self-efficacy explaining 55% of the variance of the post-test performance. Furthermore, artificially manipulating self-efficacy has a positive effect on performance and this can be achieved at both an individual and group level (Bandura & Locke 2003), providing a potential strategy for educators to improve performance in skill acquisition such as scalpel use.

It would be expected that individual students may feel variable levels of self-efficacy and anxiety based on factors such as previous experiences, having been to a podiatrist or other health professional and whether that experience was positive or negative. We would expect that the random sampling should minimise bias, however it could also be assumed that students electing to study in this field would not have had a negative experience with scalpels.

There are other limitations which need to be considered. Whilst we were able to present the mean duration between implementation of the IMI there may be individual differences in the number of actual clinics undertaken and this does not consider if a student was absent from the clinic at any time due to sickness or other reasons nor account for any variation in the number of patients they treated in each clinic. Furthermore, we were unable to compare the two university groups, and therefore cannot comment on any possible variation between sites. The effect of styles and amount of feedback, method of supervision and the intricacies of scalpel teaching may vary between sites.

Reports of learning self-efficacy have been shown to be significantly associated with actual performance scores (Tannenbaum et al. 1991). However, as with any questionnaire where a student is required to self-evaluate performance, it is possible that they may increase or decrease their scores depending on how they may consider it would affect the peer's perception of the student.

Whilst the demographic characteristics of this group seem consistent with common podiatry undergraduate cohorts, we should acknowledge that age has been identified as a source of variation with respect to motivation and therefore limits the generalisability of these findings (Kanfer & Ackerman 2000). Kanfer and Ackerman (2000) identified a negative correlation with age and motivational traits such as mastery and competitiveness.

This study was important for identifying the state-like traits of students undertaking scalpel training and to identify if the IMI was sensitive enough to changes in this population group. However, it is important to undertake further research using the IMI to establish validation of this self-evaluation tool with objective external evaluation. Furthermore, there is now scope to evaluate the effect of different methods of teaching, feedback or other variables on elements of self-efficacy, motivation and anxiety as assessed by the IMI. Previous studies have shown various correlations between learning strategies, motivation and anxiety and knowledge acquisition (Warr & Downing 2000), but this needs to be further evaluated specific to psychomotor learning and for scalpel use in the podiatry profession . It may be used to look for further correlation between IMI measures and performance in the use of a scalpel in the hope

that this may one day be utilised to identify students who may require greater input or alternatives to current teaching methods.

5.5. Conclusion

The IMI is a valid tool to evaluate a number of psychological factors affecting psychomotor learning. Through self-evaluation the IMI was able to demonstrate that during teaching and subsequent use of scalpels, students' self-efficacy improved and anxiety reduced. We recommend that this tool may be used to determine if there are methods of teaching scalpel skills which may decrease a student's anxiety and increase self-efficacy.

6. A randomised controlled trial of sensory awareness training and motor practice relating to learning scalpel skills (study three)

6.1. Introduction

Many professions and trades require skilled performance of gross and fine motor skills. The health professions are no exception with many, including podiatry, relying on skilled use of small tools such as scalpels. As previously defined, when relating to the hand and fingers this skilled performance requires good dexterity. Teaching psychomotor skills requiring high levels of dexterity can be difficult.

In Chapter 2, Section 2.3.3.2, there were some common student issues identified in the teaching of psychomotor skills, specifically scalpel skills, to podiatry students in Australia and New Zealand. This included the high level of anxiety often experienced by students, low levels of self-efficacy and issues with innate dexterity. A number of strategies to manage poor-performing students were identified, including: increased teaching and practical exposure, increased positive feedback and reducing task complexity. With the exception of increasing feedback, these strategies focus on the motor aspects of the sensorimotor system, with little consideration of afferent and cognitive elements. For example, one of the methods employed to increase the exposure of students to practical scalpel use is by implementing additional practice on colleagues and patients within the clinic setting, or to undertake simple scalpel tasks on inanimate objects. Even if practice on live participants is carefully monitored there is still an inherent risk involved, potentially putting patients, colleagues and students at risk. Furthermore, it is possible that this strategy could reinforce high levels of anxiety experienced by the student and affect self-efficacy, causing detrimental effects on psychomotor learning.

The process of using a scalpel, like all other physical activities, is dependent upon the successful integration of afferent, cognitive and efferent processes. As outlined in Chapter 4 (Section 4.1), for a podiatrist to use a scalpel effectively, the visual and peripheral sensory receptors enable a series of integral functions to occur: visual regard of the scalpel, hand and object to be debrided; initiation of predictive processes; perception of the spatial position of the body part; sensing the grip and manipulation of the scalpel and finally receiving sensory feedback during the task of debridement e.g. sensing tissue resistance. Before the efferent pathways invoke muscle activation to provide voluntary movement, significant processing and modulation has occurred through ascending impulses and central organisation at a variety of levels and in parallel throughout the central nervous system and the somatosensory cortex. Thus, learning these complex skills also relies on the integration of sensory, cognitive and motor processes.

Much of motor skill learning is implicit and even when performed intentionally, details of the motor skill and changes associated with learning generally remain outside the scope of awareness (Boutin et al. 2014). Researchers have found that movements can occur both with and without conscious awareness, depending on the attention and intent of the subject (Berti & Pia 2006; Fourneret & Jeannerod 1998). Whilst not universally accepted, it is thought that in some circumstances an increased awareness and intention of movement can result in improved motor performance (Heuer & Sulzenbruck 2012). For example, Libet et al. (1983) asked participants to perform the simple task of flexion of the fingers or wrist whilst watching an oscilloscope moving in a clock-like fashion. This movement would not normally attract conscious awareness, however when asked to direct attention to the task and identify a point of awareness of intent to move or the time of movement itself, awareness was achievable. Interestingly, they identified that the intent to move preceded the actual movement by 200 ms but followed rather than preceded brain activation in the supplementary motor area. Conscious awareness of the movement preceded the actual movement by 50 – 80 ms.

"These results suggest that awareness emerges before any sensory input reaches the brain, showing it is not linked in an absolute way to feedback from the moving muscles and joints." (Berti & Pia 2006, p.246)

This supports the theory of feedforward mechanisms involved in voluntary movement and suggests that through sensory awareness training we can influence the performance of voluntary movement.

This has been further evidenced through both animal and human studies showing brain activation with mental awareness activities such as in mental imagery. In human populations, PET, fMRI, rTMS and EEG performed during motor sequence and motor skill learning have supported this (Fontani et al. 2007; Grafton et al. 1996; Iacoboni et al. 1999; Nyberg et al. 2006; Pascual-Leone et al. 1995; Ranganathan et al. 2004). Such studies have shown that mindfulness-type exercises such as mental rotation tasks and mental imagery of movement also results in activation of many of the same regions as when performing the actual movement or undertaking motor learning (Decety 1996b, 1996a). This suggests that a mindfulness-like strategy may be useful in learning, particularly for struggling students when a safer alternative than hands-on practice may be required.

To further extrapolate this, it may be that a conscious awareness of the afferent elements contributing to a motor performance may also have a beneficial influence. A conscious awareness, whether it is action awareness or sensory awareness, sits within the realm of mindfulness. Whilst mindfulness is often considered to focus on psychological elements such as cognitive therapy for pain management or stress reduction, it can also include movement oriented therapies, such as yoga or Feldenkrais (Netz & Lidor 2003). As outlined in the introduction (Section 1.2.3.2), Feldenkrais is "an educational system that develops a functional awareness of the self in the environment" (Buchanan & Ulrich 2001, p.316) and is linked to DST.

As outlined in Chapter 1, Section 1.2.3.2, to date there is a paucity of evidence for sensory awareness training relating to psychomotor performance and learning. A study by Bitter et al. (2011) evaluated the effects of sensory awareness training compared to sham relaxation sessions on university students using two objective and one self-reported measure of dexterity. Sensory awareness training was based on the Feldenkrais method outlined above. This study involved the use of a single group-style intervention for 40 minutes duration with dexterity assessment immediately before and after the lesson. The selected objective tests included the PP (outlined further in methods, section 6.2) and the Grip-lift task (outlined in Section 4.2.1.3). A comparison

was made of the dexterity of dominant and non-dominant hands using the PP, Grip-lift task and self-perceived changes. A significant difference was found in favour of sensory awareness training on performance for the PP, and a desirable decrease in maximum grip force on the manipulandum, indicating an improvement in dexterity. Self-reported perceived changes found that 100% of the intervention group perceived changes after sensory awareness training and between their hands and a decreased difficulty when performing handwriting, compared with 50-60% of the control group perceiving differences and no change in hand-writing difficulty.

In summary, podiatry students are required to learn dexterous scalpel skills with varying levels of innate skill and self-efficacy. Task-specific, repetitive practice is linked to better motor learning. However, practising on live participants with limited early proficiency has safety implications. We wished to explore possible learning and practice strategies that did not carry risk, yet could build self-efficacy and target appropriate task-elements. The aim of this study was to undertake a randomised controlled trial with two different groups, in addition to current teaching. Students completed at least two weeks of either repeated sensory awareness training (Sensory) based on the Feldenkrais method, an alternate motor training schedule (Motor), or no additional training (Control). The alternate motor training would involve the use of simple scalpel motion replication and motor practice on inanimate objects supplied (soap or oranges), but with a focus on sustained improvement in psychomotor performance after a greater period of intervention.

We hypothesised that sensory training or motor training would produce dexterous performance superior to the control group and that sensory training would be equivalent or better than motor training. Sensory training could then provide a safer alternative to standard teaching or additional motor practice thereby decreasing anxiety, increasing self-efficacy and improving scalpel skill acquisition.

6.2. Methods

Ethics approval was granted from the Human Research Ethics Committee at the University of South Australia (protocol no. 0000027836) and the Queensland University of Technology (protocol no. 1200000722) (Appendix L) prior to recruitment (Appendix M).

Second year podiatry students from the University of South Australia (UniSA) and the Queensland University of Technology (QUT) who were about to commence learning scalpel and other related manual skills were recruited. A power calculation using an effect size of 0.75 on the PP from Bitter, Hillier and Civetta (2011), with 80% power and an alpha level of 0.05 showed 29 participants per group was required. Information sheets were dispensed during class and interested students were requested to contact the principal researcher via e-mail to express their interest in participating or ask any questions they may have had. Willing participants were provided with a consent form (Appendix N) and the modified IMI previously outlined (Section 4.2.2) to fill out prior to initial data collection. At the initial appointment demographic, medical, work and hobby information was obtained. Participants were excluded if they: had previously used a scalpel, had an occupation or hobby which required high levels of dexterity, were on medication or had a neuromuscular or musculoskeletal condition which could affect hand function. Participants were requested not to undertake vigorous exercise or drink caffeine within two hours prior to testing. Initial participant testing was undertaken on the following tests in order: PP, GPT and the Grip-lift task. An outline of hardware, software and research protocols for the GPT and Grip-lift task have been previously provided in Chapter 4, Section 4.2.1.3 and 4.2.1.6.

6.2.1.1. Purdue Pegboard (PP)

The protocol for the PP, not previously used, was as follows: the procedure of selecting pins, one at a time from the receptacle, and placing them in the holes sequentially from the bottom (closest to the participant) moving distally, was briefly demonstrated. The right array was used for the right hand and the left array for the left hand. The participant was encouraged to trial this for one or two pins prior to test commencement. To commence testing the examiner announced "One, two, three. Go" and started the timer. Each participant was then required to insert as many pins as possible into the appropriate array during a 30 s period. The hand not being tested was rested on the table or in the participant's lap and could not be used for that component of the test. Any pins which were not yet inserted or fell out during the process were not included in the total count. The process was repeated for both the dominant and non-dominant hands in that order. The additional PP test components using 'both' hands or undertaking an 'assembly' task were not used for this study.

6.2.2. Grouping and training

After baseline testing, prior to initial scalpel skill teaching, participants were randomly allocated into one of three groups by a person independent to the study using a computer-generated list, stratified across sites. The three groups comprised of the additional sensory awareness training (Sensory), additional motor practice (Motor) or usual practice only (Control) group. The importance of research rigour was emphasised and participants were requested not to discuss their activities with other study participants from other groups.

6.2.2.1. Sensory awareness training (Sensory)

Participants randomised to the Sensory group were taken into a separate classroom to receive sensory awareness training in the form of Feldenkrais ATMs from an experienced trainer (SLH) for approximately 40 minutes. This was then supplemented with audio recordings of two sessions, a 'sitting' session focusing on relaxation and awareness and another session targeting the dominant hand which were provided via CD and a link for downloading the files over the internet if required (transcripts provided in Appendix O). Participants were encouraged to undertake the sensory awareness training sessions as regularly as they could, a minimum of three times per week in their own time for at least two weeks, with the total duration dependent on when they could be booked for re-testing.

6.2.2.2. Motor practice (Motor)

The Motor group participants were also taken aside immediately and instructed in methods for motor practice in the form of staged scalpel practice including: holding a pen in the same manner as a scalpel and replicating scalpel movement either in free space or on paper varying the applied pressure; using a scalpel handle without a blade attached; and using a scalpel on inanimate objects such as soap or oranges to replicate normal usage on the foot. The QUT cohort was unable to use blades at home due to local policy and were therefore provided with dedicated times when they could undertake additional motor practice with scalpels at the university. They were also encouraged to practice with the scalpel handle without a blade at home.

Participants in both intervention groups were provided with a diary to record details of their training sessions including the frequency, duration and additional details if required (e.g. which exercises were completed). During the intervention period all

participants were sent short message service (SMS) or text messages periodically via skype to their mobile phones as a reminder to undertake their required training, provided they had not been allocated to the control group. SMS's went to all participants due to the requirement for the principal researcher to remain blinded. After a minimum intervention period of two weeks, participants were booked for post-intervention testing, with the total duration of intervention dependent on participants' timetables and availabilities. At post-intervention testing, participants were asked to complete another IMI and the objective tests used in the original testing battery using the same protocols as previously outlined, facilitated by the same assessor (RC) who reiterated to participants that he was blinded to group allocation.

6.2.3. Analysis

Continuous and categorical group characteristics were compared statistically using SPSS v.21 (IBM Corporation, Armonk, NY, USA) computer software. Categorical values such as location, sex, handedness, musical instrument history and gaming history were compared using a Chi Square analysis. Continuous variables such as age, height and intervention duration (total time) were compared using a generalised linear model univariate analysis of variance. Data were evaluated for normal distribution and transformed as necessary. IMI sub-categories were compared using repeated measures mixed models analysis with location included as a fixed effect to account for possible variation in standard teaching or intervention implementation. Objective GDTs were also compared for between group differences using repeated measures mixed models analysis. Age, sex, location, handedness and other demographic variables were either included or removed as fixed variables to determine the most appropriate model based on Bayesian Information Criterion (BIC) values (the lowest value indicating the best model (Seltman 2010)). Estimated marginal means were reported (rather than raw means) for the model, as these were the means used for comparison and are calculated by taking into account the effect of any other variables used in the model. Significance was set at $p \leq 0.05$.

6.3. Results

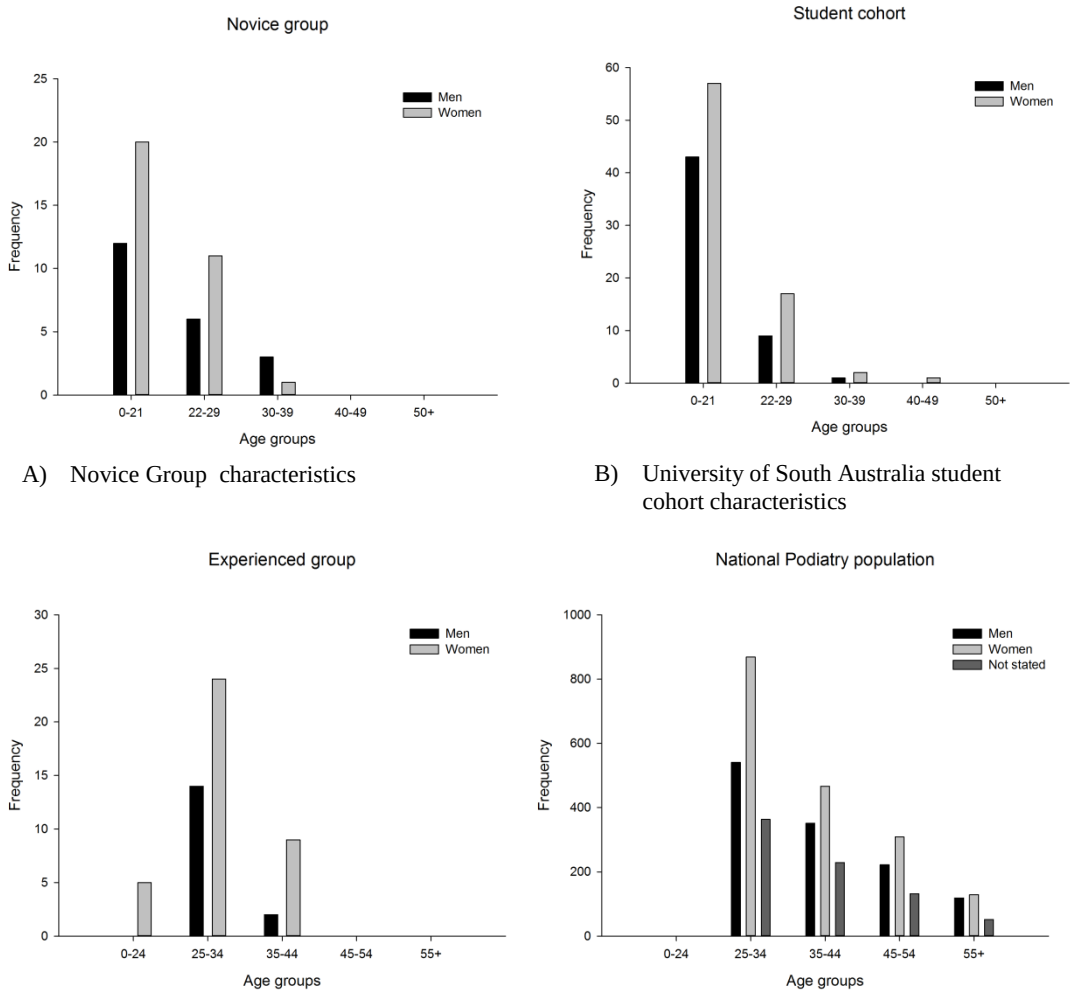
A total of 44 participants were included in the study; 65.9% were female and 84.1% were right handed. Group characteristics were balanced for all descriptive characteristics except for computer gaming history where the control group had a

significantly greater proportion with a gaming history. Details can be found in Table 6.3-1 below.

Table 6.3-1 Group demographic characteristics

	Control (n = 14)	**Sensory (n = 15)**	**Motor (n = 15)**	**p-value**
Location, n (%)				
UniSA	7 (50%)	7 (46.7%)	7 (46.7%)	0.94
QUT	7 (50%)	8 (53.3%)	8 (53.3%)	
Sex, n (%)				
Male	7 (50%)	4 (26.7%)	4 (26.7%)	0.32
Female	7 (50%)	11 (73.3%)	11 (73.3%)	
Age (years), Mean (SD)	22.4 (6.5)	23.4 (7.8)	22.9 (6.2)	0.93
Handedness, n (%)				
Right	12 (85.7%)	12 (80.0%)	13 (86.7%)	
Left	1 (7.1%)	2 (13.3%)	2 (13.3%)	0.84
Ambidextrous	1 (7.1%)	1 (6.7%)	0 (0%)	
Height (cm), Mean (SD)	172.1 (12.6)	168.7 (7.1)	167.5 (11.2)	0.49
Musical History, n (%)				
Yes	3 (21.4%)	1 (6.7%)	2 (13.3%)	0.51
No	11 (78.6%)	14 (93.3%)	13 (86.7%)	
Gaming History, n (%)				
Yes	7 (50%)	1 (6.7%)	2 (13.3%)	**0.01**
No	7 (50%)	14 (93.3%)	13 (86.7%)	

A comparison of the study group characteristics (age and sex) with the populations from which they were drawn is provided below in Figure 6.3-1.



A) Novice Group characteristics

B) University of South Australia student cohort characteristics

C) Experienced Group characteristics

D) National Podiatry workforce characteristics

Figure 6.3-1 Graphs of study groups (Novice and Experienced) and the populations from which they were drawn (University of South Australia student cohort and National Podiatry Workforce data (*National Health Workforce Dataset* 2014))

6.3.1. Intervention and data testing compliance

One participant (sensory group) was lost to follow-up due to health reasons not related to the study. A second participant (motor group) could not attend post-intervention testing and therefore was followed up for testing on the PP only by a local staff member one week later. The local staff member was also blinded to the group allocation of this participant. PP data collection was video recorded to ensure the testing protocol was adhered to. A third participant (sensory group) did not return their intervention diary recording practice duration and withdrew from the podiatry program shortly after post-intervention testing. The mixed model statistical method allows any data collected on

participants lost to follow-up to remain in the analysis and these data were therefore retained.

There was not a significant difference between the Sensory (Mean (SD) = 49.50 ± 22.39 days), Motor (Mean (SD 53.36 ± 22.86 days) and Control (Mean (SD) = 48.14 ± 21.25 days) groups on duration of intervention (ANOVA, $F_{2, 41} = 0.208$, $p = 0.813$). The difference in the mean practice time between the two intervention groups, calculated by univariate analysis, was also not significantly different; Sensory group (Mean (SD) = 293.23 ± 186 minutes), Motor group (Mean (SD) = 221.20 ± 97.86 minutes); (ANOVA, $F_{1, 27} = 1.768$, $p = 0.195$). Similarly, the difference in number of sessions undertaken by participants in the Sensory (Mean (SD) = 6.92 (3.52)) or Motor (Mean (SD) = 8.80 (3.12)) groups was not statistically significant (ANOVA, $F_{2,41} = 2.24$, $p = 0.147$). Motor group participants recorded in their practice diary which exercises were undertaken within their group parameters e.g. whether they used a scalpel handle with or without a blade to practice the motion etc. The Sensory group reported whether they performed the dominant hand lesson or sitting lesson and how their session went. This included comments such as: 'Good awareness after exercise, arm fatigued after just did (sic) dominant hand exercise'. One participant from the QUT (Sensory group) e-mailed the non-blinded researcher (SLH) to declare that participants from the sensory group were not being compliant with the intervention. The researcher then responded to the message directly and sent an e-mail to all participants outlining the importance of honesty in reporting whatever level of training they achieved, that there was no consequence of low compliance and the importance of maintaining academic rigour. No participants requested a change to their diary records.

6.3.2. Dependent variable testing

Data were analysed for normality and transformed where required. A linear mixed model analysis was undertaken with and without 'gaming history' included as a random effect covariate in order to determine the best model fit and where appropriate to account for the baseline differences between participant groups as identified in Table 6.3-1. For psychological dependent variables (IMI), the model fit was also considered with and without the inclusion of location as a random effect covariate as it was considered that subtle differences between the universities, staff and teaching may contribute to students' feelings of self-efficacy, motivation or anxiety. However, the fit

was not improved by inclusion and was therefore consequently removed from any subsequent analysis.

6.3.2.1. Psychological outcomes

There were no significant differences between the intervention groups over time on Perceived Competence, Effort/ Importance or Pressure/ Tension, as shown in Table 6.3-2. All groups showed a significant increase in Perceived Competence ($F_{1,41}$ = 13.796, p = 0.001) during the intervention period. The motor group showed the greatest increase in Perceived Competence but not significantly more than the other groups. There was no significant change in Effort/ Importance ($F_{1,39}$ = 0.006, p = 0.939) or Pressure/ Tension ($F_{1,41}$ = 0.447, p = 0.507).

Table 6.3-2 Raw mean pre- and post-intervention values for Intrinsic Motivation Inventory (IMI) and p-values calculated by linear mixed model analysis.

Means (SD)	**Control (n = 14)**		**Sensory (n = 15)**		**Motor (n = 15)**		**F value**	**P-value** (Group x Time)
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*		
Perceived Competence†	22.79 (5.63)	25.50 (3.59)	23.20 (7.43)	26.43 (6.78)	25.71 (6.57)	30.07 (5.78)	0.17	0.84
Effort / Importance	30.07 (3.45)	29.00 (4.24)	29.00 (5.21)	29.50 (4.75)	28.86 (4.64)	29.27 (5.26)	0.70	0.50
Pressure / Tension	21.64 (6.80)	22.50 (5.17)	20.07 (5.36)	20.21 (6.95)	20.50 (4.60)	17.67 (5.15)	1.62	0.21

† Model includes 'history of computer gaming' variable as a random effect

6.3.2.2. Dexterity measures

A linear mixed model analysis of the three tasks showed that only one variable, PDn for the non-dominant hand, showed a significant group difference over time ($F_{2,41}$ = 3.280, p = 0.038)(Table 6.3-3). This was calculated on Log_{10} transformed data to address the skewed distribution of data. Tables outlining degrees of freedom can be found at Appendix P and Q. There were no other significant differences between the three groups over time. Figure 6.3-2 provides a plot of the PDn of the non-dominant hand between groups (estimated marginal means from mixed model).

There was a significant within-group improvement over time for the GPT (Dominant hand) outcome ($F_{1, 40} = 4.846$, $p = 0.034$), also on Log_{10} transformed data. There were no other significant within-group changes.

Table 6.3-3 Raw mean pre and post intervention values for dexterity measures and p-values calculated by linear mixed model analysis.

Task	Outcomes	Means (SD) Control (n = 14)		Sensory (n = 15)		Motor (n = 15)		F value	P-value (Grp x Time)
		Pre	***Post***	***Pre***	***Post***	***Pre***	***Post***		
Grip-lift task	**Preload duration** (ms)								
	Dominant	176.22 (180.15)	123.37 (42.56)	98.08 (35.21)	98.58 (36.40)	157.66 (228.74)	129.13 (62.24)	0.12	0.89
	Non-dominant	181.21 (137.66)	120.00 (65.84)	72.00 (48.82)	88.44 (40.14)	90.71 (53.36)	131.20 (79.88)	3.53	**0.04**
	Maximum grip force (N)								
	Dominant	5.07 (1.99)	4.57 (1.79)	6.52 (2.89)	6.55 (2.81)	7.22 (4.73)	7.13 (3.55)	0.19	0.83
	Non-dominant	6.18 (2.57)	5.34 (2.10)	6.80 (2.67)	7.71 (6.11)	7.67 (4.27)	7.59 (3.13)	0.67	0.52
	Maximum correlation (ρ)								
	Dominant	0.77 (0.11)	0.81 (0.06)	0.77 (0.07)	0.78 (0.06)	0.78 (0.07)	0.75 (0.10)	0.35	0.71
	Non-dominant	0.77 (0.07)	0.78 (0.07)	0.76 (0.07)	0.77 (0.07)	0.78 (0.06)	0.77 (0.07)	0.47	0.63
	Average Grip (N)								
	Dominant	4.48 (1.75)	3.69 (1.27)	5.47 (3.11)	5.16 (3.14)	6.10 (3.81)	5.63 (2.68)	0.40	0.68
	Non-dominant	4.49 (1.92)	3.97 (1.55)	5.23 (2.07)	5.77 (5.54)	5.30 (2.46)	6.00 (2.73)	0.55	0.58
	SD Grip								
	Dominant	0.13 (0.07)	0.10 (0.06)	0.18 (0.13)	0.16 (0.17)	0.17 (0.11)	0.14 (0.12)	0.45	0.64
	Non-dominant	0.16 (0.07)	0.13 (0.09)	0.16 (0.07)	0.18 (0.11)	0.18 (0.08)	0.15 (0.08)	2.11	0.13
	Hold Ratio								
	Dominant	1.70 (0.76)	1.51 (0.52)	1.90 (0.83)	2.09 (1.28)	2.15 (1.36)	2.29 (1.08)	0.46	0.64
	Non-dominant	1.83 (0.79)	1.62 (0.63)	2.12 (0.84)	2.37 (2.38)	2.17 (1.04)	2.42 (1.09)	0.39	0.68
	Lift Duration (ms)								
	Dominant†	277.78 (160.24)	309.74 (129.72)	299.67 (96.32)	290.01 (86.93)	235.11 (66.37)	253.43 (86.31)	0.41	0.66
	Non-dominant	330.74 (186.32)	359.03 (150.55)	252.93 (99.38)	295.65 (123.32)	253.56 (99.23)	255.26 (102.75)	0.42	0.66
Purdue Pegboard	**No. of pegs**								
	Dominant	14.57 (1.55)	15.21 (1.76)	15.20 (1.78)	15.07 (1.90)	15.20 (1.93)	16.13 (1.41)	1.55	0.22
	Non-Dominant	14.00 (2.04)	14.21 (1.53)	13.73 (2.25)	14.57 (1.60)	14.13 (2.07)	14.67 (1.76)	0.31	0.73
Grooved Pegboard Test	**Time to complete**								
	Dominant	56.87 (7.92)	55.47 (7.66)	58.14 (11.03)	55.07 (6.82)	56.02 (7.84)	53.59 (6.36)	0.18	0.83
	Non-Dominant	62.37 (6.07)	60.77 (8.34)	61.31 (7.78)	59.09 (5.23)	62.40 (13.05)	61.59 (11.28)	0.26	0.77

† Model includes 'history of computer gaming' variable as a random effect

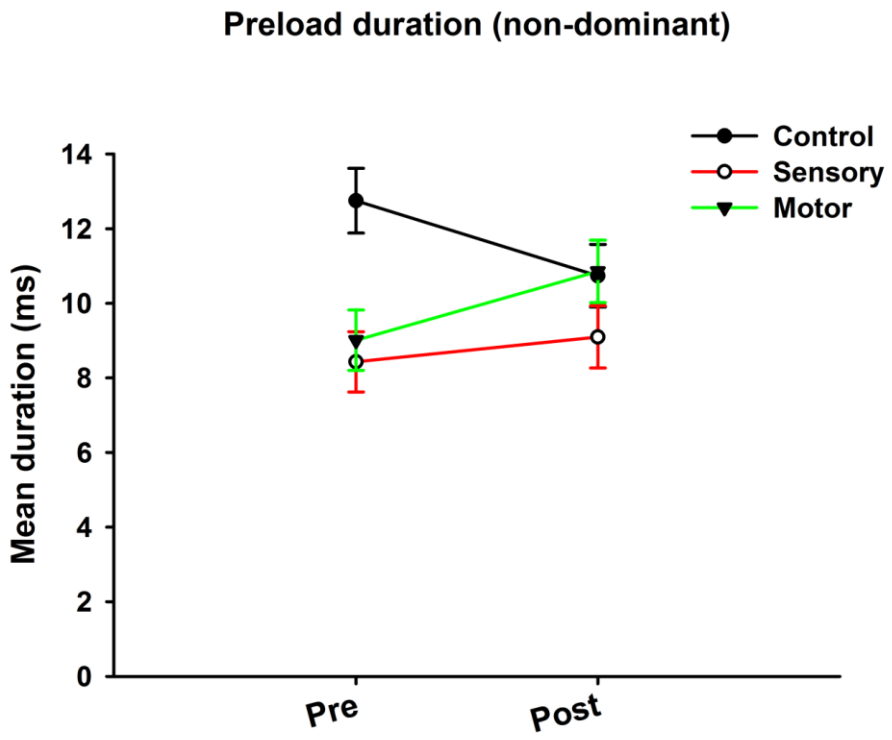


Figure 6.3-2 Preload Duration non-dominant hand effect of group change over time (estimated marginal means calculated during mixed model analysis)

6.4. Discussion

After a period of sensory awareness training, or motor practice, there were few significantly different outcomes evident between either of the experimental groups and the control condition. This included both psychological outcomes as measured by the IMI and measures of dexterity. This suggests that there is little benefit to sensory awareness training or additional motor practice over the current scalpel teaching regime employed at either of the university programs involved in the study on dexterity measures.

The only variable for which there was a significant group difference over the experimental period was PDn of the non-dominant hand for the Grip-lift task. Preload Duration represents the duration of time between when a force is applied to the manipulandum and when the manipulandum leaves the supporting surface. A longer period is indicative of a poorer strategy or performance and therefore poorer dexterity. The assumption of the grip lift task is that it represents the interaction between afferent and efferent stimuli (Westling & Johansson 1984). The main reason for this significant outcome was due to a larger improvement (decrease in mean time) displayed by the

control group, relative to a smaller deterioration (increase in mean time) for both the sensory awareness and motor groups' performance. It should also be noted that there were significant differences between the groups at baseline ($F_{2,39} = 4.008$, $p = 0.026$), with the control group performing considerably poorer than both of the experimental groups which may have contributed to the relative improvement or deterioration over the testing period consistent with the 'law of practice' where the rate of improvement is related to the amount left to improve (Schmidt & Lee 2011; Shumway-Cook & Woollacott 2011). However, we did not correct for multiple comparisons; if we had, then this outcome would not meet the required p-value of 0.007 (0.05 ÷ seven outcomes). There were no other significant differences reported for comparison.

There could be a number of reasons to explain the lack of between group differences on the psychomotor outcomes within this study. Lower recruitment than anticipated resulted in only 44 participants overall. The calculated sample size for 80% power was 29 participants per group suggesting the possibility of a type I statistical error. Unfortunately, due to logistical, cost, the timing of scalpel teaching and human resource restrictions, we were limited to UniSA and QUT for recruitment, which became an issue when recruitment from these programs was exhausted. However, despite this, there was a complete lack of change on the variables tested over time, independent of their group allocation suggesting that even with greater participant numbers and increased power it is unlikely that a significant between-group difference over time could occur.

The lack of significant findings was unexpected. As outlined in the introduction (Chapter 1, Section 1.2.3.2) precedence suggests that sensory awareness training, additional physical practice or both should have improved psychomotor performance and potentially students' self-efficacy and anxiety. The inability to blind participants to their group allocation together with the Hawthorne effect alone could have resulted in an increase or decrease in (extrinsic) motivation resulting in observable performance changes. However, this was not the case.

The individual performance response to the intervention over time for participants was quite varied. This suggests there may be unidentified confounding factors, uncontrolled elements or that the training methods need to be more specifically tailored to the individual. The varied response created quite a bit of noise within the data.

One possibility is that the GDTs chosen to evaluate hand performance do not adequately represent the elements contributing to a skilled scalpel performance. Alternatively, as outlined in the Chapter 4, Section 4.4 discussion, improved performance in specific functional tasks, such as in this case of scalpel skill learning, does not adequately transfer to GDTs. This calls into question the overall validity of GDTs or validity of the concept of an underlying dexterous ability which may be applied to any hand performance.

It is possible that the sensory awareness training (Feldenkrais ATM) chosen for this study was not appropriate. This may be the result of how it was implemented, or it may be that the technique itself was not appropriate for the overall aim. As outlined in the introduction (Chapter 1, Section 1.2.3.2) the technique is not without controversy (Ives 2003; Ives & Shelley 1998; Ives & Sosnoff 2000). Based on the limited suitable evidence available, Feldenkrais ATM lessons have been reported to have positive effects on numerous medical and physical conditions (Connors et al. 2010; Connors, Pile & Nichols 2011), facilitated improved dexterity (Bitter, Hillier & Civetta 2011) and a decrease in anxiety (Kerr, Kotynia & Kolt 2002; Kolt & McConville 2000). The most relevant of these was the study by Bitter, Hillier and Civetta (2011) on dexterous performance, which demonstrated an immediate improvement on some of the same measures as the current study, which indeed acted as the impetus for this study. The key differences in this study compared to that by Bitter, Hillier and Civetta (2011) were repeated training sessions over a longer duration rather than a single session, retention testing rather than immediate testing which is less prone to performance variability and more representative of true learning, and the face to face delivery of the intervention rather than via an audio recording.

The method of implementation may have had an effect on outcomes and one of the limitations within this study could be that *ongoing* sensory awareness training was only provided via an audio recording. This was a pragmatic choice to enable training at separate sites over an extended period, ensures consistency of instruction whilst being conscious of the time demands an alternate method would have on one trainer. A number of studies report the use of audio tapes for the delivery of instruction from inception or for home-based continuation of lessons (Lundblad, Elert & Gerdle 1999; Ruth & Kegerreis 1992; Smith, McConville & Kolt 2001). However, this is not the typical way in which the Feldenkrais method is practised and it is possible that by doing

so resulted in a diminished effect on engagement or motivation. Participant engagement is an important element of Feldenkrais theory, construed to be an important requirement in order for it to be successful. A study by Breitenstein et al. (2010) investigated intervention fidelity, identifying it as a particular issue not frequently considered with respect to intervention studies. Implementation fidelity may consider many aspects such as adherence to an intervention, content, process, participant responsiveness and program differentiation (Breitenstein et al. 2010). In this study, the engagement of the student in the intervention is of particular importance. However, despite the shortcomings of the use of audio recordings, we feel that the approach chosen for this study is more representative of a real-life scenario and best embodies how the various podiatry programs could feasibly implement this intervention.

Whilst participants were blinded to the direction of the hypothesis, the lack of blinding to group allocation may have also affected engagement. The link between motor practice and improved performance is well established. However, a link between sensory training and motor performance is not. Participants randomised to the sensory awareness training group therefore may have become disengaged, affecting performance, compliance or introduced a bias to the study.

Another possibility worthy of consideration is that there may have been a bias within the recruitment. We were obviously unable to measure the characteristics of students who did not volunteer to participate in the study. It may be that students who had high anxiety or low self-efficacy about using scalpels, did not feel they had sufficient dexterity, or another systemic issue, did not volunteer for the study, therefore skewing the study population.

A recent systematic review and meta-analysis found that non-informative vision of the body part, not related to spatial attention improves afferent function, specifically tactile acuity in the hands (Eads, Moseley & Hillier 2015). Active sensory training, such as tactile discrimination training often encourages vision occlusion. Whilst Feldenkrais ATM does not specifically require vision to be occluded, we did not control this and provides a good example of how active sensory training techniques may need to evolve with our improved understanding.

In addition to a lack of change seen in the sensory awareness training group, it was also surprising to see a lack of significant change over time in the motor practice group. It is

well known that physical practice plays one of the most important roles in motor learning, skill acquisition and development of expertise (Schmidt & Lee 2011; Wanzel, Ward & Reznick 2002). Consequently, we would expect that increased practice should also translate to improved motor performance, particularly for novices performing well below any expected ceiling effect. The motor practice intervention used in this study involved simple rehearsal of scalpel motion and practice on inanimate objects, as used by the majority of university programs as outlined in Chapter 2, Section 2.3.1. One possible explanation is that simple movement rehearsal may not sufficiently engage the motor cortex to promote plastic changes (Carey et al. 2006). In fact, researchers have been investigating the need for rehabilitation activities beyond simple movement rehearsal to increase engagement and promote richer neuroplastic change to facilitate improved recovery in stroke survivors (Carey et al. 2006). Further to this, there was no extrinsic feedback provided for sessions other than usual teaching, which as discussed in the introduction to this thesis, does play a role in the motor learning process.

In theory, performance improvement across all participants as a consequence of teaching, particularly during the early stages of motor learning and error-based feedback may be sufficiently large that subsequent motor learning experienced by control group participants may obscure subtle between-group differences occurring as a result of the intervention. In other words, the outcomes used may not be sensitive enough to discriminate small changes amongst the noise produced by the normal learning process. If this were the sole reason for the lack of between-group differences then we would still expect to see a time effect as all groups improved. However, this was not the case. Similarly, there was a large variability on the outcomes in response to training (Sensory or Motor), thus it may be that the individual response to training and the contributing or confounding factors are not well understood; leading to a lot of noise in the results. As identified by participants in Chapter 2, Section 2.3.3.2, there are select students who struggle with the learning of scalpel skills, perhaps because they lack sufficient dexterity. Maybe better participant selection, such as stratifying participants into a cohort of struggling students or excelling students, or based on their learning style would be better. We should at least consider undertaking initial performance testing subsequent to the early error-based (within-session) learning phase rather than prior.

Another potential confounding factor may be that the intervention period was insufficient to evoke a sufficient change to be detected by the tests used. The

intervention period matched teaching curriculum for scalpel learning at each of the universities with a mean of 50.3 (21.7) days between pre- and post-testing for each of the participants. Furthermore, the two groups reported a mean of 6.9 training sessions of duration 293 minutes and 8.8 sessions of duration 221 minutes for the sensory and motor groups respectively. There was not a significant difference between the two groups. As this is the first study investigating sensory awareness training in this context, we do not know how much time would be required to see a measurable change on the chosen tests. Karni et al. (1995) found a plateau in learning after three weeks of only 10-20 minutes daily training on a simple thumb opposition task, suggesting a ceiling effect was found. In the study by Bitter, Hillier and Civetta (2011) sensory awareness training for 40 minutes was provided which resulted in significant improvements on the PP, Grip-lift task and another subjective self-reported measure. Hauptmann and Karni (2002) found that transition of performance gains to a stable form and long-lasting between session gains was dependent in the first instance on the amount of practice, but that it was the saturation of priming effects not the priming effect itself which is critical to the induction of slow learning and consolidation. Consolidation will then continue independent of practice over time (Hauptmann & Karni 2002). Repetition priming is a phenomenon where performance on a given task is improved as a function of repeated experience after short or even long intervals (Hauptmann & Karni 2002). In their experiment, Hauptmann and Karni (2002) reported saturation was achieved after only six paired blocks in a single session. This was investigated on a letter enumeration task and to our knowledge this has not been investigated specifically on motor skill acquisition. Thus, based on the above, we believe that our extended intervention period similar to that of Karni et al. (1995), with training or practice undertaken in a distributed manner was plausibly sufficient to invoke a change and for this change to become stable over the prescribed period with the only exception being if there was an issue of contextual interference. There was significance between the study groups for the duration of intervention. Neither the number of sessions undertaken or time dedicated to training was significantly different between the Sensory or Motor groups. Savion-Lemieux and Penhune (2005) found that the total number of practice sessions was not influential in motor learning; rather the distribution of sessions over time was the influencing factor. Whilst we cannot specifically analyse this distribution, the lack of difference for the duration of training or for the number of sessions suggests that this is unlikely to be very different between the

groups. With respect to motor practice within this study, the sessions were kept simple and involved gradual increases in complexity. As outlined above, in the study by Bitter, Hillier and Civetta (2011) testing occurred immediately after the intervention and so therefore actually only measured immediate change in performance and not the retention of skill as a marker of long term motor learning. As outlined previously, the evaluation of retention is recognised as being a more appropriate measure of motor skill learning rather than an isolated performance, the amount of retention should more closely represent the proficiency obtained (Gomez & Gomez 1984) and is less likely to be affected by transient state-like factors (Chen et al. 2000).

There was an issue within the study regarding an e-mail received by the sensory awareness training instructor (SLH) from a sensory group participant. This e-mail reported that other group members were not maintaining compliance to the intervention. A similar issue was faced by Doheny (1993) whose study suffered from extensive cross-contamination between groups whilst investigating mental practice as an alternative to physical practice for a task involving the delivery of intramuscular injections. This was managed at the time by the non-blinded team member, which involved re-affirming with participants their obligation and the importance of maintaining scientific rigour. Self-reported practice times analysed at the conclusion of the intervention period did not support this allegation, with roughly equal practice time means for both of the intervention groups. However, as they were self-reported times validity cannot be confirmed. Future research should use objective measures or monitoring of fidelity where possible. There is a risk with this type of intervention study for cross-contamination, compliance issues or differences in motivation between intervention groups, particularly when participants are not blinded to their own group allocation, as highlighted by the email incident. As the students were novice podiatry students, studying toward a certain physical capacity, it could be that the vast improvements experienced by students over time as part of their overall studies may obscure any other potentially subtle changes occurring as a result of the additional interventions introduced (sensory awareness training or additional motor exercises). These complex issues could be avoided for future studies through an increase in fidelity and the provision of one-to-one Feldenkrais training and supervised practice.

Based on the current study, the lack of significant outcomes implies that neither of the interventions was remarkably better than current teaching practices for improving the

dexterity of novice podiatry students. In particular, there is no evidence that sensory awareness training was more beneficial to motor learning than current practice, as hypothesised, due to the lack of significant findings either between groups or even a change within-group over time. Finally, the role of GDTs as surrogate measures for skilled performance may not be appropriate. As discussed in Chapter 3 there was quite a lack of correlation with GDTs and occupational performance or task-specific activities, despite this often being the intended purpose of the test. Our findings suggest that it may be inappropriate to use such tests to infer task-specific capabilities or to measure dexterous ability subsequent to training (sensory or motor).

6.5. Conclusion

The use of sensory awareness training to target the sensory arm of the afferent, cognitive and efferent triad in motor learning and performance does not provide a more effective alternative to learn scalpel skills compared with motor practice or the control condition. Similarly, additional motor practice does not provide additional benefits in the motor learning and performance compared to current teaching practice within the university programs studied. This may be the consequence of the intervention chosen, the method of implementation and subsequent compliance of participants or the measures chosen for evaluation. Further research may be warranted using more engaged training, provision of supervision and greater participant numbers.

7. Final Discussion

As emphasised throughout this thesis, the dextrous ability of podiatrists is important for the effective management and health and safety of the patient, and a key component in practitioner success. In the case of a high-risk patient, poor management can result in injury or even amputation. When it comes to novice podiatry students, in particular those who are struggling, the risk of injury is amplified. Furthermore, difficulty learning practical skills can negatively impact on a student's anxiety levels, self-efficacy and motivation. To facilitate improvements in the dexterity of the students and allow them to gain sufficient experience there are a number of barriers which need to be overcome. First and foremost, is the paradoxical dilemma of how to allow novice podiatry students to gain the required hands-on practical experience whilst limiting the risk to themselves, colleagues or the public. This is compounded by the lack of recognised measures of dextrous ability in this population, so that a threshold level of competency may be determined or improvement evaluated. An adequate method of measure would enable the investigation of methods introduced to overcome the paradoxical dilemma faced. The concluding study of this thesis investigated a novel approach intended to improve the sensory perception of the student and therefore dexterity, and positively influencing various psychological contributors to motor skill performance.

The utilisation of a mixed methods approach to this thesis enabled the diverse needs of this topic, outlined above, to be met. A qualitative exploration of the issues and investigation into current practice provided a richness of information upon which to base the subsequent studies, particularly in light of the limited literature available. This information base, married with the rigour of a systematic evaluation of tools, and a quantitative evaluation of a selection of these, in the required context, provided the evidence necessary to undertake a randomised controlled trial. The randomised

controlled trial is unquestionably the most rigorous method for experimentally investigating any new technique or intervention and therefore important addition to any research grounding. In this way, the choice of study designs for each element was pragmatic. However, from a research training perspective the mixed methods approach also provides an opportunity for a diverse learning experience that may be ably applied to future projects.

Compounding these practical issues is the scarcity of literature relating to dexterity within the podiatric context. This includes the teaching of motor skills, the epitome of which is scalpel use. Thus, the first stage of this research was to undertake a series of structured interviews with podiatry staff from university programs around Australia and New Zealand. The premise was to establish evidence for how scalpel skills are being taught to novice podiatry students, identify the issues faced and any strategies implemented to overcome them.

The teaching of scalpel skills around Australia and New Zealand was surprisingly consistent with only small variations in practice arrangement with respect to structure and duration. Approaches to practice included the use of inanimate objects, wax on fleecy webbing which can be applied to a colleague's foot and even foot models. The greatest area of controversy was surrounding the benefits or disadvantages of practice on real patients and when this should best occur. The key issues identified for teaching manual clinical skills, in particular scalpel skills, were pertaining to clinical exposure, student motivation and levels of anxiety, and dexterity.

The choice to use structured interviews was a pragmatic one. There were only eight programs around Australia and New Zealand at the time of the study and therefore it was felt that the use of a written questionnaire may limit the depth of information which could be obtained considering the small pool of programs from which to recruit. Instead, a structured interview had the potential to increase the richness of the data through structured discussion, allowing the progression of ideas throughout the process and enabling deeper exploration of the topic if required. Thus, in order to analyse the data content-analysis methodology was used. The chosen approaches have both benefits and disadvantages.

The content analysis methodology used allows greater flexibility in coping with both structured count-type data and qualitative assessment of ideas and thoughts under a

unified structure; however, this can be quite labour intensive. Only two participants were recruited from each site, as it was felt that greater participant numbers would not strengthen the richness of the data. Whilst not mandatory, the preference was for one of the participants from each site to be a Program Director or equivalent in order to represent a broader over-arching perspective with respect to learning scalpel skills within the context of the entire program and thus improve the richness of the data. The remaining participants needed to have been involved in teaching scalpel skills either currently or at some stage previously. Some of the variable (and even contradictory) responses from participants from the same university may be reflective of the different roles, experience or current level of involvement in teaching scalpel skills.

The data reported from the interviews represents the curricula at the time the interviews were conducted; however, university programs are regularly reviewed and modified. For example, many universities are now developing digital learning strategies and pushing to adopt the increasingly available technologies. Whilst manual clinical skills, in particular scalpel skills, due to their nature are less likely to be affected by such changes, we cannot assume that they are immune from change. Thus, findings need to be considered within these limits. One of the university programs was in the midst of implementing a change in scalpel teaching, including changes in structure and timing and implementing the use of media at the time of the interviews which resulted in subtle discrepancies in the participants' responses. We did not ask any of the programs to speculate about any future change or how technology may impact on clinical skill teaching. However, if the podiatry profession follows trends in the medical and surgical disciplines then VR may play a future role. These technologies may be useful in addressing the barriers to teaching and evaluation of dexterity and manual clinical skills; however, currently cost continues to be a prohibitive factor.

Limiting participants to programs in Australia and New Zealand was necessary for this investigative study due to the potential differences which may exist with respect to podiatry scope of practice and education, and the healthcare and regulatory systems. Podiatry programs in Australian and New Zealand are accredited by the same regulatory body, professional registration is sufficiently similar between the two countries and the health care systems are closely aligned. Thus, findings may not be generalised to all podiatry programs in countries outside of Australia and New Zealand.

As discussed, the overall purpose was to explore and identify aspects of teaching scalpel skills rather than provide a comprehensive list of issues or to seek consensus (Delphi or otherwise) on how scalpel skills should be taught. However, future research in this area should include seeking consensus and forming evidence-based guidelines. This would ensure the best possible approach to teaching, enable consistency between established programs, facilitate the development of standards and provide a reference point for program accreditation. This would also provide a structure for new programs and curriculum being written. In the short span since completion of the interviews two programs for two separate universities have commenced and a third program is to be opened in the near future.

An obstacle to evaluating dexterity in the podiatric population is the lack of a gold standard and a broad variety of tests which can be used with limited validation. Thus, to determine the best method of evaluating dexterity in this population, two studies were undertaken. The first of these was a systematic search of the literature for the objective tests most commonly used in the health professional population and subsequently review any available literature relating to their psychometric properties.

The diversity of tests utilised for psychomotor testing was remarkably wide-ranging. The consequence was a large number of tests which, relatively speaking, were not used extensively or consistently in evaluating the dexterity of the health professional population. Of these, the most commonly used test was the PP which was reported in only 14 studies. By the ninth most commonly used test, the MMDT, the reported use was in only two studies. Thus, the cut-off for full review was made for the top nine, as any tests lower than this were only used on a single occasion. There was an increasing preference for the use of virtual trainers reported, particularly in the training of laparoscopic surgery. However, as the cost and utility of using such tools remains too high for general use, these studies were excluded. This form of training and testing however may play an important role in future training of scalpel skills to podiatry students as the cost of such technology reduces.

Within this review it is important to recognise that a number of the studies were published by the same research group, who for one reason or another may have a bias towards one particular test inflating its representation in the health professional literature. We did not see this as a particular issue; however, the increased use may not

represent the appropriateness of the test. Hence, a full review of psychometric properties was undertaken.

A major issue with reviewing the GDTs was the age of the tests with many of them described in the literature many years ago. This made finding adequate validity or reliability data problematic as relevant literature was hard to locate. In many cases data were never actually published in the peer-reviewed literature, instead provided only in books or manuals. When it was published in the peer-reviewed literature, articles were often so old that they were difficult to access or the article lacked the rigour expected for modern-day validity testing. Instead, validity was determined via face validity or factor analysis, if at all. Extensive research needs to be undertaken to re-establish validity of many of the tests used today. The GPT, PP and FTT were the most extensively studied tests, providing the greatest insight to validity, reliability and the effects of confounding population characteristics; however, we concluded that more rigorous evaluation was required.

Given the low utilisation of individual tests on the health professional population and relative lack of validity identified in the review, to determine the most appropriate objective tests for the podiatric population we undertook a cross-sectional observational study comparing novice podiatry students to experienced practitioners. Analysis included logistic regression analysis to determine which tests best categorised participants into their appropriate group and therefore which tests would best represent the experience levels of the podiatric population. The choice of tests for further investigation was problematic owing to the lack of conclusive findings from the review. From the review, the GPT and FTT were included in the battery. As the GPT was considered to be a more intricate pegboard test than the PP, only the GPT was included. Local experts in psychomotor testing were consulted to further consider tests for inclusion in the battery to ensure a broad range of elements, be sensitive to the healthy population and include a number of new and innovative tests sensitive to changes in psychomotor ability and sensorimotor capacity (VTT and AsTex®). Thus the final battery also included the FTT, GPT, P-MVC, G-MVC, a Grip-lift task, VTT and AsTex® tests. The influence of psychological factors were considered via the inclusion of the IMI which had been identified during the review and was reported to be sufficiently valid and reliable for our purpose, with the added benefit that redundant

subscales may be removed and item order may be altered with negligible effect (Selfdeterminationtheory.org 2014).

An issue with obtaining the required hardware for two of the tests (Grip-lift and VTT) resulted in a delay to recruitment and consequently missing the opportunity to test the graduating student cohort comprising the intermediate group. This resulted in the need to remove the group from the study. The loss of the intermediate group resulted in decreased statistical power and an increased risk of a type I error. A test of the statistical power for the logistic regression analysis indicated that sufficient power was obtained, however for many of the individual tests it was not.

Despite extensive consideration of appropriate tests of dexterity, minimal between-group differences were identified between the Novice and Experienced groups. As outlined in the study discussion, the cross-sectional design required certain inferences and assumptions to be made. For example, we made the assumption that the experienced practitioner possesses greater dexterity and psychomotor ability than the novice student. We also made the assumption that the groups are similar and that various confounders are controlled or that randomisation would sufficiently balance these factors. However, this may not be the case. The general dexterity of the experienced practitioner may not be better; superior performance may be limited to specific tasks only. Furthermore, the groups may not have been similar enough, with a number of extraneous characteristics either not realised or sufficiently controlled. This could explain the large variability on test outcomes and less statistical differences identified between the groups than expected. Alternatively, the tests may not be sufficiently sensitive to the performance differences. Every effort was made to measure or control for suspected confounding variables including history of musical instrument or computer game use, physical size (measured as height), location of study, or age.

Whilst significant differences were observed between the groups on some outcome variables from the tests of dexterity, there were considerably less than expected. Where differences were found, many were in the opposite direction to what had been hypothesised, although this was predominantly for grip-lift measures and may still be characteristic of a podiatric population. In fact, results could be explained when considering elements important for scalpel use, but not general dexterity. The logistic regression showed a reasonable proportion of group membership could be explained by

the tests. However, when considering the test variance only a small proportion could be explained. Surprisingly, the test best suited to group differentiation statistically was the AsTex® sensory test. The subsequent effect size was quite small though, suggesting that this would not be useful for our purpose.

The self-reported measures relating to scalpel use as measured with the IMI also showed significant group differences. These were consistent with the hypothesis, whereby experienced podiatrists displayed significantly greater self-efficacy (Perceived Competence) but significantly lower motivation (Effort/ Importance) and anxiety (Pressure/ Tension). Self-reported measures are less than ideal as they are subject to participant response bias and other issues. Thus, when we were provided an opportunity to re-evaluate the novice podiatry students after a minimum period of six months, we felt it would add to the validity of the IMI in evaluating this cohort and provide greater insight into the expected response. Over this period we observed a statistically significant increase in self-efficacy (Perceived Competence) and decrease in anxiety (Pressure/ Tension). The motivation (effort/ importance) did not change. This is consistent with the expected response.

The cross-sectional study highlighted the need to be careful of the relationship between podiatric experience, task performance and dexterity. Each concept is different, although in some cases the difference is subtle. However, from this it seems that performance with a scalpel is not generalisable to performance on other tasks, which is consistent with the theory that when perceptual learning involves a change to early perceptual processes, there will be less generalisation of the learning to other tasks (Goldstone 1998). Thus, we were not seeing the expected performance improvements in the experienced podiatrists on the battery of tests. This challenges our concept of general dexterity. Being good at one specific task involving the hand does not seem to mean that you have good dexterity and are consequently good at all hand-based tasks comprising similar elements. Further research involving modern brain imaging techniques may provide further insight to this.

It is likely that experience is represented by features other than just good dexterity. Jackson and Farrow (2005) write that when comparing experts and novices (in the sporting realm) improved task performance is due to improvements in the software (i.e. programming and processing), not the hardware (body movements). For example,

experienced sports people will not necessary show improvements in a reaction time test (i.e. have good reflexes), but will show improvements in anticipatory responses from various cues (i.e. will read cues and start moving towards the correct location to make a return stroke in tennis). This might explain why we see improvements in scalpel debridement but not tests of fine motor ability; because experienced podiatrists are better at interpreting the cues. Thus, it could be that for scalpel use, use-dependent plasticity and error-based learning enables rapid improvements in motor performance reaching expert levels rapidly, but it is the perceptual components such as interpretation of relevant cues which lag behind, giving us the observable differences in skill.

If these perceptual changes do play a role in expert performance, then presumably active sensory awareness training (such as Feldenkrais ATM) would provide some sort of training benefit, assuming that perceptual learning were able to generalise across tasks. The final study was proposed to investigate this. The underlying premise for the study was that the complete sensorimotor system, including sensory, cognitive and motor elements, in line with the current DST of motor learning, contributed to motor performance. By targeting the sensory-perceptual system we could positively influence motor learning and improve performance. We already had evidence that Feldenkrais ATM as an active sensory awareness technique provided improvement in task performance after a single session (Bitter, Hillier & Civetta 2011). Thus, the randomised controlled trial was planned to compare active sensory awareness training with current teaching methods and an additional intervention group which undertook additional motor practice. The additional Motor group would provide a milestone for comparison, as the evidence for improvements in motor performance after motor practice was strong and it could off-set any observed change in the Sensory group resulting solely from the Hawthorne effect. In addition to general tests of dexterity, the modified IMI, as used previously, was included to capture any potential change in self-efficacy, motivation or anxiety which could influence motor learning.

The randomised control trial on novice podiatry students was performed in two locations, UniSA and QUT. This was a pragmatic decision to minimise costs, maximise on student familiarity with the researcher or supervisors and provided greater program similarity than some of the other universities.

The tests chosen for inclusion were based on the original study which acted as the impetus for the study (Bitter, Hillier & Civetta 2011) and from the earlier cross-sectional study. Despite the AsTex® contributing significantly to the group categorisation, differences were small, testing had proved somewhat problematic, and it was therefore excluded.

From the selected measures of dexterity, there were almost no significant performance changes between the sensory training group, motor practice group or control group over the intervention period. Surprisingly this included Pressure/ Tension, a factor which had already demonstrated change with the learning of scalpel skills (Chapter 5).

As discussed in Chapter 6, Section 6.4, the biggest threats to the study were the lack of participant blinding and therefore potential for cross-contamination, together with diminished engagement and participant compliance. Due to the involvement of staff members in the project and data collection, the students involved in the study may have felt the need to artificially inflate the amount of sensory training or motor practice undertaken. A more prescriptive arrangement and an objective measure of time spent practising may have overcome this issue. With additional resources, face-to-face sensory awareness training could have been provided to participants, which may have overcome the issue of engagement.

Wong et al. (2012) found that passive proprioceptive demonstration of a particular task (circle drawing) improved motor learning. This included improvements in the cross-correlation between target and actual position, absolute position error and movement velocity. This suggests that proprioceptive training, such as guiding the student passively through the desired trajectories may be another strategy worth investigating and provide a safer alternative for scalpel learning.

Ives (2003) outline that there appears to be greater benefits on psychological rather than physiological measures for Feldenkrais ATM. Despite this, there were no changes in self-reported psychological measures. However, evidence suggests that future developments in scalpel learning relating to podiatry may need to include strategies to better address the psychological aspects.

The results provided by this thesis emphasise the complexity of psychomotor learning and performance evaluation, however it appears that it is important for the training of

scalpel skills to continue to be task specific. As costs decrease, the potential for virtual reality trainers similar to those used in medical training should be evaluated. These would also provide objective task-specific measures which may further enable us to determine threshold skill levels and identify poor performers early. It is clear that caution should be taken when using generalised measures of dexterity when relating to a healthy health professional population. Additionally, further research needs to be undertaken to determine what factors contribute to students struggling with aspects of motor learning. Once these are better understood, it may be that we can better evaluate suggested strategies for managing poor performers and their ability to learn scalpel skills as this may differ from a normal learner.

We recommend that in the teaching of scalpel skills, an evidence-based approach is adopted capitalising upon the known benefits of feedback, autonomy, externalisation of movement and working in pairs. Students should be instructed via multiple methods, which take into account self-efficacy, anxiety and motivation, and include elements of perceptual learning. In particular, students who struggle should trial sensory awareness training as a safer alternative; however, this may not suit all students. Practice should be task specific and incorporate elements of autonomy. GDTs should not be used as an indication of podiatric ability, instead further research needs to be undertaken to identify objective measures of podiatric tasks.

In addition to the future directions already mentioned, considerations for future research include expanding the understanding of scalpel training to the global level and incorporating multiple professions as a purposive sampling strategy, with the ultimate aim of establishing evidence-based guidelines. This would further establish the factors contributing to poor performance by struggling students. A useful addition to evaluating poor performance and establish practice guidelines would be to establish base thresholds for each of the phases of learning scalpel skills and required timelines. Further research into scalpel training should evaluate the student perspective and consider how to increase motivation and self-efficacy, and decrease associated anxiety. Emerging technologies, such as VR, need to be rigorously evaluated as potential methods to address these and other factors contributing to motor learning, particularly considering the increased affordability of such technologies.

A number of changes should be considered for further evaluation of the application of active sensory awareness training. This would include, specific targeting of poor-performers or learners who have a particular aptitude to this style of learning. In light of the evidence that exists for student autonomy regarding practice and feedback, student choice regarding their preferred learning method may be important and improve learner engagement. Sensory and motor training should utilise increased fidelity through the provision of one-to-one Feldenkrais ATM and via set supervised motor practice. Where possible, this research should incorporate blinding of participants as well as researchers, to prevent cross-contamination. Finally, to measure change and impact of different training methods, testing should be undertaken subsequent to the highly variable early error-based learning period and consider only retention testing as the proxy of motor learning.

This study adds to the growing body of literature in motor learning, in particular to the role of active sensory and perceptual training of complex motor skills.

8. References

Accreditation Standards for Podiatry Programs for Australia and New Zealand v1.1, 2009, Australian and New Zealand Podiatry Accreditation Council, Victoria, Australia.

Ackerman, PL 1988, 'Determinants of individual differences during skill acquisition: Cognitive abilities and information processing', *Journal of Experimental Psychology,* vol. 117, no. 3, pp. 288-318.

Ackerman, PL 1992, 'Predicting individual differences in complex skill acquisition: Dynamics of ability determinants', *Journal of Applied Psychology,* vol. 77, no. 5, pp. 598-614.

Ackerman, PL & Cianciolo, AT 2000, 'Cognitive, perceptual-speed, and psychomotor determinants of individual differences during skill acquisition', *Journal of Experimental Psychology: Applied,* vol. 6, no. 4, pp. 259-290.

Adams, JA 1971, 'A closed-loop theory of motor learning', *Journal of Motor Behavior,* vol. 3, no. 2, June, pp. 111-149.

Adams, JA 1987, 'Historical review and appraisal of research on the learning, retention, and transfer of human motor skills', *Psychological Bulletin,* vol. 101, no. 1, pp. 41-74.

Aftanas, MS & Royce, JR 1969, 'A factor analysis of brain damage tests administered to normal subjects with factor score comparisons across ages', *Multivariate Behavioural Research,* vol. 4, no. 4, pp. 459-481.

Agnew, J, Bolla-Wilson, K, Kawas, CH & Bleecker, ML 1988, 'Purdue Pegboard age and sex norms for people 40 years old and older', *Developmental Neuropsychology,* vol. 4, no. 1, pp. 29-35.

Akram, A, Ullah, R, Bashir, M, Sarwar, A, Dickson, M & Hodge, P 2008, 'Assessing manual dexterity in the BDS curriculum, *The Pan European Federation of the International Association for Dental Research Conference*, London, UK, September 10-12, 2008.

Anastakis, DJ, Regehr, G, Reznick, RK, Cusimano, M, Murnaghan, J, Brown, M & Hutchison, C 1999, 'Assessment of technical skills transfer from the bench training model to the human model', *The American Journal of Surgery,* vol. 177, no. 2, pp. 167-170.

Anderson, BO, Sun, JH, Moore, EE, Thompson, LL, Harkin, AH & Bartle, EJ 1989, 'The development and evaluation of a clinical test of surgical resident proficiency', *British Journal of Surgery,* vol. 106, no. 2, Aug, pp. 347-352.

Andres, FG, Mima, T, Schulman, AE, Dichgans, J, Hallett, M & Gerloff, C 1999, 'Functional coupling of human cortical sensorimotor areas during bimanual skill acquisition', *Brain*, vol. 122, no. 5, pp. 855-870.

Arceneaux, JM, Kirkendall, DJ, Hill, SK, Dean, RS & Anderson, JL 1997, 'Validity and reliability of rapidly alternating movement tests', *International Journal of Neuroscience,* vol. 89, no. 3/4, p. 281.

Arora, S, Aggarwal, R, Sirimanna, P, Moran, A, Grantcharov, T, Kneebone, R, Sevdalis, N & Darzi, A 2011, 'Mental practice enhances surgical technical skills: a randomized controlled study', *Annals of Surgery,* vol. 253, no. 2, February, pp. 265-270.

Ashford, D, Bennett, SJ & Davids, K 2006, 'Observational modeling effects for movement dynamics and movement outcome measures across differing task constraints: A meta-analysis', *Journal of Motor Behavior,* vol. 38, no. 3, pp. 185-205.

Ayalon, RD & Friedman, F, Jr. 2008, 'The effect of sleep deprivation on fine motor coordination in obstetrics and gynecology residents', *American Journal of Obstetrics and Gynecology,* vol. 199, no. 5, Nov, pp. 576e571- 576e575.

Babcock, H & Emerson, MR 1938, 'An analytical study of the MacQuarrie Test for mechanical ability', *Journal of Educational Psychology,* vol. 29, no. 1, January, pp. 50-55.

Bachman, K 1990, 'Using mental imagery to practice a specific psychomotor skill', *Journal of Continuing Education in Nursing,* vol. 21, no. 3, May-June, pp. 125-128.

Badami, R, VaezMousavi, M, Wulf, G & Namazizadeh, M 2011, 'Feedback after good versus poor trials affects intrinsic motivation', *Research Quarterly for Exercise and Sport,* vol. 82, no. 2, June, pp. 360-364.

Bak, JS & Greene, RL 1980, 'Changes in neuropsychological functioning in an aging population', *Journal of Consulting and Clinical Psychology,* vol. 48, no. 3, June, pp. 395-399.

Balasundaram, I, Aggarwal, R & Darzi, LA 2010, 'Development of a training curriculum for microsurgery', *The British Journal of Oral and Maxillofacial Surgery,* vol. 48, no. 8, December, pp. 598-606.

Baldwin, D, Hill, P & Hanson, G 1991, 'Performance of psychomotor skills: a comparison of two teaching strategies', *The Journal of Nursing Education,* vol. 30, no. 8, October, pp. 367-370.

Bandura, A 1991, 'Perceived self-efficacy in cognitive development and functioning', *Educational Psychologist,* vol. 28, no. 2, pp. 117-148.

Bandura, A 1997, *Self-efficacy: the exercise of control*, Worth Publishers, New York.

Bandura, A & Locke, EA 2003, 'Negative self-efficacy and goal effects revisited', *Journal of applied psychology* vol. 88, no. 1, February, pp. 87-99.

Barnsley, RH & Rabinovitch, MS 1970, 'Handedness: Proficiency versus stated preference', *Perceptual and Motor Skills,* vol. 30, no. 2, pp. 343-362.

Bartels, C, Wegrzyn, M, Wiedl, A, Ackermann, V & Ehrenreich, H 2010, 'Practice effects in healthy adults: a longitudinal study on frequent repetitive cognitive testing', *BMC Neuroscience*, vol. 11, p. 118.

Bass, BM & Stucki, RM 1951, 'A note on a modified Purdue Pegboard', *Journal of Applied Psychology*, vol. 35, pp. 312-313.

Bate, P 1994, 'Motor control theory: A possible framework for the Feldenkrais Method', *The Feldenkrais Journal*, vol. 9, pp. 1-15.

Bear-Lehman, J & Abreu, BC 1989, 'Evaluating the hand: Issues in reliability and validity', *Physical Therapy*, vol. 69, no. 12, December, pp. 1025-1033.

Belen'kii, VE, Gurfinkel, VS & Pal'tsev, EI 1967, 'Control elements of voluntary movements', *Biofizika*, vol. 12, no. 1, January-February, pp. 135-141.

Bernstein, NA 1967, *The co-ordination and regulation of movements*, Pergamon Press, New York.

Berti, A & Pia, L 2006, 'Understanding motor awareness through normal and pathological behavior', *Current Directions in Psychological Science*, vol. 15, no. 5, October, pp. 245-250.

Bezdicek, O, Nikolai, T, Hoskovcová, M, Štochl, J, Brožová, H, Dušek, P, Zárubová, K, Jech, R & Růžička, E 2014, 'Grooved Pegboard predicates more of cognitive than motor involvement in Parkinson's disease', *Assessment*, vol. 21, no. 6, March, pp. 723-730.

Bhushan, N & Shadmehr, R 1999, 'Computational nature of human adaptive control during learning of reaching movements in force fields', *Biological Cybernetics*, vol. 81, no. 1, pp. 39-60.

Bitter, F, Hillier, S & Civetta, L 2011, 'Change in dexterity with sensory awareness training: A randomised controlled trial', *Perceptual and Motor Skills*, vol. 112, no. 3, June, pp. 783-798.

Bittner Jr, AC, Echeverria, D, Woods, JS, Aposhian, HV, Naleway, C, Martin, MD, Mahurin, RK, Heyer, NJ & Cianciola, M 1998, 'Behavioral effects of low-level exposure to Hg0 among dental professionals: A cross-study evaluation of psychomotor effects', *Neurotoxicology and Teratology*, vol. 20, no. 4, July, pp. 429-439.

Boekaerts, M 1996, 'Self-regulated learning at the junction of cognition and motivation', *European Psychologist*, vol. 1, no. 2, June, pp. 100-112.

Bornstein, RA 1985, 'Normative data on selected neuropsychological measures from a nonclinical sample', *Journal of Clinical Psychology*, vol. 41, no. 5, pp. 651-659.

Bornstein, RA 1986, 'Normative data on intermanual differences on three tests of motor performance', *Journal of Clinical and Experimental Neuropsychology*, vol. 8, no. 1, January, pp. 12-20.

Bornstein, RA, Baker, GB & Douglass, AB 1987, 'Short-term retest reliability of the Halstead-Reitan Battery in a normal sample', *The Journal of Nervous and Mental disease*, vol. 175, no. 4, Apr, pp. 229-232.

Bornstein, RA & Suga, LJ 1988, 'Educational level and neuropsychological performance in healthy elderly subjects', *Developmental Neuropsychology*, vol. 4, no. 1, pp. 17-22.

Bosshardt, MJ 1988, *Utility of psychomotor tests for prediction of Navy enlisted performance*, Navy Personnel Research and Development Center, San Diego, California.

Bouisset, S & Zattara, M 1981, 'A sequence of postural movements precedes voluntary movement', *Neuroscience letters,* vol. 22, no. 3, pp. 263-270.

Bourassa, GL & Guion, RM 1959, 'A factorial study of dexterity tests', *Journal of Applied Psychology,* vol. 43, no. 3, pp. 199-204.

Boutin, A, Blandin, Y, Massen, C, Heuer, H & Badets, A 2014, 'Conscious awareness of action potentiates sensorimotor learning', *Cognition,* vol. 133, no. 1, October, pp. 1-9.

Boyce, BA 1992, 'Effects of assigned versus participant-set goals on skill acquisition and retention of a selected shooting task', *Journal of Teaching in Physical Education,* vol. 11, no. 3, pp. 220-234.

Boyd, LA & Winstein, CJ 2001, 'Implicit motor-sequence learning in humans following unilateral stroke: the impact of practice and explicit knowledge', *Neuroscience Letters,* vol. 298, no. 1, pp. 65-69.

Boyle, AM & Santelli, JC 1986, 'Assessing psychomotor skills: the role of the Crawford Small Parts Dexterity Test as a screening instrument', *Journal of Dental Education,* vol. 50, no. 3, March, pp. 176-179.

Bradshaw, A 1998, 'Defining 'competency' in nursing (Part II): An analytical review', *Journal of Clinical Nursing* vol. 7, no. 2, March, pp. 103-111.

Brashers-Krug, T, Shadmehr, R & Bizzi, E 1996, 'Consolidation in human motor memory', *Nature,* vol. 382, no. 6588, pp. 252-255.

Braun, DA, Aertsen, A, Wolpert, DM & Mehring, C 2009, 'Motor task variation induces structural learning', *Current Biology,* vol. 19, no. 4, pp. 352-357.

Breitenstein, SM, Gross, D, Garvey, CA, Hill, C, Fogg, L & Resnick, B 2010, 'Implementation fidelity in community- based interventions', *Research in Nursing & Health,* vol. 33, no. 2, pp. 164-173.

Brito, GN & Santos-Morales, TR 2002, 'Developmental norms for the Gardner Steadiness Test and the Purdue Pegboard: a study with children of a metropolitan school in Brazil', *Brazilian Journal of Medical and Biological Research,* vol. 35, no. 8, August, pp. 931-949.

Brogårdh, C, Johansson, F, Nygren, F & Sjölund, B 2010, 'Mode of hand training determines cortical reorganisation: A randomized controlled study in healthy adults', *Journal of Rehabilitation Medicine,* vol. 42, no. 8, pp. 789-794.

Bryden, PJ & Roy, EA 2005a, 'A new method of administering the Grooved Pegboard Test: Performance as a function of handedness and sex', *Brain and Cognition,* vol. 58, no. 3, pp. 258-268.

Bryden, PJ & Roy, EA 2005b, 'Unimanual performance across the age span', *Brain and Cognition,* vol. 57, no. 1, February, pp. 26-29.

Brydges, R, Carnahan, H, Backstein, D & Dubrowski, A 2007, 'Application of motor learning principles to complex surgical tasks: Searching for the optimal practice schedule', *Journal of Motor Behavior,* vol. 39, no. 1, pp. 40-48.

Buccino, G, Vogt, S, Ritzl, A, Fink, GR, Zilles, K, Freund, H-J & Rizzolatti, G 2004, 'Neural circuits underlying imitation learning of hand actions: an event-related fMRI study', *Neuron*, vol. 42, no. 2, pp. 323-334.

Buchanan, JJ & Wang, C 2012, 'Overcoming the guidance effect in motor skill learning: feedback all the time can be beneficial', *Experimental Brain Research*, vol. 219, no. 2, June, pp. 305-320.

Buchanan, PA & Ulrich, BD 2001, 'The Feldenkrais method: A dynamic approach to changing motor behavior', *Research Quarterly for Exercise and Sport*, vol. 72, no. 4, p. 315.

Buddenberg, LA & Davis, C 2000, 'Test-retest reliability of the Purdue Pegboard test', *American Journal of Occupational Therapy*, vol. 54, no. 5, September-October, pp. 555-558.

Buffington, CW, MacMurdo, SD & Ryan, CM 2006, 'Body position affects manual dexterity', *Anesthesia and analgesia*, vol. 102, no. 6, June, pp. 1879-1883.

Burr, M 1934, 'The Macquarrie Test for Manual Ability: An experiment in a nursing school', *American Journal of Nursing*, vol. 34, no. 4, April, pp. 378-381.

Byl, NN, Nagajaran, S & McKenzie, AL 2003, 'Effect of sensory discrimination training on structure and function in patients with focal hand dystonia: a case series', *Archives of Physical Medicine and Rehabilitation*, vol. 84, no. 10, pp. 1505-1514.

Byl, NN, Roderick, J, Mohamed, O, Hanny, M, Kotler, J, Smith, A, Tang, M & Abrams, G 2003, 'Effectiveness of sensory and motor rehabilitation of the upper limb following the principles of neuroplasticity: patients stable poststroke', *Neurorehabilitation and Neural Repair*, vol. 17, no. 3, pp. 176-191.

Calvo-Merino, B, Glaser, DE, Grèzes, J, Passingham, RE & Haggard, P 2005, 'Action observation and acquired motor skills: An fMRI study with expert dancers', *Cerebral Cortex*, vol. 15, no. 8, August, pp. 1243-1249.

Calvo-Merino, B, Grèzes, J, Glaser, DE, Passingham, RE & Haggard, P 2006, 'Seeing or doing? Influence of visual and motor familiarity in action observation', *Current Biology*, vol. 16, no. 19, pp. 1905-1910.

Capa, RL, Audiffren, M & Ragot, S 2008a, 'The interactive effect of achievement motivation and task difficulty on mental effort', *International Journal of Psychophysiology*, vol. 70, no. 2, November, pp. 144-150.

Capa, RL, Audiffren, M & Ragot, S 2008b, 'The effects of achievement motivation, task difficulty, and goal difficulty on physiological, behavioral, and subjective effort', *Psychophysiology*, vol. 45, no. 5, pp. 859-868.

Carey, JR, Greer, KR, Grunewald, TK, Steele, JL, Wiemiller, JW, Bhatt, E, Nagpal, A, Lungu, O & Auerbach, EJ 2006, 'Primary motor area activation during precision-demanding versus simple finger movement', *Neurorehabilitation and Neural Repair*, vol. 20, no. 3, September, pp. 361-370.

Casanova, JE, Barnas, GP, Gollup, J, Schmitt, S & Casanova, JS 1993, 'Hand dexterity in hospital personnel with multiple needlestick injuries', *Infection control and hospital epidemiology : the official journal of the Society of Hospital Epidemiologists of America*, vol. 14, no. 8, August, pp. 473-475.

Catalano, JF & Kleiner, BM 1984, 'Distant transfer in coincident timing as a function of variability of practice', *Perceptual and Motor Skills*, vol. 58, no. 3, pp. 851-856.

Catmur, C, Walsh, V & Heyes, C 2007, 'Sensorimotor learning configures the human mirror system', *Current Biology*, vol. 17, no. 17, pp. 1527-1531.

Cattaneo, L, Fabbri-Destro, M, Boria, S, Pieraccini, C, Monti, A, Cossu, G & Rizzolatti, G 2007, 'Impairment of actions chains in autism and its possible role in intention understanding', *Proceedings of the National Academy of Sciences*, vol. 104, no. 45, pp. 17825-17830.

Cattaneo, L & Rizzolatti, G 2009, 'The mirror neuron system', *Archives of Neurology* vol. 66, no. 5, May, pp. 557-560.

Causby, RS, Reed, L, McDonnell, MN & Hillier, S 2014, 'Use of objective psychomotor tests in health professionals', *Perceptual and Motor Skills* vol. 118, no. 3, pp. 765-804.

Chapman, RL 1948, 'The MacQuarrie Test for Mechanical Ability', *Psychometrika*, vol. 13, no. 3, pp. 175-179.

Chen, G, Gully, SM, Whiteman, JA & Kilcullen, RN 2000, 'Examination of relationships among trait-like individual differences, state-like individual differences, and learning performance', *Journal of Applied Psychology* vol. 85, no. 6, December, pp. 835-847.

Cheng, Y, Meltzoff, AN & Decety, J 2007, 'Motivation modulates the activity of the human mirror-neuron system', *Cerebral Cortex*, vol. 17, no. 8, pp. 1979-1986.

Chiviacowsky, S & Wulf, G 2002, 'Self-controlled feedback: does it enhance learning because performers get feedback when they need it?', *Research Quarterly for Exercise and Sport*, vol. 73, no. 4, December, pp. 408-415.

Chiviacowsky, S & Wulf, G 2005, 'Self-controlled feedback is effective if it is based on the learner's performance', *Research Quarterly for Exercise and Sport*, vol. 76, no. 1, March, pp. 42-48.

Chiviacowsky, S & Wulf, G 2007, 'Feedback after good trials enhances learning', *Research Quarterly for Exercise and Sport*, vol. 78, no. 2, March, pp. 40-47.

Chiviacowsky, S, Wulf, G & Lewthwaite, R 2012, 'Self-controlled learning: the importance of protecting perceptions of competence', *Frontiers in Psychology*, vol. 3, p. 458.

Cirillo, J, Todd, G & Semmler, JG 2011, 'Corticomotor excitability and plasticity following complex visuomotor training in young and old adults', *European Journal of Neuroscience*, vol. 34, no. 11, pp. 1847-1856.

Clark, JA & King, GF 1960, 'Perceptual and motor speed in an extended age group: A factor analysis', *Perceptual and Motor Skills* vol. 11, no. 2, pp. 99-102.

Classen, J, Liepert, J, Wise, SP, Hallett, M & Cohen, LG 1998, 'Rapid plasticity of human cortical movement representation induced by practice', *Journal of Neurophysiology*, vol. 79, no. 2, February, pp. 1117-1123.

Clevin, L & Grantcharov, TP 2008, 'Does box model training improve surgical dexterity and economy of movement during virtual reality laparoscopy? A randomised trial', *Acta Obstetricia et Gynecologica Scandinavica*, vol. 87, no. 1, pp. 99-103.

Cole, KJ 1991, 'Grasp force control in older adults', *Journal of Motor Behavior,* vol. 23, no. 4, December, pp. 251-258.

Cole, KJ & Beck, CL 1994, 'The stability of precision grip force in older adults', *Journal of Motor behavior,* vol. 26, no. 2, pp. 171-177.

Cole, KJ, Rotella, DL & Harper, JG 1999, 'Mechanisms for age-related changes of fingertip forces during precision gripping and lifting in adults', *The Journal of Neuroscience,* vol. 19, no. 8, April, pp. 3238-3247.

Colquitt, JA, LePine, JA & Noe, RA 2000, 'Toward an integrative theory of training motivation: a meta-analytic path analysis of 20 years of research', *Journal of Applied Psychology,* vol. 85, no. 5, Oct, pp. 678-707.

Conditt, MA, Gandolfo, F & Mussa-Ivaldi, FA 1997, 'The motor system does not learn the dynamics of the arm by rote memorization of past experience', *Journal of Neurophysiology,* vol. 78, no. 1, pp. 554-560.

Connors, KA, Galea, MP, Said, CM & Remedios, LJ 2010, 'Feldenkrais Method balance classes are based on principles of motor learning and postural control retraining: a qualitative research study', *Physiotherapy,* vol. 96, no. 4, December, pp. 324-336.

Connors, KA, Pile, C & Nichols, ME 2011, 'Does the Feldenkrais Method make a difference? An investigation into the use of outcome measurement tools for evaluating changes in clients', *Journal of Bodywork and Movement Therapies,* vol. 15, no. 4, October, pp. 446-452.

Cook, DA & Beckman, TJ 2006, 'Current concepts in validity and reliability for psychometric instruments: Theory and application', *The American Journal of Medicine,* vol. 119, no. 2, pp. 166.e167–166.e116.

Cordo, P & Nashner, LM 1982, 'Properties of postural adjustments associated with rapid arm movements', *Journal of Neurophysiology,* vol. 47, no. 2, pp. 287-302.

Corlett, EN, Salvendy, G & Seymour, WD 1971, 'Selecting operators for fine manual tasks: A study of the O'Connor Finger Dexterity Test and the Purdue Pegboard', *Occupational Psychology,* vol. 45, no. 1, pp. 57-65.

Coy, K, McDougall, H & Sneed, M 2003, 'Issues regarding practical validity and gender bias of the Perceptual Abilities Test (PAT)', *Journal of Dental Education,* vol. 67, no. 1, pp. 31-37.

Crawford, JE & Crawford, DM 1956, *Crawford Small Parts Dexterity Test: Manual,* Psychological Corporation, San Antonio, TX, 1956.

Cressman, EK & Henriques, DY 2009, 'Sensory recalibration of hand position following visuomotor adaptation', *Journal of Neurophysiology,* vol. 102, no. 6, pp. 3505-3518.

Cross, ES, Hamilton, AFdC & Grafton, ST 2006, 'Building a motor simulation de novo: observation of dance by dancers', *Neuroimage,* vol. 31, no. 3, pp. 1257-1267.

Crump, MJ & Logan, GD 2010, 'Episodic contributions to sequential control: learning from a typist's touch', *Journal of Experimental Psychology: Human Perception and Performance,* vol. 36, no. 3, p. 662.

Curran, T & Keele, SW 1993, 'Attentional and nonattentional forms of sequence learning', *Journal of Experimental Psychology: Learning, Memory, and Cognition,* vol. 19, no. 1, p. 189.

Darainy, M, Vahdat, S & Ostry, DJ 2013, 'Perceptual learning in sensorimotor adaptation', *Journal of Neurophysiology*, vol. 110, no. 9, pp. 2152-2162.

Data capacity and clinical placements across Australia: A discussion paper, 2008, Taskforce, NHW, National Health Workforce Taskforce, Melbourne, Victoria.

Davies, C, Mecrow, I & White, M 1982, 'Contractile properties of the human triceps surae with some observations on the effects of temperature and exercise', *European Journal of Applied Physiology and Occupational Physiology*, vol. 49, no. 2, pp. 255-269.

Dayan, E & Cohen, Leonardo G 2011, 'Neuroplasticity subserving motor skill learning', *Neuron*, vol. 72, no. 3, March, pp. 443-454.

De Andrés, AG, Sánchez, E, Hidalgo, JJ & Díaz, MJ 2004, 'Appraisal of psychomotor skills of dental students at University Complutense of Madrid', *European Journal of Dental Education*, vol. 8, no. 1, pp. 24-30.

Decety, J 1996a, 'The neurophysiological basis of motor imagery', *Behavioral Brain Research*, vol. 77, no. 1-2, May 1996, pp. 45-52.

Decety, J 1996b, 'Do imagined and executed actions share the same neural substrate?', *Cognitive brain research*, vol. 3, no. 2, pp. 87-93.

Decety, J, Grèzes, J, Costes, N, Perani, D, Jeannerod, M, Procyk, E, Grassi, F & Fazio, F 1997, 'Brain activity during observation of actions. Influence of action content and subject's strategy', *Brain*, vol. 120, no. 10, October, pp. 1763-1777.

Deci, EL, Koestner, R & Ryan, RM 1999, 'A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation', *Psychological Bulletin*, vol. 125, no. 6, November, pp. 627-668.

Del Rey, P, Wughalter, EH & Whitehurst, M 1982, 'The effects of contextual interference on females with varied experience in open sport skills', *Research Quarterly for Exercise and Sport*, vol. 53, no. 2, pp. 108-115.

Del Rey, P, Whitehurst, M & Wood, JM 1983, 'Effects of experienced and contextual interference on learning and transfer by boys and girls', *Perceptual and Motor Skills*, vol. 56, no. 2, pp. 581-582.

Demura, S, Tada, N, Matsuzawa, J, Mikami, H, Ohuchi, T, Shirane, H, Nagasawa, Y & Uchiyama, M 2006, 'The influence of gender, athletic events, and athletic experience on the subjective dominant hand and the determination of the dominant hand based on the laterality quotient (LQ) and the validity of the LQ', *Journal of Physiological Anthropology*, vol. 25, no. 5, September, pp. 321-329.

Desrosiers, J, Hébert, R, Bravo, G & Dutil, E 1995, 'The Purdue Pegboard Test: Normative data for people aged 60 and over', *Disability & Rehabilitation*, vol. 17, no. 5, pp. 217-224.

Desrosiers, J, Rochette, A, Hebert, R & Bravo, G 1997, 'The Minnesota Manual Dexterity Test: Reliability, validity and reference values studies with healthy elderly people', *Canadian Journal of Occupational Therapy*, vol. 64, no. 5, pp. 270-276.

Deubert, LW, Smith, MC, Jenkins, CB & Berry, DC 1975, 'The selection of dental students. A pilot study of an assessment of potential manual ability by psychometric tests', *British Dental Journal,* vol. 139, no. 5, September, pp. 167-170.

Diedrichsen, J, White, O, Newman, D & Lally, N 2010, 'Use-dependent and error-based learning of motor behaviors', *The Journal of Neuroscience,* vol. 30, no. 15, pp. 5159-5166.

Dikmen, SS, Heaton, RK, Grant, I & Temkin, NR 1999, 'Test-retest reliability and practice effects of expanded Halstead-Reitan neuropsychological test battery', *Journal of the International Neuropsychological Society,* vol. 5, no. 4, pp. 346-356.

Dinse, HR, Kalisch, T, Ragert, P, Pleger, B, Schwenkreis, P & Tegenthoff, M 2005, 'Improving human haptic performance in normal and impaired human populations through unattended activation-based learning', *ACM Transactions on Applied Perception,* vol. 2, no. 2, pp. 71-88.

Dodrill, CB & Troupin, AS 1975, 'Effects of repeated administrations of a comprehensive neuropsychological battery among chronic epileptics', *The Journal of Nervous and Mental Disease,* vol. 161, no. 3, September, pp. 185-190.

Doheny, MO 1993, 'Mental practice: an alternative approach to teaching motor skills', *The Journal of Nursing Education,* vol. 32, no. 6, June, pp. 260-264.

Donovan, JJ & Radosevich, DJ 1999, 'A meta-analytic review of the distribution of practice effect: Now you see it, now you don't', *Journal of Applied Psychology,* vol. 84, no. 5, pp. 795-805.

Downe-Wamboldt, B 1992, 'Content analysis: method, applications, and issues', *Health Care for Women International* vol. 13, no. 3, July-September, pp. 313-321.

Doyen, A-L & Carlier, M 2002, 'Measuring handedness: A validation study of Bishop's reaching card test', *Laterality: Asymmetries of Body, Brain and Cognition,* vol. 7, no. 2, April, pp. 115-130.

Drabek, T, Boucek, CD & Buffington, CW 2010, 'Wearing the wrong size latex surgical gloves impairs manual dexterity', *Journal of Occupational & Environmental Hygiene,* vol. 7, no. 3, March, pp. 152-155.

Duque, J, Thonnard, JL, Vandermeeren, Y, Sebire, G, Cosnard, G & Olivier, E 2003, 'Correlation between impaired dexterity and corticospinal tract dysgenesis in congenital hemiplegia', *Brain,* vol. 126, no. Pt 3, March, pp. 732-747.

Eads, J, Moseley, GL & Hillier, S 2015, 'Non-informative vision enhances tactile acuity: A systematic review and meta-analysis', *Neuropsychologia,* vol. 75, pp. 179-185.

Eckardt, MJ & Matarazzo, JD 1981, 'Test-retest reliability of the halstead impairment index in hospitalized alcoholic and nonalcoholic males with mild to moderate neuropsychological impairment', *Journal of Clinical Neuropsychology,* vol. 3, no. 3, pp. 257-269.

Elias, MF, Podraza, AM, Pierce, TW & Robbins, MA 1990, 'Determining neuropsychological cut scores for older, healthy adults', *Experimental aging research,* vol. 16, no. 4, pp. 209-220.

Elias, MF, Robbins, MA, Walter, LJ & Schultz, NR, Jr. 1993, 'The influence of gender and age on Halstead-Reitan neuropsychological test performance', *Journal of Gerontology,* vol. 48, no. 6, Nov, pp. P278-281.

Elliott, D, Grierson, LEM, Hayes, SJ & Lyons, J 2011, 'Action representations in perception, motor control and learning: implications for medical education', *Medical Education,* vol. 45, no. 2, pp. 119-131.

Elo, S & Kyngäs, H 2008, 'The qualitative content analysis process', *Journal of Advanced Nursing,* vol. 62, no. 1, pp. 107-115.

Ernst, E & Canter, P 2005, 'The Feldenkrais Method-A systematic review of randomised clinical trials', *Physikalische Medizin Rehabilitationsmedizin Kurortmedizin,* vol. 15, no. 3, pp. 151-156.

Ernst, MO & Bülthoff, HH 2004, 'Merging the senses into a robust percept', *Trends in Cognitive Sciences,* vol. 8, no. 4, pp. 162-169.

Fadiga, L, Fogassi, L, Pavesi, G & Rizzolatti, G 1995, 'Motor facilitation during action observation: a magnetic stimulation study', *Journal of Neurophysiology,* vol. 73, no. 6, June, pp. 2608-2611.

Fagan, D, Swift, CG & Tiplady, B 1988, 'Effects of caffeine on vigilance and other performance tests in normal subjects', *Journal of Psychopharmacology,* vol. 2, no. 1, January, pp. 19-25.

Fahle, M 2005, 'Perceptual learning: specificity versus generalization', *Current Opinion in Neurobiology,* vol. 15, no. 2, pp. 154-160.

Ferrari, PF, Bonini, L & Fogassi, L 2009, 'From monkey mirror neurons to primate behaviours: possible 'direct' and 'indirect' pathways', *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* vol. 364, no. 1528, August, pp. 2311-2323.

Fess, EE 1986, 'The need for reliability and validity in hand assessment instruments', *The Journal of Hand Surgery,* vol. 11, no. 5, September, pp. 621-623.

Fitts, PM & Posner, MI 1967, *Human performance,* Brooks-Cole, Belmont CA.

Flavel, SC, Koch, JD, White, JM & Todd, G 2012, 'Illicit stimulant use in humans is associated with a long-term increase in tremor', *PLoS One,* vol. 7, no. 12, p. e52025.

Flavel, SC, White, JM & Todd, G 2013, 'Abnormal maximal finger tapping in abstinent cannabis users', *Human Psychopharmacology: Clinical and Experimental,* vol. 28, no. 6, pp. 612-614.

Fleishman, EA 1953, 'Testing for psychomotor abilities by means of apparatus tests', *Psychological Bulletin,* vol. 50, no. 4, July, pp. 241-262.

Fleishman, EA & Hempel, WE 1954, 'A factor analysis of dexterity tests', *Personnel Psychology,* vol. 7, no. 1, 1954, pp. 15-32.

Fleishman, EA & Ellison, GD 1962, 'A factor analysis of fine manipulative tests', *Journal of Applied Psychology,* vol. 46, no. 2, pp. 96-105.

Fontani, G, Migliorini, S, Benocci, R, Facchini, A, Casini, M & Corradeschi, F 2007, 'Effect of mental imagery on the development of skilled motor actions', *Perceptual and Motor Skills,* vol. 105, no. 3, Dec, pp. 803-826.

Forssberg, H, Eliasson, AC, Kinoshita, H, Johansson, RS & Westling, G 1991, 'Development of human precision grip. I: Basic coordination of force', *Experimental Brain Research* vol. 85, no. 2, pp. 451-457.

Forster, FM & Shields, CD 1959, 'Cortical sensory defects causing disability', *Archives of Physical Medicine and Rehabilitation,* vol. 40, no. 2, March, pp. 56-61

Fourneret, P & Jeannerod, M 1998, 'Limited conscious monitoring of motor performance in normal subjects', *Neuropsychologia,* vol. 36, no. 11, pp. 1133-1140.

Francis, NK, Hanna, GB, Cresswell, AB, Carter, FJ & Cuschieri, A 2001, 'The performance of master surgeons on standard aptitude testing', *American Journal of Surgery,* vol. 182, no. 1, July, pp. 30-33.

Fromm-Auch, D & Yeudall, LT 1983, 'Normative data for the Halstead-Reitan neuropsychological tests', *Journal of Clinical Neuropsychology,* vol. 5, no. 3, September, pp. 221-238.

Gallagher, AG, Leonard, G & Traynor, OJ 2009, 'Role and feasibility of psychomotor and dexterity testing in selection for surgical training', *ANZ Journal of Surgery,* vol. 79, no. 3, pp. 108-113.

Gallese, V, Fadiga, L, Fogassi, L & Rizzolatti, G 1996, 'Action recognition in the premotor cortex', *Brain,* vol. 119, no. 2, pp. 593-609.

Gansky, SA, Pritchard, H, Kahl, E, Mendoza, D, Bird, W, Miller, AJ & Graham, D 2004, 'Reliability and validity of a manual dexterity test to predict preclinical grades', *Journal of Dental Education,* vol. 68, no. 9, September, pp. 985-994.

Gentile, A 1972, 'Movement organization and delayed alternation behavior of monkeys following selective ablation of frontal cortex', *Acta Neurobiologiae Experimentalis,* vol. 32, no. 2, pp. 277-304.

Gentile, A 1987, 'Skill Acquisition: Action, movement, and neuromotor processes', in Carr, J, Shepherd, J & Gordon, J (eds), *Movement science: Foundations for physical therapy in rehabilitation,* Aspen, Rockville MD, pp. 111-187.

Ghilardi, MF, Moisello, C, Silvestri, G, Ghez, C & Krakauer, JW 2009, 'Learning of a sequential motor skill comprises explicit and implicit components that consolidate differently', *Journal of Neurophysiology,* vol. 101, no. 5, pp. 2218-2229.

Ghiselli, EE 1973, 'The validity of aptitude tests in personnel selection', *Personnel Psychology,* vol. 26, no. 4, pp. 461-477.

Gibson, HB 1964, 'The Spiral Maze. A psychomotor test with implications for the study of delinquency', *British Journal of Psychology,* vol. 55, May, pp. 219-225.

Gilbert, CD, Sigman, M & Crist, RE 2001, 'The neural basis of perceptual learning', *Neuron,* vol. 31, no. 5, pp. 681-697.

Gilbert, CD, Li, W & Piech, V 2009, 'Perceptual learning and adult cortical plasticity', *The Journal of Physiology,* vol. 587, no. 12, pp. 2743-2751.

Gill, DM, Reddon, JR, Stefanyk, WO & Hans, HS 1986, 'Finger tapping: effects of trials and sessions', *Perceptual and Motor Skills,* vol. 62, no. 2, April, pp. 675-678.

Gilles, MA & Wing, AM 2003, 'Age-Related changes in grip force and dynamics of hand movement', *Journal of Motor Behavior,* vol. 35, no. 1, March, pp. 79-85.

Gist, ME & Mitchell, TR 1992, 'Self-Efficacy: A theoretical analysis of its determinants and malleability', *The Academy of Management Review,* vol. 17, no. 2, pp. 183-211.

Giuliani, M, Lajolo, C, Clemente, L, Querqui, A, Viotti, R, Boari, A & Miani, CM 2007, 'Is manual dexterity essential in the selection of dental students?', *British Dental Journal,* vol. 203, no. 3, Aug 11, pp. 149-155.

Gluskinos, U & Brennan, TF 1971, 'Selection and evaluation procedure for operating room personnel', *Journal of Applied Psychology,* vol. 55, no. 2, pp. 165-169.

Goldberg, AE, Neifeld, JP, Wolfe, LG & Goldberg, SR 2008, 'Correlation of manual dexterity with USMLE scores and medical student class rank', *Journal of Surgical Research,* vol. 147, no. 2, June, pp. 212-215.

Goldstein, SG & Braun, LS 1974, 'Reversal of expected transfer as a function of increased age', *Perceptual and Motor Skills,* vol. 38, no. 3, June, pp. 1139-1145.

Goldstone, RL 1998, 'Perceptual learning', *Annual Review of Psychology,* vol. 49, no. 1, February, pp. 585-612.

Gölge, M, Schütz, C, Dreesmann, M, Kuhtz-Buschbeck, J, Hoppe, B, Wenzelburger, R, Stephani, U & Illert, M 2003, 'Grip force parameters in precision grip of individuals with myelomeningocele', *Developmental Medicine & Child Neurology,* vol. 45, no. 04, pp. 249-256.

Gölge, M, Müller, M, Dreesmann, M, Hoppe, B, Wenzelburger, R & Kuhtz-Buschbeck, JP 2004, 'Recovery of the precision grip in children after traumatic brain injury', *Archives of Physical Medicine and Rehabilitation,* vol. 85, no. 9, pp. 1435-1444.

Gomez, GE & Gomez, EA 1984, 'The teaching of psychomotor skills in nursing', *Nurse Educator,* vol. 9, no. 4, pp. 35-39.

Gomez, GE & Gomez, EA 1987, 'Learning of psychomotor skills: laboratory versus patient care setting', *The Journal of Nursing Education,* vol. 26, no. 1, January, pp. 20-24.

Goodman, CH 1946, 'The MacQuarrie Test for Mechanical Ability: I. Selecting radio assembly operators', *Journal of Applied Psychology,* vol. 30, no. 6, pp. 586-595.

Goodman, CH 1947, 'The MacQuarrie Test for Mechanical Ability: II. Factor analysis', *Journal of Applied Psychology,* vol. 31, no. 2, pp. 150-154.

Grafton, ST, Mazziotta, JC, Presty, S, Friston, KJ, Frackowiak, R & Phelps, ME 1992, 'Functional anatomy of human procedural learning determined with regional cerebral blood flow and PET', *The Journal of Neuroscience,* vol. 12, no. 7, pp. 2542-2548.

Grafton, ST, Arbib, MA, Fadiga, L & Rizzolatti, G 1996, 'Localization of grasp representations in humans by positron emission tomography. 2. Observation compared with imagination', *Experimental brain research. Experimentelle Hirnforschung. Experimentation cerebrale,* vol. 112, no. 1, Nov, pp. 103-111.

Graneheim, UH & Lundman, B 2004, 'Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness', *Nurse Education Today,* vol. 24, no. 2, pp. 105-112.

Grantcharov, TP, Bardram, L, Funch-Jensen, P & Rosenberg, J 2003, 'Learning curves and impact of previous operative experience on performance on a virtual reality simulator to test laparoscopic surgical skills', *American Journal of Surgery,* vol. 185, no. 2, pp. 146-149.

Green, TD & Flowers, JH 1991, 'Implicit versus explicit learning processes in a probabilistic, continuous fine-motor catching task', *Journal of Motor Behavior,* vol. 23, no. 4, pp. 293-300.

Grober, ED, Hamstra, SJ, Wanzel, KR, Reznick, RK, Matsumoto, ED, Sidhu, RS & Jarvi, KA 2004, 'The educational impact of bench model fidelity on the acquisition of technical skill: the use of clinically relevant outcome measures', *Annals of Surgery,* vol. 240, no. 2, August, pp. 374-381.

Haggard, P, Newman, C & Magno, E 1999, 'On the perceived time of voluntary actions', *British Journal of Psychology,* vol. 90, no. 2, pp. 291-303.

Hall, KG & Magill, RA 1995, 'Variability of practice and contextual interference in motor skill learning', *Journal of Motor Behavior,* vol. 27, no. 4, pp. 299-309.

Hallett, M 1998, 'Overview of human tremor physiology', *Movement Disorders,* vol. 13, no. S3, pp. 43-48.

Halstead, WC 1947, *Brain and Intelligence: A quantitative study of the frontal lobes*, University of Chicago press, Chicago.

Hardy, L, Mullen, R & Jones, G 1996, 'Knowledge and conscious control of motor actions under stress', *British Journal of Psychology,* vol. 87, p. 621.

Harrell, W 1940, 'A factor analysis of mechanical ability tests', *Psychometrika,* vol. 5, no. 1, pp. 17-33.

Harris, CJ, Herbert, M & Steele, RJ 1994, 'Psychomotor skills of surgical trainees compared with those of different medical specialists', *British Journal of Surgery,* vol. 81, no. 3, March, pp. 382-383.

Harwood, TG & Garry, T 2003, 'An overview of content analysis', *Marketing Review,* vol. 3, no. 4, pp. 479-498.

Hauptmann, B & Karni, A 2002, 'From primed to learn: the saturation of repetition priming and the induction of long-term memory', *Cognitive Brain Research,* vol. 13, no. 3, pp. 313-322.

Haward, BM & Griffin, MJ 2002, 'Repeatability of grip strength and dexterity tests and the effects of age and gender', *International Archives of Occupational and Environmental Health,* vol. 75, no. 1, January, pp. 111-119.

Heathcote, A, Brown, S & Mewhort, D 2000, 'The power law repealed: The case for an exponential law of practice', *Psychonomic Bulletin & Review,* vol. 7, no. 2, pp. 185-207.

Heaton, RK, Grant, I & Matthews, CG 1986, 'Differences in neuropsychological test performance associated with age, education, and sex', in Grant, I & Adams, KM (eds), *Neuropsychological Assessment of Neuropsychiatric Disorders*, Oxford University Press, New York, pp. 100-120.

Heaton, RK, Grant, I & Matthews, CG 1991, *Comprehensive Norms for an Expanded Halstead-Reitan Battery: Demographic Corrections, Research Findings, and Clinical Applications*, Psychological Assessment Resources, Florida.

Held, R & Freedman, SJ 1963, 'Plasticity in human sensorimotor control', *Science,* vol. 142, no. 3591, pp. 455-462.

Hellebrandt, FA & Houtz, SJ 1955, 'Applications of the MacQuarrie Test for Mechanical Ability', *American Journal of Occupational Therapy,* vol. 9, no. 6, pp. 259-263.

Helliwell, S 2009, 'Does the use of a sensory re-education programme improve the somatosensory and motor function of the upper limb in subacute stroke? A single case experimental design', *The British Journal of Occupational Therapy,* vol. 72, no. 12, pp. 551-558.

Heuer, H & Sulzenbruck, S 2012, 'Mind and movement', *Psychological Research* vol. 76, no. 2, March, pp. 159-170.

Hikosaka, O, Nakahara, H, Rand, MK, Sakai, K, Lu, X, Nakamura, K, Miyachi, S & Doya, K 1999, 'Parallel neural networks for learning sequential procedures', *Trends in Neurosciences,* vol. 22, no. 10, pp. 464-471.

Hillier, S & Worley, A 2015, 'The effectiveness of the Feldenkrais Method: A systematic review of the evidence', *Evidence-Based Complementary and Alternative Medicine,* vol. 2015.

Hird, JS, Landers, DM, Thomas, JR & Horan, JJ 1991, 'Physical practice is superior to mental practice in enhancing cognitive and motor task performance', *Journal of Sport & Exercise Psychology,* vol. 13, no. 3, pp. 281-293.

Hlustik, P, Solodkin, A, Noll, DC & Small, SL 2004, 'Cortical plasticity during three-week motor skill learning', *Journal of Clinical Neurophysiology* vol. 21, no. 3, May-Jun, pp. 180-191.

Hogle, NJ, Widmann, WD, Ude, AO, Hardy, MA & Fowler, DL 2008, 'Does training novices to criteria and does rapid acquisition of skills on laparoscopic simulators have predictive validity or are we just playing video games?', *Journal of Surgical Education,* vol. 65, no. 6, pp. 431-435.

Honda, M, Deiber, MP, Ibáñez, V, Pascual-Leone, A, Zhuang, P & Hallett, M 1998, 'Dynamic cortical involvement in implicit and explicit motor sequence learning. A PET study', *Brain,* vol. 121, no. 11, pp. 2159-2173.

Horak, F, Esselman, P, Anderson, M & Lynch, M 1984, 'The effects of movement velocity, mass displaced, and task certainty on associated postural adjustments made by normal and hemiplegic individuals', *Journal of Neurology, Neurosurgery & Psychiatry,* vol. 47, no. 9, pp. 1020-1028.

Hsieh, H-F & Shannon, SE 2005, 'Three approaches to qualitative content analysis', *Qualitative Health Research,* vol. 15, no. 9, November 1, 2005, pp. 1277-1288.

Huang, VS, Haith, A, Mazzoni, P & Krakauer, JW 2011, 'Rethinking motor learning and savings in adaptation paradigms: model-free memory for successful actions combines with internal models', *Neuron,* vol. 70, no. 4, pp. 787-801.

Iacoboni, M, Woods, RP, Brass, M, Bekkering, H, Mazziotta, JC & Rizzolatti, G 1999, 'Cortical mechanisms of human imitation', *Science,* vol. 286, no. 5449, December, pp. 2526-2528.

Iacoboni, M, Molnar-Szakacs, I, Gallese, V, Buccino, G, Mazziotta, JC & Rizzolatti, G 2005, 'Grasping the intentions of others with one's own mirror neuron system', *PLoS Biology,* vol. 3, no. 3, Mar, p. e79.

Ives, JC & Shelley, GA 1998, 'The Feldenkrais Method® in rehabilitation: a review', *Work: A Journal of Prevention, Assessment and Rehabilitation,* vol. 11, no. 1, pp. 75-90.

Ives, JC & Sosnoff, J 2000, 'Beyond the mind-body exercise hype', *Physician and Sportsmedicine,* vol. 28, no. 3, pp. 67-81.

Ives, JC 2003, 'Comments on "The Feldenkrais Method®: a dynamic approach to changing motor behavior"', *Research Quarterly for Exercise and Sport,* vol. 74, no. 2, pp. 116-123.

Jackson, JH 1932a, *Selected writings of John Hughlings Jackson,* Hodder and Sotigzhton, London.

Jackson, JH 1932b, 'Remarks on the relations of different divisions of the central nervous system to one another and to parts of the body: Delivered before the Neurological Society, December 8th, 1897', *British Medical Journal,* vol. 1, p. 65.

Jackson, R & Farrow, D 2005, 'Implicit perceptual training: How, when, and why?', *Human Movement Science,* vol. 24, no. 3, pp. 308-325.

Jacobs, KM & Donoghue, JP 1991, 'Reshaping the cortical motor map by unmasking latent intracortical connections', *Science,* vol. 251, no. 4996, pp. 944-947.

Jacobson, BH, Winter-Roberts, K & Gemmell, HA 1991, 'Influence of caffeine on selected manual manipulation skills', *Perceptual and Motor Skills,* vol. 72, no. 3, June, pp. 1175-1181.

Jacobson, BH & Thurman-Lacey, SR 1992, 'Effect of caffeine on motor performance by caffeine-naive and -familiar subjects', *Perceptual and Motor Skills,* vol. 74, no. 1, Feb, pp. 151-157.

Jenkins, WM, Merzenich, MM, Ochs, MT, Allard, T & Guic-Robles, E 1990, 'Functional reorganization of primary somatosensory cortex in adult owl monkeys after behaviorally controlled tactile stimulation', *Journal of Neurophysiology,* vol. 63, no. 1, pp. 82-104.

Johansson, RS & Westling, G 1984, 'Roles of glabrous skin receptors and sensorimotor memory in automatic control of precision grip when lifting rougher or more slippery objects', *Experimental Brain Research,* vol. 56, no. 3, pp. 550-564.

Johansson, RS & Westling, G 1987, 'Significance of cutaneous input for precise hand movements', *Electroencephalography and Clinical Neurophysiology,* vol. 39, no. Supplement, pp. 53-57.

Johansson, RS & Cole, KJ 1992, 'Sensory-motor coordination during grasping and manipulative actions', *Current Opinion in Neurobiology,* vol. 2, no. 6, December, pp. 815-823.

Johnson, SK, Frederick, J, Kaufman, M & Mountjoy, B 1999, 'A controlled investigation of bodywork in multiple sclerosis', *Journal of Alternative and Complementary Medicine,* vol. 5, no. 3, pp. 237-243.

Joiner, WM & Smith, MA 2008, 'Long-term retention explained by a model of short-term learning in the adaptive control of reaching', *Journal of Neurophysiology*, vol. 100, no. 5, pp. 2948-2955.

Jones, E, Hanly, JG, Mooney, R, Rand, LL, Spurway, PM, Eastwood, BJ & Jones, JV 1991, 'Strength and function in the normal and rheumatoid hand', *The Journal of Rheumatology*, vol. 18, no. 9, Sep, pp. 1313-1318.

Kalron, A, Greenberg-Abrahami, M, Gelav, S & Achiron, A 2013, 'Effects of a new sensory re-education training tool on hand sensibility and manual dexterity in people with multiple sclerosis', *Neuro Rehabilitation*, vol. 32, no. 4, pp. 943-948.

Kamm, K, Thelen, E & Jensen, JL 1990, 'A dynamical systems approach to motor development', *Physical therapy*, vol. 70, no. 12, pp. 763-775.

Kanfer, R & Ackerman, PL 1989, 'Motivation and cognitive abilities: An integrative/aptitude-treatment interaction approach to skill acquisition', *Journal of Applied Psychology* vol. 74, pp. 657-690

Kanfer, R, Ackerman, PL, Murtha, TC, Dugdale, B & Nelson, L 1994, 'Goal setting, conditions of practice, and task performance: A resource allocation perspective', *Journal of Applied Psychology*, vol. 79, no. 6, p. 826.

Kanfer, R & Heggestad, ED 1997, 'Motivational traits and skills: A person-centred approach to work motivation', *Research in Organizational Behavior*, vol. 19, pp. 1-56.

Kanfer, R & Ackerman, PL 2000, 'Individual differences in work motivation: further explorations of a trait framework', *Applied Psychology: An International Review*, vol. 49, no. 3, pp. 470-482.

Karni, A, Meyer, G, Jezzard, P, Adams, MM, Turner, R & Ungerleider, LG 1995, 'Functional MRI evidence for adult motor cortex plasticity during motor skill learning', *Nature*, vol. 377, no. 6545, September, pp. 155-158.

Karni, A, Meyer, G, Rey-Hipolito, C, Jezzard, P, Adams, MM, Turner, R & Ungerleider, LG 1998, 'The acquisition of skilled motor performance: fast and slow experience-driven changes in primary motor cortex', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 95, no. 3, pp. 861-868.

Kaufman, HH, Wiegand, RL & Tunick, RH 1987, 'Teaching surgeons to operate--principles of psychomotor skills training', *Acta Neurochirurgica*, vol. 87, no. 1-2, pp. 1-7.

Keele, SW, Ivry, R, Mayr, U, Hazeltine, E & Heuer, H 2003, 'The cognitive and neural architecture of sequence representation', *Psychological Review*, vol. 110, no. 2, p. 316.

Kerr, CE, Shaw, JR, Wasserman, RH, Chen, VW, Kanojia, A, Bayer, T & Kelley, JM 2008, 'Tactile acuity in experienced Tai Chi practitioners: evidence for use dependent plasticity as an effect of sensory-attentional training', *Experimental Brain Research*, vol. 188, no. 2, pp. 317-322.

Kerr, GA, Kotynia, F & Kolt, GS 2002, 'Feldenkrais® awareness through movement and state anxiety', *Journal of Bodywork and Movement Therapies*, vol. 6, no. 2, pp. 102-107.

Kinoshita, H & Francis, PR 1996, 'A comparison of prehension force control in young and elderly individuals', *European Journal of Applied Physiology and Occupational Physiology* vol. 74, no. 5, pp. 450-460.

Kirby, TJ 1979, 'Dexterity testing and residents' surgical performance', *Transactions of the American Ophthalmological Society,* vol. 77, pp. 294-307.

Klein, T, Magerl, W, Hopf, H-C, Sandkühler, J & Treede, R-D 2004, 'Perceptual correlates of nociceptive long-term potentiation and long-term depression in humans', *The Journal of Neuroscience,* vol. 24, no. 4, pp. 964-971.

Kløve, H 1963, 'Clinical Neuropsychology', in Forster, EM (ed), *The Medical Clinics of North America,* Saunders, New York.

Knight, CM 1998, 'Evaluating a skills centre: the acquisition of psychomotor skills in nursing--a review of the literature', *Nurse Education Today,* vol. 18, no. 6, Aug, pp. 441-447.

Kohler, E, Keysers, C, Umilta, MA, Fogassi, L, Gallese, V & Rizzolatti, G 2002, 'Hearing sounds, understanding actions: action representation in mirror neurons', *Science,* vol. 297, no. 5582, pp. 846-848.

Kolt, GS & McConville, JC 2000, 'The effects of a Feldenkrais® Awareness Through Movement program on state anxiety', *Journal of Bodywork and Movement Therapies,* vol. 4, no. 3, pp. 216-220.

Kopta, JA 1971, 'The development of motor skills in orthopaedic education', *Clinical orthopaedics and related research,* vol. 75, Mar-Apr, pp. 80-85.

Korttila, K, Pfaffli, P, Linnoila, M, Blomgren, E, Hanninen, H & Hakkinen, S 1978, 'Operating room nurses' psychomotor and driving skills after occupational exposure to halothane and nitrous oxide', *Acta Anaesthesiologica Scandinavica,* vol. 22, no. 1, pp. 33-39.

Kozin, SH, Porter, S, Clark, P & Thoder, JJ 1999, 'The Contribution of the intrinsic muscles to grip and pinch strength', *The Journal of Hand surgery,* vol. 24, no. 1, pp. 64-72.

Krakauer, JW 2006, 'Motor learning: its relevance to stroke recovery and neurorehabilitation', *Current Opinion in Neurology,* vol. 19, no. 1, pp. 84-90.

Krakauer, JW & Shadmehr, R 2006, 'Consolidation of motor memory', *Trends in Neurosciences,* vol. 29, no. 1, pp. 58-64.

Krakauer, JW & Mazzoni, P 2011, 'Human sensorimotor learning: adaptation, skill, and beyond', *Current Opinion in Neurobiology,* vol. 21, no. 4, Aug, pp. 636-644.

Krippendorff, K 2004, *Content analysis : an introduction to its methodology,* 2 edn, Sage, Thousand Oaks, California, USA.

Kyllo, LB & Landers, DM 1995, 'Goal setting in sport and exercise: A research synthesis to resolve the controversy', *Journal of Sport & Exercise Psychology,* vol. 17, no. 2, June, pp. 117-137.

Lakie, M 2010, 'The influence of muscle tremor on shooting performance', *Experimental Physiology,* vol. 95, no. 3, pp. 441-450.

Lansdell, H & Donnelly, EF 1977, 'Factor analysis of the Wechsler Adult Intelligence Scale subtests and the Halstead-Reitan Category and Tapping tests', *Journal of Consulting and Clinical Psychology,* vol. 45, no. 3, pp. 412-416.

Lauf, E & LeCompte, G 1982, 'Manual dexterity: its importance in podiatry', *Journal of the American Podiatric Medical Association,* vol. 72, no. 6, Jun, pp. 291-298.

Lee, JY, Kerbl, DC, McDougall, EM & Mucksavage, P 2012, 'Medical students pursuing surgical fields have no greater innate motor dexterity than those pursuing nonsurgical fields', *Journal of Surgical Education,* vol. 69, no. 3, pp. 360-363.

Levine, A, Miller, E, Becker, J, Selnes, O & Cohen, B 2004, 'Normative data for determining significance of test–retest differences on eight common neuropsychological instruments', *Clinical Neuropsychologist,* vol. 18, no. 3, pp. 373-384.

Lezak, MD, Loring, DW & Howieson, DB 2004, *Neuropsychological assessment*, 4th edn, Oxford University Press, Oxford.

Libet, B, Gleason, CA, Wright, EW & Pearl, DK 1983, 'Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential) the unconscious initiation of a freely voluntary act', *Brain,* vol. 106, no. 3, pp. 623-642.

Liepert, J 2010, 'Evidence-based therapies for upper extremity dysfunction', *Current Opinion in Neurology,* vol. 23, no. 6, pp. 678-682.

Lister, MJ 1991, 'Contemporary management of motor control problems: proceedings of the II-Step Conference
II step conference, Alexandria.

Locke, EA & Latham, GP 1985, 'The application of goal setting to sports', *Journal of Sport Psychology,* vol. 7, pp. 205-222.

Locke, EA 1996, 'Motivation through conscious goal setting', *Applied and Preventive Psychology,* vol. 5, no. 2, pp. 117-124.

Lorr, M & McNair, D 1982, *Bipolar Profile of Moods States Manual*, Educational and Industry Testing Service (EDITS), San Diego, CA: .

Love, B, McAdams, C, Patton, DM, Rankin, EJ & Roberts, J 1989, 'Teaching psychomotor skills in nursing: a randomized control trial', *Journal of Advanced Nursing,* vol. 14, no. 11, pp. 970-975.

Luck, O, Reitemeier, B & Scheuch, K 2000, 'Testing of fine motor skills in dental students', *European Journal of Dental Education,* vol. 4, no. 1, February, pp. 10-14.

Lundblad, I, Elert, J & Gerdle, B 1999, 'Randomized controlled trial of physiotherapy and Feldenkrais interventions in female workers with neck-shoulder complaints', *Journal of Occupational Rehabilitation,* vol. 9, no. 3, pp. 179-194.

Lundergan, WP & Lyon, L 2007, 'Research on hand dexterity and the practice of dentistry: reality and myth', *The Journal of the American College of Dentists,* vol. 74, no. 3, pp. 15-16.

Lundergan, WP, Soderstrom, EJ & Chambers, DW 2007, 'Tweezer dexterity aptitude of dental students', *Journal of Dental Education,* vol. 71, no. 8, August, pp. 1090-1097.

Lyttle, TS 1997, 'The feldenkrais method: application, practice and principles', *Journal of Bodywork and Movement Therapies*, vol. 1, no. 5, pp. 262-269.

Mackay, S, Morgan, P, Datta, V, Chang, A & Darzi, A 2002, 'Practice distribution in procedural skills training', *Surgical Endoscopy*, vol. 16, no. 6, pp. 957-961.

MacQuarrie, TW 1925, *MacQuarrie Test for Manual Ability*, McGraw-Hill, Monterey CA, 1925.

MacQuarrie, TW 1927, 'A mechanical ability test', *Journal of Personnel Research*, vol. 5, no. 9, January, p. 336.

Mageau, GA & Vallerand, RJ 2003, 'The coach-athlete relationship: a motivational model', *Journal of Sports Sciences*, vol. 21, no. 11, November, pp. 883-904.

Magill, RA & Hall, KG 1990, 'A review of the contextual interference effect in motor skill acquisition', *Human Movement Science*, vol. 9, no. 3, pp. 241-289.

Maiden, D & Dyson, M 1997, 'An examination of the validity of the Morrisby Manual Dexterity Test', *Australian Occupational Therapy Journal*, vol. 44, no. 4, December, pp. 177-185.

Manjunath, NK & Telles, S 1999, 'Factors influencing changes in tweezer dexterity scores following yoga training', *Indian Journal of Physiology and Pharmacology*, vol. 43, no. 2, April, pp. 225-229.

Mapping clinical placements: Capturing opportunities for growth - supply (clinical training provider) study, 2011, Australia, HW, Health Workforce Australia, Adelaide, South Australia.

Markland, D & Hardy, L 1997, 'On the factorial and construct validity of the Intrinsic Motivation Inventory: Conceptual and operational concerns', *Research Quarterly for Exercise and Sport*, vol. 68, no. 1, pp. 20-32.

Marmon, AR, Pascoe, MA, Schwartz, RS & Enoka, RM 2011, 'Associations among strength, steadiness, and hand function across the adult life span', *Medicine and Science in Sports and Exercise*, vol. 43, no. 4, pp. 560-567.

Mars, RB, Coles, MGH, Grol, MJ, Holroyd, CB, Nieuwenhuis, S, Hulstijn, W & Toni, I 2005, 'Neural dynamics of error processing in medial frontal cortex', *Neuroimage*, vol. 28, no. 4, pp. 1007-1013.

Martocchio, JJ 1994, 'Effects of conceptions of ability on anxiety, self-efficacy, and learning in training', *Journal of Applied Psychology*, vol. 79, no. 6, pp. 819-825.

Maslovat, D, Hodges, NJ, Krigolson, OE & Handy, TC 2010, 'Observational practice benefits are limited to perceptual improvements in the acquisition of a novel coordination skill', *Experimental Brain Research*, vol. 204, no. 1, July, pp. 119-130.

Masters, RSW 1992, 'Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure', *British Journal of Psychology*, vol. 83, no. 3, pp. 343-358.

Masters, RSW, Lo, CY, Maxwell, JP & Patil, NG 2008, 'Implicit motor learning in surgery: Implications for multi-tasking', *Surgery*, vol. 143, no. 1, pp. 140-145.

Masters, RSW, Poolton, JM & Maxwell, JP 2008, 'Stable implicit motor processes despite aerobic locomotor fatigue', *Consciousness and Cognition,* vol. 17, no. 1, pp. 335-338.

Masud, D, Undre, S & Darzi, A 2012, 'Using manual dexterity to predict the quality of the final product in the small bowel anastomosis after a period of training', *American Journal of Surgery,* vol. 203, no. 6, June, pp. 776-781.

Matarazzo, JD, Wiens, AN, Matarazzo, RG & Goldstein, SG 1974, 'Psychometric and clinical test-retest reliability of the Halstead impairment index in a sample of healthy, young, normal men', *The Journal of Nervous and Mental Disease,* vol. 158, no. 1, January, pp. 37-49.

Mathieu, JE, Tannenbaum, SI & Salas, E 1992, 'Influences of individual and situational characteristics on measures of training effectiveness', *The Academy of Management Journal,* vol. 35, no. 4, pp. 828-847.

Mathiowetz, V, Kashman, N, Volland, G, Weber, K, Dowe, M & Rogers, S 1985, 'Grip and pinch strength: normative data for adults', *Archives of Physical Medicine and Rehabilitation,* vol. 66, no. 2, February, pp. 69-74.

Mathiowetz, V, Rogers, SL, Dowe-Keval, M, Donahoe, L & Rennells, C 1986, 'The Purdue Pegboard: Norms for 14- to 19-year-olds', *American Journal of Occupational Therapy,* vol. 40, no. 3, March, pp. 174-179.

Mathiowetz, V & Haugen, JB 1994, 'Motor behavior research: implications for therapeutic approaches to central nervous system dysfunction', *American Journal of Occupational Therapy,* vol. 48, no. 8, pp. 733-745.

Matsumoto, ED, Hamstra, SJ, Radomski, SB & Cusimano, MD 2002, 'The effect of bench model fidelity on endourological skills: a randomized controlled study', *The Journal of Urology,* vol. 167, no. 3, March, pp. 1243-1247.

Mattar, AA & Gribble, PL 2005, 'Motor learning by observing', *Neuron,* vol. 46, no. 1, April, pp. 153-160.

Maxwell, J, Masters, R, Kerr, E & Weedon, E 2001, 'The implicit benefit of learning without errors', *The Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology,* vol. 54, no. 4, pp. 1049-1068.

McAuley, E, Duncan, T & Tammen, VV 1989, 'Psychometric properties of the Intrinsic Motivation Inventory in a competitive sport setting: a confirmatory factor analysis', *Research Quarterly for Exercise and Sport,* vol. 60, no. 1, March, pp. 48-58.

McCaffrey, RJ, Ortega, A & Haase, RF 1993, 'Effects of repeated neuropsychological assessments', *Archives of Clinical Neuropsychology,* vol. 8, no. 6, November, pp. 519-524.

McCaffrey, RJ, Duff, K & Westervelt, HJ 2000, *Practitioners' guide to evaluating change with neuropsychological assessment instruments,* Kluwer Academic/Plenum Publishing, New York.

McCullagh, P & Caird, JK 1990, 'Correct and learning models and the use of model knowledge of results in the acquisition and retention of a motor skill', *Journal of Human Movement Studies,* vol. 18, pp. 107-116.

McCurry, SM, Gibbons, LE, Uomoto, JM, Thompson, ML, Graves, AB, Edland, SD, Bowen, J, McCormick, WC & Larson, EB 2001, 'Neuropsychological test performance in a cognitively

intact sample of older Japanese American adults', *Archives of Clinical Neuropsychology*, vol. 16, no. 5, pp. 447-459.

McDonnell, MN, Ridding, MC, Flavel, SC & Miles, TS 2005, 'Effect of human grip strategy on force control in precision tasks', *Experimental Brain Research*, vol. 161, no. 3, pp. 368-373.

McDonnell, MN & Ridding, MC 2006, 'Afferent stimulation facilitates performance on a novel motor task', *Experimental Brain Research*, vol. 170, no. 1, pp. 109-115.

McDonnell, MN, Hillier, SL, Miles, TS, Thompson, PD & Ridding, MC 2007, 'Influence of combined afferent stimulation and task-specific training following stroke: A pilot randomized controlled trial', *Neurorehabilitation and Neural Repair*, vol. 21, no. 5, September-October, pp. 435-443.

McDonnell, MN, Hillier, SL & Esterman, AJ 2013, 'Standardizing the approach to evidence-based upper limb rehabilitation after stroke', *Topics in Stroke Rehabilitation*, vol. 20, no. 5, September-October, pp. 432-440.

McMeekan, ERL & Lishman, WA 1975, 'Retest reliabilities and interrelationship of the Annett Hand Preference Questionnaire and the Edinburgh Handedness Inventory', *British Journal of Psychology*, vol. 66, no. 1, p. 53.

McNevin, NH, Wulf, G & Carlson, C 2000, 'Effects of attentional focus, self-control, and dyad training on motor learning: implications for physical rehabilitation', *Physical Therapy*, vol. 80, no. 4, April, pp. 373-385.

Miall, R & Wolpert, DM 1996, 'Forward models for physiological motor control', *Neural Networks*, vol. 9, no. 8, pp. 1265-1279.

Milde, FK 1988, 'The function of feedback in psychomotor-skill learning', *Western Journal of Nursing Research*, vol. 10, no. 4, August, pp. 425-434.

Miller, KJ 2008, *Procedure for sensory assessment of the hands using the Astex*, The University of Melbourne.

Miller, KJ, Phillips, B, Martin, C, Wheat, H, Goodwin, A & Galea, M 2009, 'The AsTex ®: clinimetric properties of a new tool for evaluating hand sensation following stroke', *Clinical Rehabilitation*, vol. 23, no. 12, December 1, 2009, pp. 1104-1115.

Miller, LK, Chester, R & Jerosch-Herold, C 2012, 'Effects of sensory reeducation programs on functional hand sensibility after median and ulnar repair: a systematic review', *Journal of Hand Therapy*, vol. 25, no. 3, pp. 297-307.

Minnesota Rate of Manipulation Test 1931, Educational Test Bureau, Minneapolis, Minnesota.

Mitrushina, M, Fogel, T, D'Elia, L, Uchiyama, C & Satz, P 1995, 'Performance on motor tasks as an indication of increased behavioral asymmetry with advancing age', *Neuropsychologia*, vol. 33, no. 3, pp. 359-364.

Mitrushina, M, Boone, KB & Razani, J 2005, *Handbook of normative data for neuropsychological assessment*, 2 edn, New York, USA, Oxford.

Moberg, E 1962, 'Criticism and study of methods for examining sensibility in the hand', *Neurology*, vol. 12, January, pp. 8-19.

Morrison, MW, Gregory, RJ & Paul, JJ 1979, 'Reliability of the Finger Tapping Test and a note on sex differences', *Perceptual and Motor Skills*, vol. 48, no. 1, February, pp. 139-142.

Moulton, CA, Dubrowski, A, Macrae, H, Graham, B, Grober, E & Reznick, R 2006, 'Teaching surgical skills: what kind of practice makes perfect?: a randomized, controlled trial', *Annals of Surgery*, vol. 244, no. 3, September, pp. 400-409.

Mucksavage, P, Kerbl, DC & Lee, JY 2011, 'The Da Vinci surgical system overcomes innate hand dominance', *Journal of Endourology*, vol. 25, no. 8, August, pp. 1385-1388.

Mueller, S, Winkelmann, C, Krause, F & Grunwald, M 2014, 'Occupation-related long-term sensory training enhances roughness discrimination but not tactile acuity', *Experimental Brain Research*, vol. 232, no. 6, pp. 1905-1914.

Muller, MD, Ryan, EJ, Kim, C-H, Muller, SM & Glickman, EL 2011, 'Test–retest reliability of Purdue Pegboard performance in thermoneutral and cold ambient conditions', *Ergonomics*, vol. 54, no. 11, November, pp. 1081-1087.

Munz, Y, Kumar, BD, Moorthy, K, Bann, S & Darzi, A 2004a, 'Laparoscopic virtual reality and box trainers: is one superior to the other?', *Surgical Endoscopy*, vol. 18, no. 3, March, pp. 485-494.

Munz, Y, Moorthy, K, Bann, S, Shah, J, Ivanova, S & Darzi, SA 2004b, 'Ceiling effect in technical skills of surgical residents', *American Journal of Surgery*, vol. 188, no. 3, September, pp. 294-300.

Mussa-Ivaldi, FA 1999, 'Modular features of motor control and learning', *Current Opinion in Neurobiology*, vol. 9, no. 6, pp. 713-717.

Naik, VN, Matsumoto, ED, Houston, PL, Hamstra, SJ, Yeung, RY-M, Mallon, JS & Martire, TM 2001, 'Fiberoptic orotracheal intubation on anesthetized patients: Do manipulation skills learned on a simple model transfer into the operating room?', *Anesthesiology*, vol. 95, no. 2, pp. 343-348.

Nakada, M & Uchida, H 1997, 'Case study of a five-stage sensory reeducation program', *Journal of Hand Therapy*, vol. 10, no. 3, pp. 232-239.

Nakamura, K, Sakai, K & Hikosaka, O 1998, 'Neuronal activity in medial frontal cortex during learning of sequential procedures', *Journal of Neurophysiology*, vol. 80, no. 5, pp. 2671-2687.

National Health Workforce Dataset 2014, Canberra, Australia.

Neiburger, E 1992, 'Latex gloves and manual dexterity. A study of 50 Midwest dentists.', *New York State Dental Journal*, vol. 58, no. 1, pp. 24-28.

Netz, Y & Lidor, R 2003, 'Mood alterations in mindful versus aerobic exercise modes', *The Journal of Psychology*, vol. 137, no. 5, pp. 405-419.

Newell, KM 1991, 'Motor skill acquisition', *Annual Review of Psychology*, vol. 42, no. 1, pp. 213-237.

Nieuwenhuis, S, Slagter, HA, Von Geusau, NJA, Heslenfeld, DJ & Holroyd, CB 2005, 'Knowing good from bad: differential activation of human cortical areas by positive and negative outcomes', *European Journal of Neuroscience*, vol. 21, no. 11, pp. 3161-3168.

Nissen, MJ & Bullemer, P 1987, 'Attentional requirements of learning: Evidence from performance measures', *Cognitive Psychology,* vol. 19, no. 1, pp. 1-32.

Noe, RA & Schmitt, N 1986, 'The influence of trainee attitudes on training effectiveness: Test of a model ', *Personnel Psychology,* vol. 39, no. 3, pp. 497-523.

Noppeney, U, Waberski, TD, Gobbelé, R & Buchner, H 1999, 'Spatial attention modulates the cortical somatosensory representation of the digits in humans', *Neuroreport,* vol. 10, no. 15, pp. 3137-3141.

Nyberg, L, Eriksson, J, Larsson, A & Marklund, P 2006, 'Learning by doing versus learning by thinking: An fMRI study of motor and mental training', *Neuropsychologia,* vol. 44, no. 5, pp. 711-717.

O'Connor, A, Schwaitzberg, SD & Cao, CGL 2008, 'How much feedback is necessary for learning to suture', *Surgical Endoscopy,* vol. 22, pp. 1614-1619.

O'Connor, J 1925, *A scientific method of selecting employees*, Monogram (General Electric Company), November 1925.

Oermann, MH 1990, 'Psychomotor skill development', *Journal of Continuing Education in Nursing,* vol. 21, no. 5, September-October, pp. 202-204.

Oldfield, RC 1971, 'The assessment and analysis of handedness: the Edinburgh inventory', *Neuropsychologia,* vol. 9, no. 1, March, pp. 97-113.

Ostry, DJ, Darainy, M, Mattar, AA, Wong, J & Gribble, PL 2010, 'Somatosensory plasticity and motor learning', *The Journal of Neuroscience,* vol. 30, no. 15, April, pp. 5384-5393.

Oudshoorn, WC 2003, 'The utility of Canadian DAT Perceptual Ability and Carving Dexterity scores as predictors of psychomotor performance in first-year operative dentistry', *Journal of Dental Education,* vol. 67, no. 11, pp. 1201-1208.

Pascual-Leone, A, Grafman, J & Hallett, M 1994, 'Modulation of cortical motor output maps during development of implicit and explicit knowledge', *Science,* vol. 263, no. 5151, pp. 1287-1289.

Pascual-Leone, A, Nguyet, D, Cohen, LG, Brasil-Neto, JP, Cammarota, A & Hallett, M 1995, 'Modulation of muscle responses evoked by transcranial magnetic stimulation during the acquisition of new fine motor skills', *Journal of Neurophysiology,* vol. 74, no. 3, September, pp. 1037-1045.

Patton, MQ 2002, *Qualitative research and evaluation methods*, 3rd edn, Sage Publications, Thousand Oaks, California.

Pavlides, C, Miyashita, E & Asanuma, H 1993, 'Projection from the sensory to the motor cortex is important in learning motor skills in the monkey', *Journal of Neurophysiology,* vol. 70, pp. 733-733.

Phillips, AM, Birch, NC & Ribbans, WJ 1997, 'Protective gloves for use in high-risk patients: how much do they affect the dexterity of the surgeon?', *Annals of the Royal College of Surgeons of England* vol. 79, no. 2, March, pp. 124-127.

Pilz, K, Veit, R, Braun, C & Godde, B 2004, 'Effects of co-activation on cortical organization and discrimination performance', *Neuroreport,* vol. 15, no. 17, pp. 2669-2672.

Pleger, B, Foerster, A-F, Ragert, P, Dinse, HR, Schwenkreis, P, Malin, J-P, Nicolas, V & Tegenthoff, M 2003, 'Functional imaging of perceptual learning in human primary and secondary somatosensory cortex', *Neuron,* vol. 40, no. 3, pp. 643-653.

Podiatry Practice Act (SA) (Adelaide) 2005

Podiatry registrant data 2014, Australian Health Practitioner Regulation Agency (AHPRA). viewed April 2014, <http://www.podiatryboard.gov.au/documents/default.aspx?record=WD14%2f13785&dbid=AP&chksum=PcBKCN%2b6TfG8vDA9ZHSHiA%3d%3d>.

Poirier, F 1988, 'Dexterity as a valid measure of hand function', *Occupational Therapy in Health Care,* vol. 4, no. 3-4, pp. 69-83.

Poldrack, RA, Clark, J, Pare-Blagoev, E, Shohamy, D, Moyano, JC, Myers, C & Gluck, M 2001, 'Interactive memory systems in the human brain', *Nature,* vol. 414, no. 6863, pp. 546-550.

Polit, A & Bizzi, E 1979, 'Characteristics of motor programs underlying arm movements in monkeys', *Journal of Neurophysiology,* vol. 42, no. 1, pp. 183-194.

Pollock, A, Farmer, SE, Brady, MC, Langhorne, P, Mead, GE, Mehrholz, J & van Wijck, F 2014, 'Interventions for improving upper limb function after stroke', *Cochrane Database of Systematic Reviews,* vol. 11, September, pp. 1-170.

Poolton, J, Masters, R & Maxwell, J 2005, 'The relationship between initial errorless learning conditions and subsequent performance', *Human Movement Science,* vol. 24, no. 3, pp. 362-378.

Poolton, J, Masters, R & Maxwell, J 2007, 'Passing thoughts on the evolutionary stability of implicit motor behaviour: Performance retention under physiological fatigue', *Consciousness and Cognition,* vol. 16, no. 2, pp. 456-468.

Porte, MC, Xeroulis, G, Reznick, RK & Dubrowski, A 2007, 'Verbal feedback from an expert is more effective than self-accessed feedback about motion efficiency in learning new surgical skills', *The American Journal of Surgery,* vol. 193, no. 1, pp. 105-110.

Portney, LG & Watkins, MP 2009, *Foundations of clinical research: applications to practice*, 3rd edn, Pearson/Prentice Hall, Upper Saddle River, New Jersey.

Posner, MI, DiGirolamo, GJ & Fernandez-Duque, D 1997, 'Brain mechanisms of cognitive skills', *Consciousness and Cognition,* vol. 6, no. 2, pp. 267-290.

Post, PG, Fairbrother, JT & Barros, JAC 2011, 'Self-controlled amount of practice benefits learning of a motor skill', *Research Quarterly for Exercise and Sport,* vol. 82, no. 3, September, pp. 474-481.

Prat-Sala, M & Redford, P 2010, 'The interplay between motivation, self-efficacy, and approaches to studying', *British Journal of Educational Psychology,* vol. 80, no. 2, pp. 283-305.

Ragert, P, Schmidt, A, Altenmüller, E & Dinse, HR 2004, 'Superior tactile performance and learning in professional pianists: evidence for meta- plasticity in musicians', *European Journal of Neuroscience,* vol. 19, no. 2, pp. 473-478.

Ranganathan, VK, Siemionow, V, Liu, JZ, Sahgal, V & Yue, GH 2004, 'From mental power to muscle power—gaining strength by using the mind', *Neuropsychologia,* vol. 42, no. 7, pp. 944-956.

Ranney, RR, Wilson, MB & Bennett, RB 2005, 'Evaluation of applicants to predoctoral dental education programs: review of the literature', *Journal of Dental Education,* vol. 69, no. 10, October, pp. 1095-1106.

Raybould, TP, Raggard, DC & Norton, JC 1983, 'Psychomotor skills and technical ability in dental school', *Journal of Dental Education,* vol. 47, no. 9, September, pp. 594-598.

Recanzone, GH, Merzenich, MM, Jenkins, WM, Grajski, KA & Dinse, HR 1992, 'Topographic reorganization of the hand representation in cortical area 3b owl monkeys trained in a frequency-discrimination task', *Journal of Neurophysiology,* vol. 67, no. 5, pp. 1031-1056.

Reddon, JR, Gill, DM, Gauk, SE & Maerz, MD 1988, 'Purdue Pegboard: Test-retest estimates', *Perceptual and Motor Skills,* vol. 66, no. 2, April, pp. 503-506.

Rees, K, Allen, D & Lader, M 1999, 'The influences of age and caffeine on psychomotor and cognitive function', *Psychopharmacology,* vol. 145, no. 2, July, pp. 181-188.

Rizzolatti, G, Fadiga, L, Gallese, V & Fogassi, L 1996a, 'Premotor cortex and the recognition of motor actions', *Cognitive Brain Research,* vol. 3, no. 2, pp. 131-141.

Rizzolatti, G, Fadiga, L, Matelli, M, Bettinardi, V, Paulesu, E, Perani, D & Fazio, F 1996b, 'Localization of grasp representations in humans by PET: 1. Observation versus execution', *Experimental Brain Research,* vol. 111, no. 2, September, pp. 246-252.

Rizzolatti, G, Fogassi, L & Gallese, V 2001, 'Neurophysiological mechanisms underlying the understanding and imitation of action', *Nature Reviews Neuroscience,* vol. 2, no. 9, pp. 661-670.

Rizzolatti, G & Craighero, L 2004, 'The mirror-neuron system', *Annual Review of Neuroscience,* vol. 27, no. 1, pp. 169-192.

Rizzolatti, G 2005, 'The mirror neuron system and its function in humans', *Anatomy and Embryology,* vol. 210, no. 5, pp. 419-421.

Rogasch, NC & Todd, G 2013, 'rTMS over human motor cortex can modulate tremor during movement', *European Journal of Neuroscience,* vol. 37, no. 2, pp. 323-329.

Rogers, DA, Regehr, G, Yeh, KA & Howdieshell, TR 1998, 'Computer-assisted learning versus a lecture and feedback seminar for teaching a basic surgical technical skill', *The American Journal of Surgery,* vol. 175, no. 6, pp. 508-510.

Rogers, WH & Noddin, EM 1984, 'Manual performance in the cold with gloves and bare hands', *Perceptual and Motor Skills* vol. 59, no. 1, pp. 3-13.

Rose, DJ & Christina, RW 2006, *A multilevel approach to the study of motor control and learning,* 2nd edn, Pearson/Benjamin Cummings, San Francisco, California.

Rosenkranz, K & Rothwell, JC 2012, 'Modulation of proprioceptive integration in the motor cortex shapes human motor learning', *The Journal of Neuroscience,* vol. 32, no. 26, pp. 9000-9006.

Rothwell, J, Traub, M, Day, B, Obeso, J, Thomas, P & Marsden, C 1982, 'Manual motor performance in a deafferented man', *Brain*, vol. 105, no. 3, pp. 515-542.

Ruff, RM & Parker, SB 1993, 'Gender- and age-specific changes in motor speed and eye-hand coordination in adults: normative values for the Finger Tapping and Grooved Pegboard Tests', *Perceptual and Motor Skills*, vol. 76, no. 3 Pt 2, June, pp. 1219-1230.

Ruth, S & Kegerreis, S 1992, 'Facilitating cervical flexion using a Feldenkrais method: Awareness through movement', *Journal of Orthopaedic & Sports Physical Therapy*, vol. 16, no. 1, pp. 25-29.

Ryan, RM 1982, 'Control and information in the intrapersonal sphere: An extension of cognitive evaluation theory', *Journal of Personality and Social Psychology*, vol. 43, pp. 450-461.

Sakamoto, T, Arissian, K & Asanuma, H 1989, 'Functional role of the sensory cortex in learning motor skills in cats', *Brain Research*, vol. 503, no. 2, pp. 258-264.

Sakong, J, Kang, P-S, Kim, C-Y, Hwang, T-Y, Jeon, M-J, Park, S-Y, Lee, S-j, Won, K-C, Lee, S-B & Chung, J-H 2007, 'Evaluation of reliability of traditional and computerized neurobehavioral tests', *Neurotoxicology*, vol. 28, no. 2, pp. 235-239.

Salmoni, AW, Schmidt, RA & Walter, CB 1984, 'Knowledge of results and motor learning: A review and critical reappraisal', *Psychological Bulletin*, vol. 95, no. 3, pp. 355-386.

Sanes, JN & Donoghue, JP 2000, 'Plasticity and primary motor cortex', *Annual Review of Neuroscience* vol. 23, pp. 393-415.

Sattler, JMEJ 1982, 'Sex differences on Purdue Pegboard norms for children', *Journal of Clinical Child Psychology*, vol. 11, no. 1, p. 72.

Savion-Lemieux, T & Penhune, VB 2005, 'The effects of practice and delay on motor skill learning and retention', *Experimental Brain Research*, vol. 161, no. 4, March, pp. 423-431.

Schabrun, SM & Hillier, SL 2009, 'Evidence for the retraining of sensation after stroke: a systematic review', *Clinical Rehabilitation*, vol. 23, no. 1, pp. 27-39.

Schijven, MP, Jakimowicz, JJ & Carter, FJ 2004, 'How to select aspirant laparoscopic surgical trainees: establishing concurrent validity comparing Xitact LS500 index performance scores with standardized psychomotor aptitude test battery scores', *Journal of Surgical Research*, vol. 121, no. 1, September, pp. 112-119.

Schmidt, RA 1975, 'A schema theory of discrete motor skill learning', *Psychological Review*, vol. 82, no. 4, p. 225.

Schmidt, RA, Young, DE, Swinnen, S & Shapiro, DC 1989, 'Summary knowledge of results for skill acquisition: support for the guidance hypothesis', *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 15, no. 2, p. 352.

Schmidt, RA & Lee, TD 2005, *Motor control and learning : a behavioral emphasis*, 4th edn, Human Kinetics, Champaign, IL.

Schmidt, RA & Lee, TD 2011, *Motor control and learning : a behavioral emphasis*, 5th edn, Human Kinetics, Champaign, IL.

Schmidt, SL, Oliveira, RM, Rocha, FoR & Abreu-Villaca, Y 2000, 'Influences of handedness and gender on the grooved pegboard test', *Brain and Cognition*, vol. 44, no. 3, pp. 445-454.

Schueneman, AL, Pickleman, J, Hesslein, R & Freeark, RJ 1984, 'Neuropsychologic predictors of operative skill among general surgery residents', *Surgery*, vol. 96, no. 2, August, pp. 288-295.

Seitz, AR & Dinse, HR 2007, 'A common framework for perceptual learning', *Current Opinion in Neurobiology*, vol. 17, no. 2, pp. 148-153.

Seitz, RJ, Roland, PE, Bohm, C, Greitz, T & Stone-Elander, S 1990, 'Motor learning in man: a positron emission tomographic study', *Neuroreport*, vol. 1, no. 1, pp. 57-60.

Selfdeterminationtheory.org 2014, *Intrinsic Motivation Inventory*, updated 2014, viewed June 2011, 2014, <http://www.selfdeterminationtheory.org/intrinsic-motivation-inventory/>.

Selnes, OA, Jacobson, L, Machado, AM, Becker, JT, Wesch, J, Miller, EN, Visscher, B & McArthur, JC 1991, 'Normative data for a brief neuropsychological screening battery. Multicenter AIDS Cohort Study', *Perceptual and Motor Skills*, vol. 73, no. 2, Oct, pp. 539-550.

Seltman, H 2010, *Experimental design and analysis*. <http://www.stat.cmu.edu/~hseltman/309/Book/>

Seymour, NE, Gallagher, AG, Roman, SA, O'Brien, MK, Bansal, VK, Andersen, DK & Satava, RM 2002, 'Virtual reality training improves operating room performance: results of a randomized, double-blinded study', *Annals of Surgery*, vol. 236, no. 4, October, pp. 458-463.

Shadmehr, R & Holcomb, HH 1997, 'Neural correlates of motor memory consolidation', *Science*, vol. 277, no. 5327, pp. 821-825.

Shadmehr, R, Smith, MA & Krakauer, JW 2010, 'Error correction, sensory prediction, and adaptation in motor control', *Annual Review of Neuroscience* vol. 33, pp. 89-108.

Shea, CH & Kohl, RM 1991, 'Composition of practice: Influence on the retention of motor skills', *Research Quarterly for Exercise and Sport*, vol. 62, no. 2, pp. 187-195.

Shea, CH, Wulf, G & Whitacre, C 1999, 'Enhancing training efficiency and effectiveness through the use of dyad training', *Journal of Motor Behavior*, vol. 31, no. 2, June, pp. 119-125.

Shea, CH, Lai, Q, Black, C & Park, J-H 2000a, 'Spacing practice sessions across days benefits the learning of motor skills', *Human Movement Science*, vol. 19, no. 5, pp. 737-760.

Shea, CH, Wright, DL, Wulf, G & Whitacre, C 2000b, 'Physical and observational practice afford unique learning opportunities', *Journal of Motor Behavior*, vol. 32, no. 1, p. 27.

Shebilske, WL, Regian, JW, Arthur, W & Jordan, JA 1992, 'A dyadic protocol for training complex skills', *Human Factors*, vol. 34, no. 3, June, pp. 369-374.

Shebilske, WL, Jordan, JA, Goettl, BP & Paulus, LE 1998, 'Observation versus hands-on practice of complex skills in dyadic, triadic, and tetradic training-teams', *Human Factors*, vol. 40, no. 4, pp. 525-525.

Sherrington, CS 1906, *The integrative action of the nervous system*, Yale University Press, New Haven, Connecticut.

Shik, ML & Orlovsky, GN 1976, 'Neurophysiology of locomotor automatism', *Physiological Reviews*, vol. 56, no. 3, pp. 465-501.

Shimoyama, I, Ninchoji, T & Uemura, K 1990, 'The finger-tapping test. A quantitative analysis', *Archives of Neurology*, vol. 47, no. 6, June, pp. 681-684.

Shumway-Cook, A & Woollacott, MH 2011, *Motor control : Translating research into clinical practice*, 4th edn, Wolters Kluwer Health/Lippincott Williams & Wilkins, Philadelphia.

Simon, JF & Chambers, DW 1992, 'The search for a profile of aptitudes that characterize dentists', *Journal of Dental Education*, vol. 56, no. 5, May, pp. 317-321.

Smania, N, Montagnana, B, Faccioli, S, Fiaschi, A & Aglioti, SM 2003, 'Rehabilitation of somatic sensation and related deficit of motor control in patients with pure sensory stroke', *Archives of Physical Medicine and Rehabilitation*, vol. 84, no. 11, pp. 1692-1702.

Smith, AL, McConville, JC & Kolt, GS 2001, 'The effect of the Feldenkrais method on pain and anxiety in people experiencing chronic low back pain', *New Zealand Journal of Physiotherapy*, vol. 29, no. 1, pp. 6-14.

Spaeth, RK 1972, 'Maximizing goal attainment', *Research Quarterly. American Association for Health, Physical Education and Recreation*, vol. 43, no. 3, pp. 337-361.

Spielberger, CD 1983, *Manual for the State-Trait Anxiety Inventory (STAI)*

Spratley, MH 1990, 'Aptitude testing and the selection of dental students', *Australian Dental Journal*, vol. 35, no. 2 Supp, pp. 159-168.

Squire, D, Giachino, AA, Profitt, AW & Heaney, C 1989, 'Objective comparison of manual dexterity in physicians and surgeons', *Canadian Journal of Surgery*, vol. 32, no. 6, November, pp. 467-470.

Stalling, LM 1976, 'Application of an information-processing model', *Motor Skills: Theory into practice*, vol. 1, no. 1, pp. 12-22.

Steele, RJ, Walder, C & Herbert, M 1992, 'Psychomotor testing and the ability to perform an anastomosis in junior surgical trainees', *British Journal of Surgery*, vol. 79, no. 10, October, pp. 1065-1067.

Stefan, K, Classen, J, Celnik, P & Cohen, L 2008, 'Concurrent action observation modulates practice- induced motor memory formation', *European Journal of Neuroscience*, vol. 27, no. 3, pp. 730-738.

Stefanidis, D, Korndorffer Jr, JR, Black, FW, Dunne, JB, Sierra, R, Touchard, CL, Rice, DA, Markert, RJ, Kastl, PR & Scott, DJ 2006, 'Psychomotor testing predicts rate of skill acquisition for proficiency-based laparoscopic skills training', *Surgery*, vol. 140, no. 2, August, pp. 252-262.

Stefanidis, D, Korndorffer Jr, JR, Heniford, BT & Scott, DJ 2007, 'Limited feedback and video tutorials optimize learning and resource utilization during laparoscopic simulator training', *Surgery*, vol. 142, no. 2, pp. 202-206.

Stein, ML 1927, 'A trial with criteria of the MacQuarrie Test of Mechanical Ability', *Journal of Applied Psychology*, vol. 11, no. 5, pp. 391-393.

Sterne, DM 1969, 'The Purdue pegboard and MacQuarrie tapping and dotting tasks as measures of motor functioning', *Perceptual and Motor Skills,* vol. 28, no. 2, April, p. 556.

Stevens, D, Anderson, DI, O'Dwyer, NJ & Mark Williams, A 2012, 'Does self-efficacy mediate transfer effects in the learning of easy and difficult motor skills?', *Consciousness and Cognition,* vol. 21, no. 3, pp. 1122-1128.

Strauss, E, Sherman, EMS & Spreen, O 2006, *A compendium of neuropsychological tests : administration, norms, and commentary,* 3rd edn, Oxford University Press, New York, NY.

Strenge, H, Niederberger, U & Seelhorst, U 2002, 'Correlation between tests of attention and peformance on Grooved and Purdue Pegbaoards in normal subjects', *Perceptual and Motor Skills,* vol. 95, no. 6, p. 507.

Suksudaj, N, Townsend, GC, Kaidonis, J, Lekkas, D & Winning, TA 2012, 'Acquiring psychomotor skills in operative dentistry: do innate ability and motivation matter?', *European Journal of Dental Education,* vol. 16, no. 1, February, pp. e187-194.

Sun, R, Merrill, E & Peterson, T 2001, 'From implicit skills to explicit knowledge: A bottom-up model of skill learning', *Cognitive Science,* vol. 25, no. 2, pp. 203-244.

Sun, R, Slusarz, P & Terry, C 2005, 'The interaction of the explicit and the implicit in skill learning: a dual-process approach', *Psychological Review,* vol. 112, no. 1, p. 159.

Tannenbaum, SI, Mathieu, JE, Salas, E & Cannon-Bowers, JA 1991, 'Meeting trainees' expectations: The influence of training fulfillment on the development of commitment, self-efficacy, and motivation', *Journal of Applied Psychology,* vol. 76, no. 6, pp. 759-769.

Taub, E, Crago, JE, Burgio, LD, Groomes, TE, Cook, EW, 3rd, DeLuca, SC & Miller, NE 1994, 'An operant approach to rehabilitation medicine: overcoming learned nonuse by shaping', *Journal of the Experimental Analysis of Behavior,* vol. 61, no. 2, March, pp. 281-293.

Tegenthoff, M, Ragert, P, Pleger, B, Schwenkreis, P, Forster, A, Nicolas, V & Dinse, HR 2005, 'Improvement of tactile discrimination performance and enlargement of cortical somatosensory maps after 5 Hz rTMS', *PLoS Biology,* vol. 3, no. 11, p. 2031.

Thorndike, EL 1927, 'The law of effect', *The American Journal of Psychology,* vol. 39, pp. 212-222.

Thuraisingam, AI, MacDonald, J & Shaw, IS 2006, 'Insights into endoscopy training: a qualitative study of learning experience', *Medical Teacher,* vol. 28, no. 5, August, pp. 453-459.

Tiffin, J & Asher, EJ 1948, 'The Purdue Pegboard; norms and studies of reliability and validity', *Journal of Applied Psychology,* vol. 32, no. 3, June, pp. 234-247.

Tiffin, J 1968, *Purdue Pegboard Examiner's Manual,* London House, Rosemont IL, p. 15.

Titzer, R, Shea, J & Romack, J 1993, 'The effect of learner control on the acquisition and retention of a motor task', *Sport and Exercise Psychology,* vol. 15, no. Supplementary, p. S84.

Todd, G, Rogasch, NC, Flavel, SC & Ridding, MC 2009, 'Voluntary movement and repetitive transcranial magnetic stimulation over human motor cortex', *Journal of applied physiology,* vol. 106, no. 5, May, pp. 1593-1603.

Torkington, J, Smith, SGT, Rees, BI & Darzi, A 2001, 'Skill transfer from virtual reality to a real laparoscopic task', *Surgical Endoscopy*, vol. 15, no. 10, pp. 1076-1079.

Touwen, BCL 1995, 'The neurological development of prehension: a developmental neurologist's view', *International Journal of Psychophysiology* vol. 19, no. 2, March, pp. 115-127.

Triggs, WJ, Calvanio, R, Levine, M, Heaton, RK & Heilman, KM 2000, 'Predicting hand preference with performance on motor tasks', *Cortex*, vol. 36, no. 5, December, pp. 679-689.

Trites, RL 1977, *Neuropsychological Test Manual*, Royal Ottowa Hospital, Ottowa, Ontario, Canada.

Umilta, MA, Kohler, E, Gallese, V, Fogassi, L, Fadiga, L, Keysers, C & Rizzolatti, G 2001, 'I know what you are doing: a neurophysiological study', *Neuron*, vol. 31, no. 1, pp. 155-165.

Vahdat, S, Darainy, M & Ostry, DJ 2014, 'Structure of plasticity in human sensory and motor networks due to perceptual learning', *The Journal of Neuroscience*, vol. 34, no. 7, pp. 2451-2463.

Vallerand, RJ & Rousseau, FL 2001, 'Intrinsic and extrinsic motivation in sport and exercise: a review using the hierarchical model of intrinsic and extrinsic motivation', in Singer, RN, Hausenblas, HA & C.M., J (eds), *Handbook of Sport Psychology 2nd Edition*, Wiley, New York, pp. 389-416.

Van Beers, RJ, Wolpert, DM & Haggard, P 2002, 'When feeling is more important than seeing in sensorimotor adaptation', *Current Biology*, vol. 12, no. 10, pp. 834-837.

Van Herzeele, I, O'Donoghue, KGL, Aggarwal, R, Vermassen, F, Darzi, A & Cheshire, NJW 2010, 'Visuospatial and psychomotor aptitude predicts endovascular performance of inexperienced individuals on a virtual reality simulator', *Journal of Vascular Surgery*, vol. 51, no. 4, April, pp. 1035-1042.

Van Mier, H, Tempel, L, Perlmutter, J, Raichle, M & Petersen, S 1998, 'Changes in brain activity during motor learning measured with PET: effects of hand of performance and practice', *Journal of Neurophysiology*, vol. 80, no. 4, pp. 2177-2199.

Vance, J, Wulf, G, Töllner, T, McNevin, N & Mercer, J 2004, 'EMG activity as a function of the performer's focus of attention', *Journal of Motor Behavior*, vol. 36, no. 4, pp. 450-459.

Vega, A, Jr. & Parsons, OA 1967, 'Cross-validation of the Halstead-Reitan tests for brain damage', *Journal of Consulting Psychology*, vol. 31, no. 6, December, pp. 619-625.

Verdolini-Marston, K & Balota, DA 1994, 'Role of elaborative and perceptual integrative processes in perceptual-motor performance', *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 20, no. 3, p. 739.

Vereijken, B, Emmerik, REAv, Whiting, HTA & Newell, KM 1992, 'Free(z)ing degrees of freedom in skill acquisition', *Journal of Motor Behavior*, vol. 24, no. 1, pp. 133-142.

Vidoni, ED & Boyd, LA 2007, 'Achieving enlightenment: what do we know about the implicit learning system and its interaction with explicit knowledge?', *Journal of Neurologic Physical Therapy*, vol. 31, no. 3, pp. 145-154.

Villardita, C, Cultrera, S, Cupone, V & Mejìa, R 1985, 'Neuropsychological test performances and normal aging', *Archives of Gerontology and Geriatrics*, vol. 4, no. 4, pp. 311-319.

Vogt, S, Buccino, G, Wohlschläger, AM, Canessa, N, Shah, NJ, Zilles, K, Eickhoff, SB, Freund, H-J, Rizzolatti, G & Fink, GR 2007, 'Prefrontal involvement in imitation learning of hand actions: Effects of practice and expertise', *Neuroimage*, vol. 37, no. 4, pp. 1371-1383.

Waldman, KB, Macdonald, G & Wilson, SG 1995, 'The relationship between standardized psychomotor tests and basic clinical dental hygiene skills', *Journal of Dental Hygiene*, vol. 69, no. 4, July-August, pp. 163-168.

Waldron, EM, Jr. & Anton, BS 1995, 'Effects of exercise on dexterity', *Perceptual and Motor Skills*, vol. 80, no. 3 Pt 1, June, pp. 883-889.

Wanzel, KR, Ward, M & Reznick, RK 2002, 'Teaching the surgical craft: From selection to certification', *Current Problems in Surgery*, vol. 39, no. 6, June, pp. 573-659.

Wanzel, KR, Hamstra, SJ, Caminiti, MF, Anastakis, DJ, Grober, ED & Reznick, RK 2003, 'Visual-spatial ability correlates with efficiency of hand motion and successful surgical performance', *Surgery*, vol. 134, no. 5, November, pp. 750-757.

Warr, P & Bunce, D 1995, 'Trainee characteristics and the outcomes of open learning', *Personnel Psychology*, vol. 48, no. 2, pp. 347-375.

Warr, P & Downing, J 2000, 'Learning strategies, learning anxiety and knowledge acquisition', *British Journal of Psychology*, vol. 91, no. 3, August, pp. 311-333.

Waterman, AS 2005, 'When effort is enjoyed: Two studies of intrinsic motivation for personally salient activities', *Motivation and Emotion*, vol. 29, no. 3, pp. 165-188.

Weinstein, P, Kiyak, HA, Milgrom, P, Ratener, P & Morrison, K 1979, 'Manual dexterity as a predictor of quality of care among dental practitioners', *Journal of Dental Education*, vol. 43, no. 3, March, pp. 165-169.

Westling, G & Johansson, RS 1984, 'Factors influencing the force control during precision grip', *Experimental Brain Research*, vol. 53, no. 2, pp. 277-284.

Wierinck, E, Puttemans, V, Swinnen, S & van Steenberghe, D 2005, 'Effect of augmented visual feedback from a virtual reality simulation system on manual dexterity training', *European Journal of Dental Education*, vol. 9, no. 1, pp. 10-16.

Wierinck, E, Puttemans, V & van Steenberghe, D 2006, 'Effect of reducing frequency of augmented feedback on manual dexterity training and its retention', *Journal of Dentistry*, vol. 34, no. 9, pp. 641-647.

Willingham, DB, Nissen, MJ & Bullemer, P 1989, 'On the development of procedural knowledge', *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 15, no. 6, pp. 1047-1060.

Willingham, DB & Goedert-Eschmann, K 1999, 'The relation between implicit and explicit learning: Evidence for parallel development', *Psychological Science*, vol. 10, no. 6, pp. 531-534.

Wilson, BC, Iacoviello, JM, Wilson, JJ & Risucci, DA 1982, 'Purdue Pegboard performance of normal preschool children', *Journal of Clinical Neuropsychology*, vol. 4, no. 1, pp. 19-26.

Wilson, SG, Waldman, KB & MacDonald, G 1991, 'An analysis of abilities underlying early periodontal skill development of dental students', *Evaluation & the Health Professions*, vol. 14, no. 1, March, pp. 41-60.

Wolpert, DM & Kawato, M 1998, 'Multiple paired forward and inverse models for motor control', *Neural Networks*, vol. 11, no. 7–8, pp. 1317-1329.

Wolpert, DM, Diedrichsen, J & Flanagan, JR 2011, 'Principles of sensorimotor learning', *Nature Reviews Neuroscience*, vol. 12, no. 12, pp. 739-751.

Wong, M, Peters, RM & Goldreich, D 2013, 'A physical constraint on perceptual learning: tactile spatial acuity improves with training to a limit set by finger size', *The Journal of Neuroscience*, vol. 33, no. 22, pp. 9345-9352.

Wood, RE, Mento, AJ & Locke, EA 1987, 'Task complexity as a moderator of goal effects: a meta-analysis', *Journal of Applied Psychology*, vol. 72, no. 3, p. 416.

Wulf, G & Schmidt, RA 1997, 'Variability of practice and implicit motor learning', *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 23, no. 4, p. 987.

Wulf, G & Weigelt, C 1997, 'Instructions about physical principles in learning a complex motor skill: To tell or not to tell…', *Research Quarterly for Exercise and Sport*, vol. 68, no. 4, pp. 362-367.

Wulf, G, Höß, M & Prinz, W 1998, 'Instructions for motor learning: Differential effects of internal versus external focus of attention', *Journal of motor behavior*, vol. 30, no. 2, pp. 169-179.

Wulf, G, McNevin, N & Shea, CH 2001, 'The automaticity of complex motor skill learning as a function of attentional focus', *The Quarterly Journal of Experimental Psychology: Section A Human Experimental Psychology*, vol. 54, no. 4, pp. 1143-1154.

Wulf, G & Shea, CH 2002, 'Principles derived from the study of simple skills do not generalize to complex skill learning', *Psychonomic bulletin & review*, vol. 9, no. 2, June, pp. 185-211.

Wulf, G, Raupach, M & Pfeiffer, F 2005, 'Self-controlled observational practice enhances learning', *Research Quarterly for Exercise and Sport*, vol. 76, no. 1, March, pp. 107-111.

Wulf, G 2007, 'Self-controlled practice enhances motor learning: implications for Physiotherapy', *Physiotherapy*, vol. 93, pp. 96-101.

Wulf, G, Shea, CH & Lewthwaite, R 2010, 'Motor skill learning and performance: a review of influential factors', *Medical Education*, vol. 44, no. 1, pp. 75-84.

Xerri, C, Merzenich, MM, Jenkins, W & Santucci, S 1999, 'Representational plasticity in cortical area 3b paralleling tactual-motor skill acquisition in adult monkeys', *Cerebral Cortex*, vol. 9, no. 3, pp. 264-276.

Yadav, R & O'Regan, DJ 2010, 'Left out: A study to determine bimanual dexterity in practising surgeons', *Bulletin of The Royal College of Surgeons of England*, vol. 92, no. 6, pp. 1-6.

Yamada, M, Kawachi, T, Kawamitsu, H, Yamada, T, Konishi, J, Fujii, M, Sugimura, K, Maeda, K & Kawamata, T 2010, 'Effect of perceptual learning on motor skills of hands: a functional magnetic resonance imaging study', *The Kobe Journal of Medical Sciences* vol. 56, no. 1, pp. E29-37.

Yeudall, LT, Fromm, D, Reddon, JR & Stefanyk, WO 1986, 'Normative data stratified by age and sex for 12 neuropsychological tests', *Journal of Clinical Psychology*, vol. 42, no. 6, pp. 918-946.

Yeudall, LT, Reddon, JR, Gill, DM & Stefanyk, WO 1987, 'Normative data for the Halstead-Reitan neuropsychological tests stratified by age and sex', *Journal of Clinical Psychology*, vol. 43, no. 3, May, pp. 346-367.

Zachry, T, Wulf, G, Mercer, J & Bezodis, N 2005, 'Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention', *Brain Research Bulletin*, vol. 67, no. 4, pp. 304-309.

Zattara, M & Bouisset, S 1988, 'Posturo-kinetic organisation during the early phase of voluntary upper limb movement. 1. Normal subjects', *Journal of Neurology, Neurosurgery & Psychiatry*, vol. 51, no. 7, July 1, 1988, pp. 956-965.

Zeuner, KE, Bara- Jimenez, W, Noguchi, PS, Goldstein, SR, Dambrosia, JM & Hallett, M 2002, 'Sensory training for patients with focal hand dystonia', *Annals of Neurology*, vol. 51, no. 5, pp. 593-598.

Zeuner, KE & Hallett, M 2003, 'Sensory training as treatment for focal hand dystonia: A 1-year follow- up', *Movement Disorders*, vol. 18, no. 9, pp. 1044-1047.

Zullo, TG 1971, 'A factor analysis of perceptual and motor abilities of dental students', *Journal of Dental Education*, vol. 35, no. 6, June, pp. 356-361.

Zwicker, JG & Harris, SR 2009, 'A reflection on motor learning theory in pediatric occupational therapy practice', *Canadian Journal of Occupational Therapy*, vol. 76, no. 1, pp. 29-37.

Appendix A Permission for figure 1.2-2

Recently you requested personal assistance from our on-line support center. Below is a summary of your request and our response.

If you are receiving this in response to a request you made, a summary is below. If you have not made a request, the following is a communication on behalf of your LWW Sales Representative.

Thank you for allowing us to be of service to you.

To access your question from our support site, click here.

Subject

Shumway-Cook A and Woollacott MH Book Permissions Request

Discussion Thread

Response Via Email (Caren Erlichman) 11/06/2015 01:16 PM

Hello Ryan.

Thank you for contacting us. We do allow material from Shumway-Cook to be borrowed, and since you will remove it from the electronic copy of your thesis that will be posted to your University repository, we will be able to grant you permission to use Figure 1.1 from page 4 in print format.

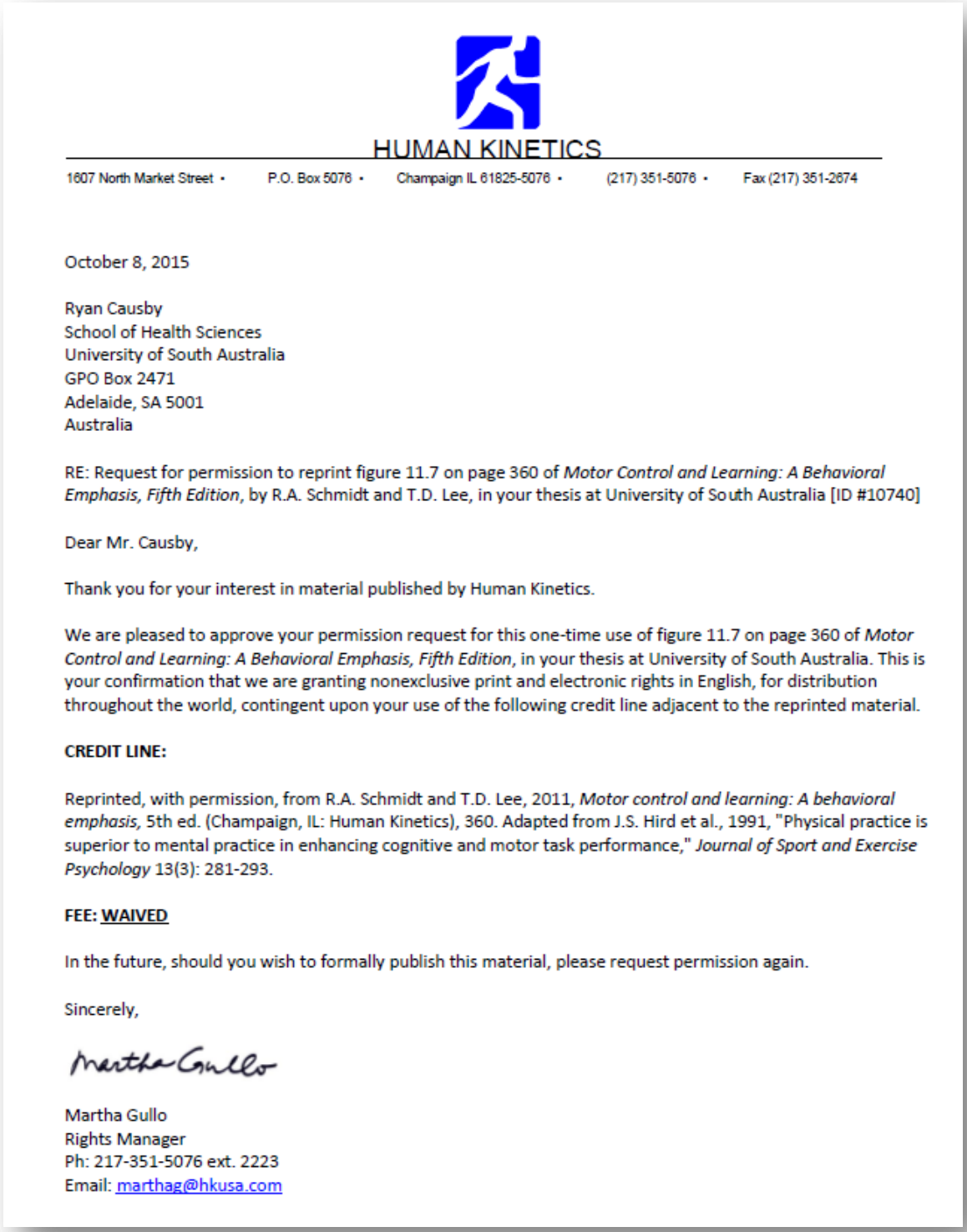
I have attached a link to our Terms and Conditions for the permission. Those, along with this email, can serve as your formal letter of permission. Thank you.

www.lww.com/healthpermissions-terms

Sincerely,

Caren Erlichman
Health Permissions Team
Health Learning, Research and Practice
Wolters Kluwer

Appendix B Permission for figure 1.2-4



HUMAN KINETICS

1607 North Market Street • P.O. Box 5076 • Champaign IL 61825-5076 • (217) 351-5076 • Fax (217) 351-2674

October 8, 2015

Ryan Causby
School of Health Sciences
University of South Australia
GPO Box 2471
Adelaide, SA 5001
Australia

RE: Request for permission to reprint figure 11.7 on page 360 of *Motor Control and Learning: A Behavioral Emphasis, Fifth Edition*, by R.A. Schmidt and T.D. Lee, in your thesis at University of South Australia [ID #10740]

Dear Mr. Causby,

Thank you for your interest in material published by Human Kinetics.

We are pleased to approve your permission request for this one-time use of figure 11.7 on page 360 of *Motor Control and Learning: A Behavioral Emphasis, Fifth Edition*, in your thesis at University of South Australia. This is your confirmation that we are granting nonexclusive print and electronic rights in English, for distribution throughout the world, contingent upon your use of the following credit line adjacent to the reprinted material.

CREDIT LINE:

Reprinted, with permission, from R.A. Schmidt and T.D. Lee, 2011, *Motor control and learning: A behavioral emphasis,* 5th ed. (Champaign, IL: Human Kinetics), 360. Adapted from J.S. Hird et al., 1991, "Physical practice is superior to mental practice in enhancing cognitive and motor task performance," *Journal of Sport and Exercise Psychology* 13(3): 281-293.

FEE: WAIVED

In the future, should you wish to formally publish this material, please request permission again.

Sincerely,

Martha Gullo

Martha Gullo
Rights Manager
Ph: 217-351-5076 ext. 2223
Email: marthag@hkusa.com

Appendix C Ethics approval study one

-----Original Message-----
From: no_reply@unisa.edu.au [mailto:no_reply@unisa.edu.au]
Sent: Wednesday, 7 September 2011 9:40 AM
To: Causby, Ryan Scott - caurs001
Cc: Michelle McDonnell; Causby, Ryan Scott - caurs001; Susan Hillier; Research Services
Subject: Human Ethics: Application approved

Dear Applicant

Re: Ethics protocol "Teaching of podiatric manual clinical skills in Australia and New Zealand"

Thank you for submitting your ethics protocol for consideration. Your protocol has been considered by the E1 Committee Review Group.

I am pleased to advise that your protocol has been granted ethics approval and meet the requirements of the National Statement on Ethical Conduct in Human Research. Please note that the E1 Committee Review Group's decision will be reported to the next meeting of the Human Research Ethics Committee for endorsement.

Please regard this email as formal notification of approval.

Ethics approval is always made on the basis of a number of conditions detailed at http://www.unisa.edu.au/res/forms/docs/humanresearchethics_conditions.doc; it is important that you are familiar with, and abide by, these conditions. It is also essential that you conduct all research according to UniSA guidelines, which can be found at http://www.unisa.edu.au/res/ethics/default.asp

Please note, if your project is a clinical trial you are required to register it in a publicly accessible trials registry prior to enrolment of the first participant (e.g. Australian New Zealand Clinical Trials Registry http://www.anzctr.org.au/Survey/UserQuestion.aspx) as a condition of ethics approval.

Best wishes for your research.

Vicki Allen
Executive Officer
UniSA's Human Research Ethics Committee CRICOS provider number 00121B

This is an automated email and cannot be replied to. Please direct your query to the relevant person.

Appendix D Recruitment email study one

We need your help!

As part of his PhD project at the University of South Australia, lecturer Ryan Causby is researching the teaching of manual clinical skills in podiatry (particularly scalpel skills). As part of this research he is investigating how manual clinical skills are currently being taught in podiatry programs in Australia and New Zealand.

What does it involve?

If you choose to participate, you will be provided with a list of interview questions via e-mail. If you are uncertain of an answer relevant to your program then you may discuss these with your colleagues. Approximately one week subsequent to receiving the interview questions you will be contacted by the primary researcher at a time convenient to you in order to provide answers to the questions. The interview will be recorded for later transcription.

Can I withdraw if I no longer want to participate?

You may withdraw at any stage without any consequence.

How do I become involved?

If you are happy to become involved or have any further questions, simply reply to this e-mail to Ryan.Causby@unisa.edu.au or make a call to the primary researcher , Tel: +61 8302 1542 OR +61 418 800 696…. It's as easy as that!

Finally…

The aim is to interview the Program Director and one other staff member directly involved in clinical teaching from each of the Universities teaching podiatry. Consequently, are you able to nominate another staff member involved in clinical teaching which we could contact to participate in the study?

Appendix E Consent form study one

University of South Australia

CONSENT FORM

Project title..... Teaching of Podiatric manual clinical skills in Australia and New Zealand

Researcher's name & contact details... Mr Ryan Causby, Phone 08 8302 1542, Ryan.Causby@unisa.edu.au .....

Supervisor's name & contact details..... Dr Susan Hillier, Phone 08 8302 2544, Susan.Hillier@unisa.edu.au; Dr Michelle McDonnell, Phone 08 8302 1684, Michelle.McDonnell@unisa.edu.au; Associate Professor Lloyd Reed, Phone 07 3138 5623, l.reed@qut.edu.au .....

- I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part.
- I understand the purpose of the research project and my involvement in it.
- I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential.
- I understand that I will be audiotaped during the interview.
- I understand that the tape will be stored in the office of the primary researcher or primary supervisor in a lockable filing cabinet and that only the research team will have access to the recording.

Name of participant.....

Signed.....**Date**.....

I have provided information about the research to the research participant and believe that he/she understands what is involved.

Researcher's signature and date.....

This project has been approved by the University of South Australia's Human Research Ethics Committee. If you have any ethical concerns about the project or questions about your rights as a participant please contact the Executive Officer of this Committee, Tel: +61 8 8302 3118; Email: Vicki.allen@unisa.edu.au

Appendix F Authorship form for published article

STATEMENT OF AUTHORSHIP

The Use of Objective Psychomotor Tests on the Health Professional Population
Perceptual and Motor Skills; 2014, 118/3, pp. 765.804

Name of candidate: Ryan Causby

I undertook the conceptualisation of the study, undertook the search and analysis of the articles. I wrote the draft manuscript and made appropriate changes before publication.

I hereby certify that this statement of contribution to the above-named paper is correct.

Signed: _____ *Date:* 10/11/15

Author 2:

Michelle McDonnell

I was involved in conceptualisation of the study and provided supervisory input into the manuscript draft.

I hereby certify that this statement of contribution to the above-named paper is correct, and I give permission for the inclusion of the paper in the thesis.

Signed: _____ *Date:* 10/11/15

Author 3:

Lloyd Reed

I was involved in conceptualisation of the study and provided supervisory input into the manuscript draft.

I hereby certify that this statement of contribution to the above-named paper is correct, and I give permission for the inclusion of the paper in the thesis.

Signed: _____ *Date:* 10.11.15

Author 4:

Susan Hillier

I was involved in conceptualisation of the study, evaluated the extracted data pertaining to validity and reliability and provided supervisory input into the manuscript draft.

I hereby certify that this statement of contribution to the above-named paper is correct, and I give permission for the inclusion of the paper in the thesis.

Signed: _____ *Date:* 10.11.15

Appendix G Data extraction form for review of tools

Full Name of Outcome measure		
Abbreviated name		
Designer of Outcome measure		
Reported clinimetric properties		
Measure	Temporal / Integer (ratio) / Integer (Interval)	
External Validity		
1. Tool has been validated on healthy population		Y/N/ unsure
	i. Learning	Y/N/ Not tested
	ii. Dominant : Non-dominant	Y/N/ Not tested
	iii. Gender	Y/N/ Not tested
	iv. Education	Y/N/ Not tested
	v. IQ	Y/N/ Not tested
	vi. Other……	Y/N/ Not tested
2. Normative values available		Y/N/Not stated
i. Populations:		
Internal Validity		
3. Factor Analysis undertaken		Y/N/Not stated
	i. Factor I	……
	ii. Factor II	……
	iii. Factor II	……
4. Face/Content validity		Y/N/ equivocal / NS
5. Criterion Validity		Y/N/ equivocal / NS
6. Sensitivity/Specificity		Y/N/ equivocal / NS
7. Floor/Ceiling effects		Y/N/ equivocal / NS
8. Factors affecting performance		
	i. Age	Y/N/ equivocal / NS
	ii. Gender	Y/N/ equivocal / NS
	iii. Handedness	Y/N/ equivocal / NS
	iv. Education	Y/N/ equivocal / NS
	v. IQ	Y/N/ equivocal / NS
9. Practice Effects		Y/N/ equivocal / NS
Reliability		
10. Sufficient Test – Retest reliability		Y/N/ equivocal / NS
11. Sufficient Inter-rater reliability		Y/N/ equivocal / NS
Application		
12. Equipment needs/availability	Easy / moderate / hard	
13. Knowledge requirements	Easy / moderate / hard	
14. Ease of application	Easy / moderate / hard	

Appendix H Overview of tests

Purdue Pegboard (PP)

(Tiffin, 1968; Tiffin & Asher, 1948)

The PP consists of a board with four cups across the top and two vertical rows of 25 small holes down the centre. Two of the cups contain 25 pins each; another contains 40 washers; and the fourth cup contains 20 collars. The test requires subjects to insert pins, using the left hand, right hand or both. When both hands are employed the pins are inserted with both hands simultaneously in two separate columns. Finally an assembly sub-test also utilises washers and collars, which are placed over the pins.

O'Connor Finger and Tweezers Dexterity Tests

(Hines & O'Connor, 1926; O'Connor, 1925)

The O'Con (F) test requires hand placement of 3 pins per hole. Consisting of 100 holes 4.76 mm diameter, holes are arranged in ten rows and spaced 12.7 mm apart. The Tweezers version utilises a similar board arrangement, but with holes of 1.59 mm size and therefore only a single pin inserted but with a pair of tweezers.

Grooved Pegboard Test (GPT)

(Kløve, 1963)

The GPT test has 25 keyhole style slots of varying orientation in a 5 x 5 metal board arrangement. Incorporated into the pegboard is a dish that contains matching pins of key-like presentation, which must be inserted accurately by manipulation.

Crawford Small Parts Dexterity Test (CSPDT)

(Crawford & Crawford, 1956)

The CSPDT utilises a wooden board (25.4 cm x 25.4 cm x 2.54 cm) with separate wells for pins, collars and screws. Subjects are then required to perform two separate tasks. The first, using tweezers requires the subject to insert small pins into close fitting holes in a plate, and then place small collars over them. The second task involves inserting screws to threaded holes in the plate until they are firmly in place.

Gibson Spiral Maze Test (GSM)

(Gibson, 1964)

The GSM Test was first designed as a psychomotor test of delinquency. Partly as it was believed to be a test of risk-taking, whereby participants forgo accuracy for speed. The test uses 25.4 cm square cards, with a heavy black line spiral printed on it, creating a pathway 135 cm long. Interspersed along the pathway are obstacles in the 'O' shape. Participants are required to negotiate the pathway as quick as possible avoiding the obstacles along the way. The examiner is also required to pointedly request they go faster every 15 seconds to introduce an element of stress (Gibson, 1964).

MacQuarrie Test

(MacQuarrie, 1927)

The MacQuarrie test is a paper and pencil test of psychomotor ability originally comprising of three specific sub-tests; Tracing, Tapping and Dotting. For the tracing test a continuous line is drawn through 80 small gaps within vertical lines, without touching them. For the tapping test participants attempt to make three dots in each 1cm diameter circle. The dotting test requires a dot to be made in each 5 mm diameter circle without touching the circumference.

All of the articles identified in the systematic search only report utilising the tapping, tracing and dotting sub-tests. Nevertheless, it should be noted that early references to the MacQuarrie test infrequently mention other sub-tests. These include the 'copying' subtest in which the subject is required to reproduce four-line angular figures in respect to length of a line and size of angles; the 'location' test in which the subject places points in small squares in homologous positions to given points in a large square; and the Block counting and Pursuit sub-tests which do not require any manual interaction (Babcock & Emerson, 1938).

Finger Tapping Test (FTT)

(Halstead, 1947)

The FTT (also known as the Finger Oscillation test) was originally a psychomotor measure within the Halstead impairment index (Mitrushina, et al., 2005). The original

device was a lever attached to a counter, which needs to be depressed by the examinee with the heel of their hand remaining in contact with the table. More recently other electronic devices have been used.

Minnesota Rate of Manipulation and Minnesota Manual Dexterity test (MRMT; MMDT)

(Minnesota Rate of Manipulation Test, 1931; Minnesota Rate of Manipulation Test, 1969)

The MRMT and MMDT are often confused as being the same test. However, there are in fact distinct differences. The original test, known as the 'MMDT' was first manufactured in 1931 and contained the 'placing' and 'turning' sub-tests only (Surrey et al., 2003). In 1933 a revision was made to the test and the name changed to the 'MRMT'. However, it was not until the mid-1940's that the additional sub-tests were added, being the 'displacing, one-hand turning and placing and the two-hand turning and placing'. Finally, physical changes were made to the test in 1969 including a change to the board thickness (Surrey, et al., 2003). Due to the associated confusion, where possible, the terminology will represent the terms used in the article reviewed.

The current setup of the Minnesota Manual Dexterity test consists of 50 wooden cylindrical discs, a Masonite board with holes to match the cylinders complemented with a carrying case. The test involves a manipulation of the small discs with the board lying flat on the table in five sub-tests: *Placing, Turning, Displacing, One-Hand Turning/Placing, and Two-Hand Turning/Placing.* The discs have a different colour on the bottom to allow differentiation for the turning sub-test. Each of the sub-tests are repeated a number of times.

Appendix I Ethics approval study two

-----Original Message-----
From: no_reply@unisa.edu.au [mailto:no_reply@unisa.edu.au]
Sent: Tuesday, 6 September 2011 1:37 PM
To: Causby, Ryan Scott - caurs001
Cc: Research Services; Michelle McDonnell; Causby, Ryan Scott - caurs001; Susan Hillier
Subject: Human Ethics: Application approved

Dear Applicant

Re: Ethics protocol "Dextrous performance and self-efficacy of Podiatry students and Podiatrists of different experience levels"

Thank you for submitting your ethics protocol for consideration. Your protocol has been considered by the E2 Committee Review Group.

I am pleased to advise that your protocol has been granted ethics approval and meet the requirements of the National Statement on Ethical Conduct in Human Research.

Please note that the E2 Committee Review Group's decision will be reported to the next meeting of the Human Research Ethics Committee for endorsement.

Please regard this email as formal notification of approval.

Ethics approval is always made on the basis of a number of conditions detailed at http://www.unisa.edu.au/res/forms/docs/humanresearchethics_conditions.doc; it is important that you are familiar with, and abide by, these conditions. It is also essential that you conduct all research according to UniSA guidelines, which can be found at http://www.unisa.edu.au/res/ethics/default.asp

Please note, if your project is a clinical trial you are required to register it in a publicly accessible trials registry prior to enrolment of the first participant (e.g. Australian New Zealand Clinical Trials Registry http://www.anzctr.org.au/Survey/UserQuestion.aspx) as a condition of ethics approval.

Best wishes for your research.

Vicki Allen
Executive Officer
UniSA's Human Research Ethics Committee
CRICOS provider number 00121B

This is an automated email and cannot be replied to. Please direct your query to the relevant person.

-----Original Message-----
From: QUT Research Ethics Unit

Sent: Tuesday, 1 November 2011 4:09 PM
To: Lloyd Reed
Cc: Janette Lamb
Subject: Ethics Application Approval -- 1100001362

Dear A/Prof Lloyd Reed

Project Title:
Dextrous performance and self-efficacy of podiatry students and podiatrists of different experience levels

Approval Number: 1100001362
Clearance Until: 1/03/2013
Ethics Category: Human

This email is to advise that your application has been reviewed by the Chair, University Human Research Ethics Committee and confirmed as meeting the requirements of the National Statement on Ethical Conduct in Human Research. We note ethics clearance has already been obtained from another institution.

Whilst the data collection of your project has received ethical clearance, the decision to commence and authority to commence may be dependent on factors beyond the remit of the ethics review process. For example, your research may need ethics clearance from other organisations or permissions from other organisations to access staff. Therefore the proposed data collection should not commence until you have satisfied these requirements.

If you require a formal approval certificate, please respond via reply email and one will be issued.

This project has been awarded ethical clearance until 1/03/2013 and a progress report must be submitted for an active ethical clearance at least once every twelve months. Researchers who fail to submit an appropriate progress report may have their ethical clearance revoked and/or the ethical clearances of other projects suspended. When your project has been completed please advise us by email at your earliest convenience.

For information regarding the use of social media in research, please go to:
http://www.research.qut.edu.au/ethics/humans/faqs/index.jsp

For variations, please ensure that approval has been sought from the lead university before completing and submit the QUT online variation form:
http://www.research.qut.edu.au/ethics/forms/hum/var/variation.jsp

Please do not hesitate to contact the unit if you have any queries.

Regards

Janette Lamb on behalf of the Chair UHREC
Research Ethics Unit | Office of Research
Level 4 | 88 Musk Avenue | Kelvin Grove
p: +61 7 3138 5123
e: ethicscontact@qut.edu.au
w: http://www.research.qut.edu.au/ethics/

Appendix J Recruitment email study two

We need your help…..!

As part of his PhD project at the University of South Australia, lecturer Ryan Causby is researching the teaching of manual clinical skills in podiatry (i.e. scalpel work). As part of this research he is investigating the variation in dexterity which exists between Novice, Intermediate and Experienced practitioners. To do this, a battery of tests will be applied to participants in each of the groups and the results compared. You are invited to participate in this study to help the long-term teaching of manual clinical skills to the profession. Participation is voluntary. To help you decide here are the answers to a few questions you may have:

What is dexterity?

Skilfulness in the use of one's hands or body

What does it involve?

If you choose to participate, you will be required to attend an appointment with the researcher, at which time you will undertake the battery of dexterity tests ranging from simple finger-tapping to a more complex computer task. You will be required to abstain from caffeine or exercise immediately prior to the testing period. At the completion of the battery of tests you will be asked to fill in a motivation questionnaire and undertake a basic podiatry task which may be videotaped….that's it!

What happens to my information?

Data will be recorded in hard copy and electronic format. Electronic information will be stored on the computer of the primary researcher with password protection. Hard-copy information will be stored in a lockable filing cabinet in the office of the primary researcher. All information will only be accessible by the research team. All records containing personal information will remain confidential and no information which could lead to identification of any individual will be released.

Can I withdraw if I no longer want to participate?

You may withdraw at any stage without any consequence.

How do I become involved?

If you want to become involved or have any further questions, simply send an e-mail or make a call to the primary researcher …. It's as easy as that!

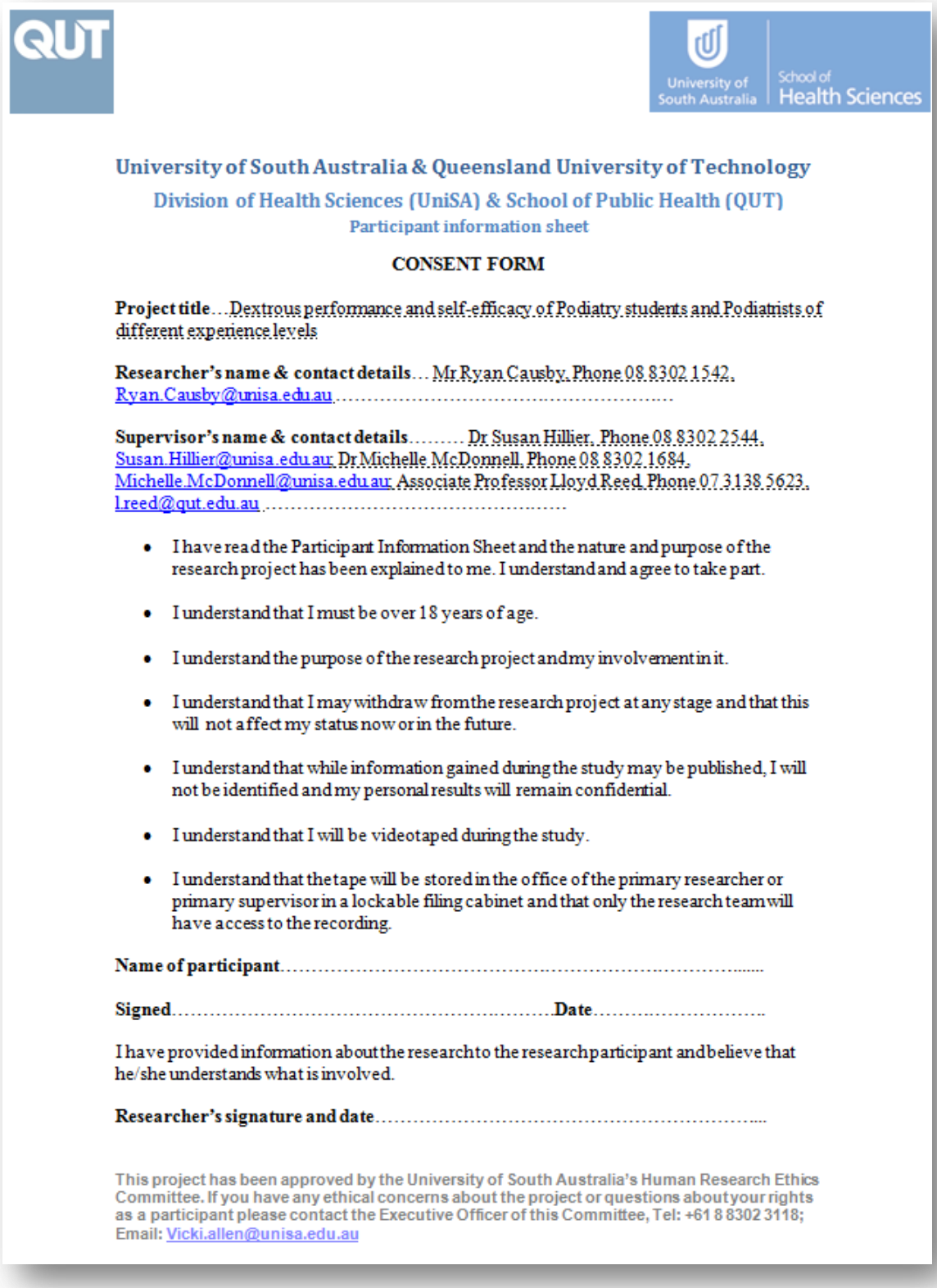
Primary Researcher: Mr Ryan Causby, Tel: +61 8302 1542, Ryan.Causby@unisa.edu.au

Principal Supervisor: Dr Susan Hillier, Tel: +61 8302 2544, Susan.Hillier@unisa.edu.au

Assoc. Supervisors: Dr Michelle McDonnell, Tel: +8302 1684, Michelle.McDonnell@unisa.edu.au A/Prof Lloyd Reed, Tel: +8302 1684, lreed@qut.edu.au

This project has been approved by the University of South Australia's Human Research Ethics Committee. If you have any ethical concerns about the project or questions about your rights as a participant please contact the Executive Officer of this committee, Tel: +61 8302 3118; Email: Vicki.allen@unisa.edu.au

Appendix K Consent form study two



University of South Australia & Queensland University of Technology

Division of Health Sciences (UniSA) & School of Public Health (QUT)

Participant information sheet

CONSENT FORM

Project title…Dextrous performance and self-efficacy of Podiatry students and Podiatrists of different experience levels

Researcher's name & contact details… Mr Ryan Causby, Phone 08 8302 1542, Ryan.Causby@unisa.edu.au……

Supervisor's name & contact details…… Dr Susan Hillier, Phone 08 8302 2544, Susan.Hillier@unisa.edu.au; Dr Michelle McDonnell, Phone 08 8302 1684, Michelle.McDonnell@unisa.edu.au; Associate Professor Lloyd Reed, Phone 07 3138 5623, l.reed@qut.edu.au ……

- I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part.
- I understand that I must be over 18 years of age.
- I understand the purpose of the research project and my involvement in it.
- I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential.
- I understand that I will be videotaped during the study.
- I understand that the tape will be stored in the office of the primary researcher or primary supervisor in a lockable filing cabinet and that only the research team will have access to the recording.

Name of participant……

Signed……**Date**……

I have provided information about the research to the research participant and believe that he/she understands what is involved.

Researcher's signature and date……

This project has been approved by the University of South Australia's Human Research Ethics Committee. If you have any ethical concerns about the project or questions about your rights as a participant please contact the Executive Officer of this Committee, Tel: +61 8 8302 3118; Email: Vicki.allen@unisa.edu.au

Appendix L Ethics approval study three

-----Original Message-----
From: no_reply@unisa.edu.au [mailto:no_reply@unisa.edu.au]
Sent: Tuesday, 20 March 2012 5:53 PM
To: Causby, Ryan Scott - caurs001; RCH Ethics
Cc: Lloyd Reed; Causby, Ryan Scott - caurs001; Susan Hillier
Subject: Human Ethics: Application approved subject to

Dear Applicant

Re: Ethics protocol "Improving dexterity in novice Podiatry students"

Thank you for submitting your ethics protocol for consideration. Your protocol has been considered by the E2 Committee Review Group.

I am pleased to advise that your protocol has been Approved Subject To you making a number of changes. Please refer to the page and/or summary comments entered in the application to see what amendments are required (if you are unsure how to view and/or respond to comments, please refer to the user guide available at http://www.unisa.edu.au/res/ethics/human/onlinesystemadvice.asp).

Please regard this email as formal notification of assessment.

Under the national guidelines, you must not begin your research before receiving final approval. Once you have submitted the necessary amendments, and they have been accepted, your approval will be finalised and you may commence your research.

Ethics approval is always made on the basis of a number of conditions detailed at http://www.unisa.edu.au/res/forms/docs/humanresearchethics_conditions.doc; it is important that you are familiar with, and abide by, these conditions. It is also essential that you conduct all research according to UniSA guidelines, which can be found at http://www.unisa.edu.au/res/ethics/human.asp. These guidelines should assist you with the formulation of necessary papers such as the information sheet and the consent form.

Please note, if your project is a clinical trial you are required to register it in a publicly accessible trials registry prior to enrolment of the first participant (e.g. Australian New Zealand Clinical Trials Registry http://www.anzctr.org.au/Survey/UserQuestion.aspx) as a condition of ethics approval.

We look forward to receiving your amendments in the near future. In the meantime, please contact me if you have any questions. Please note that if you do not respond to the Committee Review Groups comments and submit the application within 6 months of this review decision, your application will be marked as withdrawn and you will need to start a new application.

Kind regards

Executive Officer

UniSA' Human Research Ethics Committee
CRICOS provider number 00121B

This is an automated email and cannot be replied to. Please direct your query to ethics@unisa.edu.au.

-----Original Message-----
From: QUT Research Ethics Unit
Sent: Thursday, 24 January 2013 2:48 PM
To: Lloyd Reed
Cc: Janette Lamb
Subject: Ethics Application Approval -- 1200000722

Dear A/Prof Lloyd Reed

Project Title: Improving dexterity in novice podiatry students

Ethics category: Human - Administrative Review
QUT approval number: 1200000722 (University of South Australia HREC approval number: 0000027836)
QUT clearance until: 28/02/2014 (as per University of South Australia HREC approval)

We are pleased to advise that your administrative review application has been reviewed by the Chair, University Human Research Ethics Committee (UHREC), and confirmed as meeting the requirements of the National Statement on Ethical Conduct in Human Research (2007).

I can therefore confirm that your application has received QUT administrative review approval based on the approval gained from University of South Australia Human Research Ethics Committee (HREC), approval number 0000027836. We note this HREC has awarded the project ethical clearance until 28/02/2014.

CONDITIONS OF APPROVAL
Please ensure you and all other team members read through and understand all UHREC conditions of approval prior to commencing any data collection:
- Standard: Please see attached or www.research.qut.edu.au/ethics/humans/stdconditions.jsp
- Specific: None apply

VARIATIONS
University of South Australia HREC should be considered the lead HREC in terms of the ethical review of this project. As such, all variations must first be approved by University of South Australia HREC before submission to QUT for ratification. Please submit to QUT using our online variation form: www.research.qut.edu.au/ethics/humans/var/

MONITORING
Please ensure you also provide QUT with a copy of each adverse event report and progress report submitted to University of South Australia HREC.

Administrative review decisions are subject to ratification at the next available UHREC meeting. You will only be contacted again in relation to this matter if UHREC raises additional questions or concerns.

Please don't hesitate to contact us if you have any queries.

We wish you all the best with your research.

Kind regards

Janette Lamb on behalf of the Chair UHREC Research Ethics Unit | Office of Research | Level 4 88 Musk Avenue Kelvin Grove | Queensland University of Technology
p: +61 7 3138 5123 | e: ethicscontact@qut.edu.au | w: www.research.qut.edu.au/ethics/

Appendix M Recruitment email study three

We need your help…..!

As part of his PhD project at the University of South Australia, lecturer Ryan Causby is researching the teaching of manual clinical skills in podiatry (i.e. scalpel work). As part of this research he intends to trial the effect of two different activities on '**dexterity'** and '**confidence'** in undertaking scalpel skills. You are invited to participate in this study to help the long-term teaching of manual clinical skills to the profession. Participation is voluntary. To help you decide here are the answers to a few questions you may have:

What is dexterity?

Skilfulness in the use of one's hands or body

What does it involve?

If you choose to participate, you will be required to attend a short training session immediately after you have been introduced to scalpel technique. This training session will outline the activities you will be requested to do at regular intervals over a four week period. At this time you will also be tested on two separate measures of dexterity and required to fill out a confidence questionnaire. The activities will not be overly difficult or time consuming and can be undertaken at a time of your convenience. After the four week period we will re-measure you using the same dexterity measures and confidence questionnaire.

What happens to my information?

Data will be recorded in hard copy and electronic format. Electronic information will be stored on the computer of the primary researcher with password protection. Hard-copy information will be stored in a lockable filing cabinet in the office of the primary researcher. All information will only be accessible by the research team. All records containing personal information will remain confidential and no information which could lead to identification of any individual will be released.

Can I withdraw if I no longer want to participate?

You may withdraw at any stage without any consequence.

How do I become involved?

If you want to become involved or have any further questions, simply send an e-mail or make a call to the primary researcher or any member of the research team.

Primary Researcher: Mr Ryan Causby, Tel: +61 8302 1542,
Ryan.Causby@unisa.edu.au

Principal Supervisor: Dr Susan Hillier, Tel: +61 8302 2544,
Susan.Hillier@unisa.edu.au

Assoc. Supervisors: Dr Michelle McDonnell, Tel: +8302 1684,
Michelle.McDonnell@unisa.edu.au

A/Prof Lloyd Reed, Tel: +8302 1684, ***lreed@qut.edu.au***

This project has been approved by the University of South Australia's Human Research Ethics Committee. If you have any ethical concerns about the project or questions about your rights as a participant please contact the Executive Officer of this committee, Tel: +61 8302 3118; Email: *Vicki.allen@unisa.edu.au*

Appendix N Consent form study three

University of South Australia & Queensland University of Technology

Division of Health Sciences (UniSA) & School of Public Health (QUT)

Participant information sheet

CONSENT FORM

Project title…Improving dexterity in novice Podiatry students

Researcher's name & contact details… Mr Ryan Causby, Phone 08 8302 1542, Ryan.Causby@unisa.edu.au .....

Supervisor's name & contact details..... Dr Susan Hillier, Phone 08 8302 2544, Susan.Hillier@unisa.edu.au; Dr Michelle McDonnell, Phone 08 8302 1684, Michelle.McDonnell@unisa.edu.au; Associate Professor Lloyd Reed, Phone 07 3138 5623, l.reed@qut.edu.au .....

- I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part.
- I understand that I must be over 18 years of age.
- I understand the purpose of the research project and my involvement in it.
- I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential.
- I understand that the tape will be stored in the office of the primary researcher or primary supervisor in a lockable filing cabinet and that only the research team will have access to the recording.

Name of participant.....

Signed.....**Date**.....

I have provided information about the research to the research participant and believe that he/she understands what is involved.

Researcher's signature and date.....

This project has been approved by the University of South Australia's Human Research Ethics Committee. If you have any ethical concerns about the project or questions about your rights as a participant please contact the Executive Officer of this Committee, Tel: +61 8 8302 3118; Email: Vicki.allen@unisa.edu.au

Appendix O Transcript of Feldenkrais ATM lessons

Feldenkrais ATM sitting awareness lesson

Adapted from Larry Goldfarb "Airport Lesson" © Mind In Motion 2005 Written by Larry Goldfarb, CFT, Ph.D.

Preamble – long scan of sitting position and contact with chair and floor. Explanation of how to do lesson and how it relates to podiatry practice – keeping sitting posture stable and also dynamic so that hands can be dextrous for scalpel work and that breathing can be free and relaxed to reduce tension. N.B. a lot of comments made throughout the tape are not in the transcripts, such as comments related to podiatry practice

0) The starting position: Sitting, elbows on knees, heels of your hands together with your chin in your hands. Your knees are over your feet with your feet resting comfortably on the floor.

1) Take your elbows just barely off your knees, lifting your head and arms together. Then slowly, gently, return your elbows to your knees. Is it easy? Where do you work? Taking your time, explore how you do this movement as you repeat it a few times. Can you let your attention be wide-ranging and inclusive? Do you notice what you do with the rest of yourself? Stop.

2) Slowly begin to slide your right elbow back toward your right hip. Can you do just a small movement and sense how your whole self has to adjust to make this motion possible? It is easier to do if you start by shifting your weight off your right elbow before you start to slide it back. Find a way to glide your elbow along your thigh, minimizing friction and staying in contact. Do you hold your breath? Does your weight shift? What happens in spine & chest? Does your pelvis move?

Rest, sitting comfortably.

3) Return to the starting position.

4) Tilt your head to the right, slowly, many times. Keep your hands touching your head and each other. Can you sense movement in your neck and wrists? Notice how your right wrist bends back as the left wrist straightens. Onto which knee and foot does the

weight of your head shift? Can you breathe easily as you repeat this? Can you make the journey home as smooth and continuous as tilting the head to the right?

Pause a moment.

5) Slowly tip your head to the left, many times. How easily does the movement begin? "Pour" the weight of your head through your forearm onto your left leg. Do your wrists move equally well in this direction?

6) Tilt your head alternately right and left, slowly leaning your head from one forearm and then the other. In which direction is the very beginning of the movement easier? Move only as far in the easy direction as you move in the less easy direction. Can you sense the movement in your wrists and spine . . . and track your shifting weight at the same time?

Sit back up and rest a moment.

7) Return to the elbows-on-knees, head-in-hands position.

8) Slowly begin to slide your right elbow toward your right hip. Keeping the heels of your hands together, do just the beginning of this action. Has this movement changed? How does your spine or chest move to allow your elbow to slide back? Do you have a different, fuller sense of how the rest of you is involved?

9) Keeping your head resting in your hands, slowly look up, allowing your head to tilt, and then look forward again. Can you notice that your wrists move slightly? When you look up, the outsides of the heels of your hands (the sides of the small fingers) separate as the thumb side of the heels of your hands roll towards one another. Your forearms participate in the movement by turning slightly. Repeat this movement ever so slowly, many times, making the action fluid and easy. Can you stay in the comfort zone, repeating the movement without interfering with your breathing? Do you sense how looking up and tilting your head asks your neck, chest and forearms to move?

Pause a moment.

10) Now look down, ever so gently tilting your face down, in the direction of the floor. Can you sense how your arms turn in the opposite direction, the base of each thumb moving away from the other as you roll gently to the outside of the heels of your hands?

Slowly look forward. Repeat this several times, sensing the turning of the arms in relationship to the tilting of your gaze. What happens in your spine and chest? Does your back round or arch? Does your pelvis move?

11) Slowly, begin to look up and down alternately, allowing your head to tilt, your neck move in an easy range as your forearms turn. Can you stay in the range of ease? How does the rest of you participate?

Sit up and rest.

12) Return to the starting position.

13) Slide your right elbow toward your right hip. Do you notice what happens with your wrists? With each of your forearms? Your chest & spine? If you can sense how the rest of you needs to adjust and shift, you can allow the range of this movement increase a little. Notice your jaw and tongue. Is your tongue pressing against your teeth? Are your teeth pressing together? Can you let your tongue and jaw be soft?

Pause a moment.

14) Slide your left elbow toward your left hip. Can you find a way to decrease the friction, the pressure under your elbow? Glide your elbow along your thigh, maintaining continuous, light contact. How does the left elbow compare to the right? What happens in your hips joints? Does your pelvis move?

Pause.

15) Making only small movements, alternately slide each elbow back toward its hip. Make the tiniest of movements, noticing your breath and exploring just the beginning of each action. How do you listen to all the movements that contribute to your elbows sliding? What happens with your chest and spine? Does your pelvis move as each elbow slides slowly back and forth? Do both of your hip joints move symmetrically? Simultaneously?

Stop.

16) Now slide both elbows back a little bit, simultaneously. Make a small slow movement and repeat it several times. Make the movement legato rather than staccato. Can you sense where – in your shoulders, chest, spine, belly – you move to allow your

elbows to glide easily on your thighs? Make the quality more important than the quantity: making the movement legato rather than staccato. Does your pelvis shift forward or back? Can you notice the places that make small contributions to the larger movement?

Pause again.

17) Slowly roll your pelvis backwards, just the smallest amount, without moving your elbows. The contact under your pelvis rolls backward slightly. Allow the front of your pelvis to move backward away from the front of your thigh as your hip joints open a bit. Does your weight shift? Do this without any forcing, any struggling. Stay in the range of absolute ease. Do both hip joints open at the same time? What happens in your spine? Can you sense where your back moves back? Repeat this movement.

Can you allow your spine to yield softly as you roll back? How do you move to return to the starting position?

Pause.

18) Slowly slide both elbows back towards your pelvis again. Is this movement easier now? Do your pelvis and spine participate? Keep your pelvis still while you continue to glide your elbows back and forth. Keep the range small. How does fixing your pelvis affect the relative ease of this movement?

Pause.

19) Slowly roll your pelvis back and forth, just a little bit. Stop with your pelvis rolled back. Staying in small, comfortable range, slide both elbows unhurriedly back towards your pelvis and then forward to your knees. In which direction is the movement easier with your pelvis rolled back? Keep your pelvis rolled back while you continue to glide your elbows back and forth, making the movement a little bit easier and smoother each time.

Pause. You can sit up and rest a moment. How are you sitting now?

20) Return to the basic position.

21) As slide your elbows backward, allow your pelvis to roll back, too. Can you find a way to allow your spine and hips joints to participate in the movement of your elbows?

Roll your pelvis forward to the starting position as your bring your elbows to your knees. Can you coordinate these movements, making them one action? Find a way to breathe as you move. Can you make this movement even smoother, even easier?

Pause.

22) Gently round your back and let your pelvis roll back a wee bit, without moving your elbows. Starting with your pelvis rolled back, slide your elbows gradually back as you roll your pelvis slowly forward then slide your elbows forward to your knees as you roll your pelvis easily backward. Can you synchronize the movements of your centre and your elbows this way? Stay in the easiest range.

Pause a moment.

23) Slide both elbows backward at the same time. Is the movement easier? How do you harmonize the movement of your arms and your trunk? Bring your elbows to your knees. Once again slide only your right elbow toward your right hip. Do you notice what happens with your wrists and forearms? With your pelvis, spine and chest? Keeping the movement small, making it as smooth as possible, what do you notice now?

Take a full rest.

24) Return to the elbows-on-knees, head-in-hands position.

25) Now begin to slowly slide your right elbow forward, past your right knee and toward your foot and return. Make just a small movement. What happens with your belly & back as your elbow reaches past your knees and glides down the front of your lower leg? Can you make the movement a question and have what you notice be the answer? Just do what is absolutely easy.

Pause a moment with your head resting on your hands.

26) Slide your right elbow gently back & forth, sensing what it takes to make this small movement possible. Can you move without interfering with your breath?

Pause (or take a full rest).

27) Begin to slide your right elbow outside your right knee, just a little bit. What happens with your wrists? Forearms? Chest & spine? Keep the movement small and make it as smooth as possible. What can you do with the rest of yourself to make it possible for your right elbow to reach outside your right leg?

28) Glide your right elbow toward the inside of your right knee and down along the inside of your lower leg, making just a small movement. Can you proceed without even the slightest hint of struggling or forcing? What happens with your belly & back? How does your weight shift?

29) Keeping your chin resting in your palms, slowly slide right elbow alternately a bit to the right & left, bringing it inside and outside your leg. Where do you have to move to make this possible?

Pause. Sense how you are making contact with the chair.

30) Take your right elbow to visit each of the places you have been around your right knee, connecting the directions to make a small, smooth circle. Remember, there are no corners or straight lines in a circle. Where else do you make a circle? What happens in your chest? With your head? Your pelvis? Can you make the circle smaller, smoother? Whenever the quality of the movement changes or the effort increases, notice where you stop moving. Are you holding your breath? Locking your chest? Or fixing your pelvis? Can you find a way to make the circle smaller and rounder?

Take a full rest.

31) Return to the starting position.

32) Slide your left elbow back toward your left hip and back to the beginning place. Breathe easily as you move. Keep movement small and make it as unforced and smooth as possible. Can you notice what happens with your wrists now? With your forearms? Chest & spine?

Pause.

33) Slowly slide left elbow just a little bit past your left knee, toward your foot. Is this beginning of the movement different than on the other side? What do you do at the very beginning of the motion? What happens with your belly & back? What do you have to

do with your pelvis, spine and chest to have your left elbow slide forward of your knee? How can you make this as easy as possible?

Pause and notice your breathing.

34) Begin, ever so slowly, to slide your left elbow backwards & forwards just the tiniest amount. Can you sense how your trunk changes shape and your weight shifts? What happens at your feet and ankles?

35) Explore this movement slowly and easily. Rather than trying to move further, can you open your attention to get a more inclusive sense of each of the small changes that contribute to this movement?

Pause (or rest).

36) Now begin to slide your left elbow outside your left knee – just a bit toward the outside of your left foot – and gently return your elbow to your knee. What happens with your wrists and forearms? With your chest & spine as your elbow slides to the left and back onto your knee? Keep movement small, making it smooth as possible.

Pause a moment.

37) Slide your left elbow inside your left knee and back, making a small, easy movement. Can you sense what happens now, what is unique about this elbow going in this direction and coming back? In particular, are you developing a clearer sense of what happens with your belly & back?

38) Let the movement increase slightly so that you are sliding your left elbow to the left & then to the right.

Pause.

39) When you are ready, begin to make small circles with your with your left elbow around left knee.

40) Trace a line of contact just around the knee, making a smooth, curved trajectory. How are you breathing? Are there moments when your breathing becomes more difficult or stops? Go slowly, sensing how and where your torso changes shape so that your elbow can make a circle.

Please take a rest, sitting up.

41) Return to the beginning position.

42) Gently bring each elbow inside each knee then slowly around to the front of your knees . . . gradually come around to the outside of each knee and unhurriedly back to the top. Allowing yourself to breath easily, circle your knees with your elbows in opposite directions at a leisurely pace. What does this ask of your spine and chest? What is the difference when both elbows move compared to when one is fixed?

43) Pause a moment and reverse the circling of your elbows, slowly moving them in the opposite direction. Make the circle smaller and the motion smoother.

Sit back & rest.

44) Return to the elbows-on-knees, head-in-hands position.

45) Take both elbows to the right of your knees . . . slowly to the front . . . allowing yourself to breathe as you move gently to the left . . . smoothly back to the top . . . circling each elbow around each knee, moving both in the same direction. Can you move your elbows simultaneously? How do your spine and chest move now? What happens in your lower back and belly?

Pause.

46) Slowly slide your right elbow again toward your right hip. Can you do just a small movement and feel how your whole self now adjusts to make this motion possible? What do you notice in your spine & chest? Do you breathe more easily? Does your weight shift? Does your pelvis move?

47) Now once again gently lift both of your elbows and your head from knees. Is it easier now? Has the pattern changed? Or the contact you make with the chair? Your breathing?

Feldenkrais ATM dominant hand lesson

0) Please rest in a comfortable position. You will be working with your dominant hand (the one you usually write with). Position your arm so that it is resting on the elbow and your forearm is towards the ceiling, with your hand and fingers also pointing towards the ceiling. If you feel comfortable closing your eyes please do so – this way you can pay more attention to the movement.

1) Now slowly loosen your hand and fingers so that they lower forward (hang down) in the most comfortable position then slowly lift it back up, with very delicate movements. Notice that this is not a movement of letting go suddenly but of paying attention and lowering slowly then slowly straightening your wrist. This is not a kind of exercise, it is an opportunity to notice the different sensations as you slowly lower and raise your hand – your attention may be drawn to the hand and fingers – this makes sense as the brain and the hand and fingers have such a rich connection. Is there anywhere else that you notice as you slowly lower and raise your hand?

2) Now intentionally try to bend the wrist the other way – stretch it backwards and straighten the fingers – pay attention to how this feels different to the first movement, notice the change in effort.

3) Now allow your wrist to soften and allow your hand to hang forward again – don't throw it down – let it fold by its own weight slowly. Then pay attention as you straighten it so that you don't go past the point of being straight – not bending it backwards at all. Pay attention, slowly down and up with less and less force each time, noticing there is less and less strain.

4) Sense your fingers – notice if you hold them together or if they move individually at different parts of the motion. Are there some that stay together and some that have a life of their own? Notice how it is for you. If you are not sure, try keeping them together purposefully for several cycles and then stop that. Does this give you more information?

5) Now try to listen to each finger in turn as you continue to do the movement of hanging the hand down then straightening it. Can you sense the thumb, the index

finger, the middle finger, the ring finger, the little finger? (may need to expand the instructions here to sense length, orientation, parts etc.)

6) Now whilst the hand is hanging down keep it there and make a small movement of the thumb – keep it tiny and light. Leave it.

7) With the index finger only do small movement – pay attention whilst the hand is hanging – tiny, simple. Is there movement elsewhere in another finger or the hand – can you keep the movement small enough that only the index finger moves.

8) Now do a small movement of the middle finger only – tiny delicate, not fast – do any others want to join in?

9) Try a small movement of the ring finger only – still with your hand hanging down – what other fingers want to be included? Can you sense this and make the movement even tinier with even less strain to sense what changes this makes?

10) And now move only the little finger – small tiny movements, paying attention to which fingers want to move with the little finger.

11) Now once again, straighten the hand slowly. Notice when it is straight again, when the fingers are directed to the ceiling in a continuation of the forearm, then let it go down slowly as if it is sinking in honey or thick oil – it is not falling it is sinking. As the hand goes down try to notice what the fingers do – do they bend more or do they straighten? Pay attention, is there a pattern? Do these several times so that you can sense what your fingers do as your wrist bends and straightens.

12) Let the hand hang now and turn it (whilst it hangs) so that your fingers point more towards your face, and then turn them away again. Sense the turn in your forearm and how it carries your hand and fingers so that they are facing more towards your face and then away. Do this movement slowly and with the hand hanging – as if it is the wind blowing your hand around rather than you. Without forcing the hand to go far by producing effort, simply try to notice what it is that stops you wanting to go further one way and the other way. Try to sense the natural place where to go further would require strain – stay within the range that feels comfortable. If you habitually feel the impulse to push as far as you can, try to do it differently this time, try to work within comfort as your guideline.

13) Next time your hand is in the outward position – that is fingers are pointing away from your face - keep it there and slowly straighten and lower your wrist in this position. Go so slowly that you can really feel what it is like to hang and lift your hand with minimal effort, how can you reduce any elements of strain even further?

14) Next time your hand is hanging allow it to rotate back so that your fingers are pointing inward, more toward your face. Stay in this position and again resume straightening and lowering your hand. Can you do this simple movement more and more as if it were happening without your intentional movement of pushing – can it feel as if this movement is occurring by itself? Leave it.

15) Now with the hand hanging and turned so that the fingers are more towards the face make the tiniest movement of lifting your elbow off the rest. Imagine it is being lifted towards the ceiling – so that your forearm is moving upward in a straight line towards the ceiling as your elbow slowly rises from its rest. Make the movements of raising and lowering your elbow light and easy, only increase the amount of lift as you feel the ease being maintained. The hand stays hanging down – only the elbow and the shoulder work. Only lift higher if you can maintain the feeling of your arm floating upward. Notice as you lift higher that your spine needs to become involved. Is there a tendency for you to clench your jaw or hold your breath to lift your arm? Notice these and allow them to stop if they are unnecessary, so that you are lifting and lowering your arm slowly and gently with minimal effort and paying attention to comfort and ease. Leave it.

16) Once more return to the movement of hanging and straightening the hand. Notice the space between the fingers as your hand hangs. Notice how your hand comes up straight without having to bend more towards the little finger side or the thumb side.

17) Now with the hand in the comfortable upward position, without strain try to move the thumb in the direction of the little finger and back. Notice I said "in the direction of" – not necessarily straight to touch it. Stay within the range that feels easy and allow yourself to stop short of the range that requires strain or excessive effort. Can you do this slowly, without jerkiness – opening and closing the thumb, slowly so that it feels soft and light.

18) Now still with the hand upright, move the little finger in the direction of the thumb. Feel no compulsion to get there straight away. Sense which other fingers want to move with the little finger. How small or slow do you need to make the movement to keep it just within the little finger?

19) Slowly try to touch the tip of the little finger with the tip of the thumb – both moving. If possible pay attention to the other fingers – do they want to move to? Can you bring the little finger and thumb tips together so slowly that the other fingers can stay out of the action? If you cannot feel the other fingers moving – open your eyes for a few moves and see if they are actually still.

20) Try just once putting the tip of the little finger on the nail of the thumb and then just once the tip of the thumb on the nail of the little finger. Attend to the other fingers as you do this again – try making the movement simpler, with less force. Does this help the movement of just the thumb and little finger?

21) Keeping the tips of the thumb and little finger together let the hand hang down (it has been kept upright). What do the three middle fingers do when you let the hand hang down – do they straighten or bend? Do it again so that you can feel what is happening in these three fingers.

22) Keep the hand hanging down with the thumb and little finger still touching, then intentionally bend and straighten the three middle fingers – all the while keeping the wrist hanging and the thumb and little finger touching. Go slowly so that you can sense what the fingers can do easily – bending and straightening within these constraints. Leave it.

23) Now straighten the hand slowly – still with the thumb and little finger in contact – and again bend and straighten just the three middle fingers. Slowly to maintain the quality and to monitor what wants to happen at your wrist and in your thumb and little finger. You may want to watch your hand and fingers for a little bit to see if you are sensing all that is happening. Leave it – rest your arm fully.

24) Return your arm to the position where you are standing your forearm on the elbow again. Slowly hang and raise your hand – make the movement gradual, slow and soft. Sense your fingers are soft, without strain and with a space between them.

25) Next time the hand is hanging turn it towards your face – in the direction so that your fingers are pointing more towards your face. Go back and forth gently and easily with a fanlike rhythm.

26) Return to the first movement – of lowering and raising your hand. Change your intention so that instead of your fingers hanging limp they now initiate the movement. Get the sense that instead of your wrist drawing your hand and fingers upward and downward that your fingers are drawing your hand and wrist back and forth. Play with initiating the movement with only your thumb for a few movements. Then start the upward and downward movement with your little finger. Go slowly so that you can be clear about the pattern of the movement. Try similarly with your index finger. Was one digit better at initiating than the other? Leave it.

27) Place your hand on your sternum – your chest bone – just below your throat. Rest it there gently and then find a way to raise and lower your elbow whilst your hand stays resting lightly. Do this several times, rest when you need to. Feel the corresponding motion in your shoulders and chest. Now find a way to move your elbow left and right – again with your arm resting lightly on your sternum. What do feel needs to happen in your ribs – do you hold your breath? Can you now combine these movements so that your elbow is drawing a circle in the air? Do this a few times and then leave it – rest your arm fully.

28) For the last time rest your arm on the elbow, with your hand and fingers in the direction of the ceiling. Slowly lower and raise your hand gently easily. Can you remember what that felt like the first time you did it? How are your fingers – can you sense each one – can you track them as a whole and individually as your raise and lower your hand?

29) Rest and spend a few moments comparing your sense of your dominant hand – the one you have been working with – to the other hand that has been laying relatively quietly during the session. Do they feel different to each other? Does one have different qualities? Lighter, heavier, bigger, smaller, more lively, less lively? Which would you use spontaneously now to pick up a cup or smooth your hair? Try both.

30) When you are ready become more aware of the external surroundings – bring your attention to the chair and the room.

Appendix P F-statistics and degrees of freedom for dexterity measures

Task	Outcome	*Numerator df*	*Denominator df*	F value	P-value
Grip-lift task	**Preload duration** (ms)				
	Dominant	2	41.89	0.12	0.89
	Non-dominant	2	43.55	3.53	**0.04**
	Maximum grip force (N)				
	Dominant	2	43.25	0.19	0.83
	Non-dominant	2	43.68	0.67	0.52
	Maximum correlation (ρ)				
	Dominant	2	43.22	0.35	0.71
	Non-dominant	2	43.91	0.47	0.63
	Average Grip (N)				
	Dominant	2	42.58	0.40	0.68
	Non-dominant	2	42.11	0.55	0.58
	SD Grip				
	Dominant	2	43.86	0.45	0.64
	Non-dominant	2	43.70	2.11	0.13
	Hold Ratio				
	Dominant	2	42.54	0.46	0.64
	Non-dominant	2	40.99	0.39	0.68
	Lift Duration (ms)				
	Dominant†	2	37.99	0.41	0.66
	Non-dominant	2	42.51	0.42	0.66
Purdue Pegboard	**No. of pegs**				
	Dominant	2	43.13	1.55	0.22
	Non-Dominant	2	42.29	0.31	0.73
Grooved Pegboard Test	**Time to complete**				
	Dominant	2	42.94	0.18	0.83
	Non-Dominant	2	42.46	0.26	0.77

Appendix Q F-statistics and degrees of freedom for psychological measures

Outcome	*Numerator df*	*Denominator df*	F value	P-value
Perceived Competence†	2	42.06	0.17	0.84
Effort / Importance	2	41.57	0.70	0.50
Pressure / Tension	2	43.61	1.62	0.21

† Model includes 'history of computer gaming' variable as a random effect