Improving students’ learning and performance in pre-clinical endodontics

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<th>Description</th>
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<tbody>
<tr>
<td>AIC</td>
<td>Akaike Information Criterion</td>
</tr>
<tr>
<td>BDS</td>
<td>Bachelor of Dental Surgery</td>
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<tr>
<td>BFT</td>
<td>Balanced Force Technique</td>
</tr>
<tr>
<td>CF</td>
<td>Cognitive Failure</td>
</tr>
<tr>
<td>CFA</td>
<td>Confirmatory Factor Analysis</td>
</tr>
<tr>
<td>CFI</td>
<td>Comparative Fit Index</td>
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<tr>
<td>CMP</td>
<td>Conscious Motor Processing</td>
</tr>
<tr>
<td>COM1</td>
<td>Comparative group (Study 1)</td>
</tr>
<tr>
<td>COM2</td>
<td>Comparative group (Study 2)</td>
</tr>
<tr>
<td>DRe</td>
<td>Decision Reinvestment</td>
</tr>
<tr>
<td>DRu</td>
<td>Decision Rumination</td>
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<td>DSRS</td>
<td>Decision-Specific Reinvestment Scale</td>
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<tr>
<td>EFA</td>
<td>Exploratory Factor Analysis</td>
</tr>
<tr>
<td>E ful</td>
<td>Errorful</td>
</tr>
<tr>
<td>E less</td>
<td>Error less</td>
</tr>
<tr>
<td>GFI</td>
<td>Goodness-of-Fit Index</td>
</tr>
<tr>
<td>GO</td>
<td>Guided-observation</td>
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<tr>
<td>HR</td>
<td>Heart Rate</td>
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<td>IO</td>
<td>Instructed-observation</td>
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<td>ISAT</td>
<td>Imperial Stress Assessment Tool</td>
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<td>MSC</td>
<td>Movement Self-Consciousness</td>
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<td>MSRS</td>
<td>Movement-Specific Reinvestment Scale</td>
</tr>
<tr>
<td>N0°</td>
<td>Narrow straight canal block</td>
</tr>
<tr>
<td>N20°</td>
<td>Narrow 20° curved canal block</td>
</tr>
<tr>
<td>NiTi</td>
<td>Nickel-titanium</td>
</tr>
<tr>
<td>OO</td>
<td>Observation-only</td>
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<td>PrSC</td>
<td>Private Self-Consciousness</td>
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<td>PSS</td>
<td>Perceived Stress Scale</td>
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<td>PuSC</td>
<td>Public Self-Consciousness</td>
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<td>RH</td>
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<tr>
<td>RMSEA</td>
<td>Root Mean Square Error of Approximation</td>
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<tr>
<td>RS</td>
<td>Reinvestment Scale</td>
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<tr>
<td>SRMR</td>
<td>Standardised Root Mean-squared Residual</td>
</tr>
<tr>
<td>STAI</td>
<td>State-Trait Anxiety Inventory</td>
</tr>
<tr>
<td>W0°</td>
<td>Wide straight canal block</td>
</tr>
<tr>
<td>W20°</td>
<td>Wide 20° curved canal block</td>
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Abstract

There has been limited use of contemporary learning theories or available evidence when designing activities to develop fine motor skills in dentistry. Recent evidence from non-dental studies concerning levels of performance following fine motor skill learning highlights the negative impact of reinvestment, i.e. conscious monitoring and control of movements when learning, particularly during the early stages of learning. Learning implicitly so that minimal conscious involvement is required (e.g. approaches that minimise errors or involve observation with physical guidance), has been shown to limit the effect of reinvestment on subsequent performance. This leads to positive and sustained outcomes, even under multi-tasking or stressful conditions, in comparison to commonly used explicit approaches (e.g. approaches that involve error production or observation with instructions) (Maxwell et al., 2001; Poolton et al., 2011).

Outcomes of learning implicitly are important in dentistry because working under stressful conditions (e.g. physiological or psychological) is a consistent characteristic, either during undergraduate study or in practice. However, there are no published data about this approach for learning dental skills. The aim of this research was to evaluate the effect of learning approaches, consistent with implicit or explicit learning, on the acquisition of endodontic hand instrumentation skills among dental students. It was hypothesised that learning implicitly (e.g. by limiting errors or observation with guidance) would result in minimal decrement in performance under pressured or stressful conditions. In contrast, it was expected that learning explicitly (e.g. through increasing errors or observation with instructions and observation alone)
would lead to a reduction in performance under pressured or stressful conditions. It was also aimed to investigate the impact of reinvestment on performance of the dental students. It was hypothesised that individuals with a high propensity for conscious monitoring during root canal preparation would not perform as well as low reinvesters, as a consequence of allocating working memory resources to monitoring and controlling their movements.

Participants were volunteer dental students from the University of Adelaide, with no previous endodontic work or learning experiences. These students were randomly assigned to the experimental groups. Other volunteer dental students who had completed the normal pre-clinical learning activities provided comparative performance data.

Participants performed fundamental root-canal hand instrumentation tasks during learning (experimental groups: 1.5-2h; comparative groups: 15-20h) and testing phases (0.5-1h). During learning, participants in the experimental groups prepared standardised canals with different canal diameters and curvatures using the balanced force technique. Learning methods in the experimental groups involved minimising (errorless: n=21) or maximising errors (errorful: n=21) in Study 1, or guided-observation (n=23), instructed-observation (n=23), or observation-only (n=13) in Study 2. Participants in Study 1 and Study 2 completed the three previously published reinvestment surveys related to propensity to reinvest. These were used to evaluate participants’ focus of attention behaviours on learning and performance in general.

To test performance levels after the learning phases, all participants prepared the distal canal on a plastic tooth (Test 1), then completed the same task under multi-
tasking condition (Test 2), with the observation groups completing Test 1 again but under stressful conditions (Test 3). Performance was assessed by preparation accuracy, completion time, procedural errors, and reported rules. For accuracy and time, repeated measures ANOVA and post-hoc analyses were used to assess differences within and between groups, while procedural errors were analysed using Wilcoxon Rank Sum Test and Kruskal-Wallis Test. Differences in the number of reported rules between the groups were assessed by an unpaired t-tests for Study 1 and a one way ANOVA and post-hoc analyses for Study 2.

Performance by the experimental groups was similar during learning. When tested, accuracy of preparation and completion time in the errorless and comparative groups did not change significantly under multi-tasking conditions (p>0.05), whereas, learners who learnt with errors showed a significant deterioration in preparation accuracy when multi-tasking (p<0.05). Participants’ reported significantly increased stress levels in all observation groups for all tests (p< 0.05). However, preparation accuracy did not differ significantly within or between the experimental observation and comparative groups (p> 0.05). The errorful and instructed-observation learning groups reported significantly more ‘root canal instrumentation rules’ than the errorless, guided-observation and observation-only groups. Correlation analyses of data from the Reinvestment Scale (RS), the Movement-specific Reinvestment Scale (MSRS), and the Decision-Specific Reinvestment Scale (DSRS) showed significant association between the three reinvestment surveys. However, no significant differences for the three reinvestment surveys were found between experimental and comparative groups in Study 1 and 2. Furthermore, no significant differences in accuracy of canal preparation or completion times were found between ‘low’ and
‘high’ reinvesters based on a median split for the primary task, under multi-tasking, or under stressful conditions.

Findings from Study 1 provide the first evidence that learning endodontic skills implicitly, i.e. under conditions that limit errors, resulted in stable performance when multi-tasking. This may be explained by reduced use of working memory for error management when learning. However, the learning strategies adopted when learning by observation with guidance were not consistent with implicit learning approaches. This conclusion is supported by the high number of errors produced during learning trials on plastic blocks and the apparent low level of accuracy of performance during transfer tests. This finding highlights difficulties associated with designing approaches that are consistent with learning implicitly in the real world.

The apparently low impact of reinvestment on performance of participants in Study 1 and 2 may be explained by the small number of low and high reinvesters in both studies and the variable level of complexity in the instructions provided. Propensity to reinvest is suggested to be dependent on performance context and task attentional demands. The fine motor learning context in endodontics and the complexity of dental tasks are likely to be different to those encountered in sports or in surgery, which might explain the variable impact of reinvestment on performance. Further research of learning other skills by dental students is needed, including testing different implicit learning paradigms and investigating the role that the reinvestment might play when learning endodontic skills. These studies should lead to better outcomes, especially during multi-tasking and under stressful environments.
Thesis declaration

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1 Introduction

Root canal treatment is a complex task involving various procedures which require the development and integration of both theoretical knowledge and fine motor skills (Seijo et al., 2013; Murray and Chandler, 2014). The conventional approach for motor skill learning in dentistry, surgery, and endodontics has involved learning explicitly. This involves consciously following detailed textual and/or verbal instructions and demonstrations showing how to carry out motor skill tasks (Hendricson et al., 2006; Suksudaj et al., 2015). Although this explicit approach of learning is routine, it has been proposed recently that a shift to reduce conscious involvement (i.e. by learning implicitly) in training strategies might be more beneficial for learning motor skills (Masters, 1992; Masters and Poolton, 2012). Implicit learning of motor skills includes learning skills without the accumulation of expressed verbal knowledge (e.g. rules) of motor task performance such that these “implicitly learned skills are (unconsciously) retrieved from implicit memory” (Kleynen et al., 2014). Examples for learning implicitly include learning motor skills under secondary task conditions (Masters, 1992); learning by reducing errors (i.e. errorless learning) (Maxwell et al., 2001; Poolton et al., 2005; Lam et al., 2010b); learning with physical ‘guidance’ (Wulf et al., 1998; Masters et al., 2008b); learning by analogy (Liao and Masters, 2001); or learning from observation (Masters et al., 2008a).

Studies have found that implicit motor learning in novices is beneficial for acquiring motor skills as performance is robust under stressful conditions, fatigue and when high levels of cognitive effort are required (Masters and Maxwell, 2008). Outcomes of implicit motor learning are of importance in dentistry because working under stressful
conditions (e.g. physiological or psychological) is a consistent characteristic, either during undergraduate study or in practice (Alzahem et al., 2011). Stressors related to dental students’ transfer from pre-clinical to clinical settings can result in deterioration of performance (Elani et al., 2014). It is suggested that learning implicitly in the simulation stage can reduce loss of performance with the move to clinical settings (Malhotra et al., 2012). Therefore, further investigation of effective methods for learning dental fine motor skills is indicated, using conditions that result in robust performance, even under multi-tasking and stressful conditions.

The main aim of this project was to evaluate the effect of different learning approaches (specifically approaches that are consistent with implicit and explicit learning) on the acquisition of fine motor skills associated with root canal hand instrumentation in pre-clinical endodontics. These involved testing two learning approaches that are consistent with implicit learning, namely errorless (Study 1) and guided-observation (Study 2) approaches compared with two approaches considered to be more explicit, namely errorful and instructed observation approaches. The impact of stress (i.e. the combined effect of time pressure and evaluation stressors) on the performance of trained pre-clinical dental students was also investigated in Study 2. Both subjective (psychological, i.e. self-report questionnaires) and objective (physiologic, i.e. heart rate) measures of stress were assessed. Another aim was to investigate the impact of reinvestment on performance of the dental students who participated in Study 1 and Study 2.

It was hypothesised that attention loads would be reduced when manipulation skills were learnt by limiting errors or observation with guidance. These methods
would allow learners to process critical information required for completing the task enabling them to complete complex root canal treatment procedures accurately while maintaining performance under multi-tasking or stressful conditions. In contrast, it was expected that learning under errorful conditions or by observation with or without instructions would result in a reduction in performance under these pressured conditions. It was hypothesised that individuals with a high propensity for conscious monitoring during root canal preparation would not perform as well as low reinvesters, as a consequence of allocating working memory resources to monitoring and controlling their movements.

This thesis investigates the effect of different learning approaches on the acquisition of root canal preparation skills in pre-clinical endodontics. The current introduction is followed by a review of the literature (see Chapter 2) which identifies gaps in knowledge related to fine motor skill learning in endodontics and explores factors affecting motor skill learning. It also, explores research work undertaken to investigate motor skill learning and relevant theories that explain how motor skills are developed, coordinated and stored in our memory system. This chapter concludes with the aims and hypotheses.

The next chapter (Chapter 3) presents results of an investigation of the impact of errorless (implicit) and errorful (explicit) approaches for learning endodontic motor skills. The second study (Chapter 4) was informed by results from the first study and investigated alternative approaches for learning implicitly and explicitly. Specifically, these approaches included guided-observation (implicit) and instructed-observation (explicit) motor learning approaches. In addition, the second study examined the
impact of the combined stress of evaluation and time pressure on the performance of pre-clinical dental students.

The third study (Chapter 5) concentrates on the impact of reinvestment on performance of experimental and comparative groups in both Study 1 and Study 2. Three reinvestment surveys (Masters et al., 1993; Masters et al., 2005; Kinrade et al., 2010) designed to explore a propensity to conscious monitoring and control were used.

Chapter 6 presents a general discussion of this research, including key findings from Study 1 and 2, study limitations, implications for practice and suggestions for further research, while Chapter 7 provides the general conclusions. A list of references is provided at the end of this thesis, together with some appendices.

The findings from this research have implications for improving our understanding of fine motor skill learning in endodontics. They will also be relevant to inform current and planned investigations in other areas of dentistry that require fine motor skills, e.g. cavity preparation, crown preparation, and minor surgical skills. By exploring effective methods for learning fine motor skills, this research work can be used by dental and clinical educators to design and develop learning activities that can result in robust performance that is maintained under multi-tasking and stressful conditions, both of which are commonly encountered when learning and practising clinical dentistry.
2 Literature review

The purpose of this literature review is to explore the available body of knowledge related to learning fine motor skills. It also aims to provide the theoretical background and role of key factors in learning these skills. It is designed to familiarise the reader with definitions and theoretical explanations concerning motor skill learning based on extensive research. Section 2.1 highlights the gaps in our knowledge relating to motor skill learning in dentistry. Section 2.2 outlines the importance of learning root canal preparation skills in endodontics, describes the stages involved in root canal preparation procedures, and highlights the limited application of learning theories to support the design of motor skill learning activities. Section 2.3 describes the neurophysiology of fine motor skill learning addressing brain control and the sensory input involved. Sections 2.4 and 2.5 discuss key factors affecting motor skill learning and theories used to explain and support the learning of these skills. Sections 2.6 and 2.7 summarise knowledge from previous research and present the rationale for the current line of investigation, including aims and hypotheses of this study.

2.1 Current knowledge related to motor skill learning in dentistry

Procedural and cognitive skills are essential abilities for clinical dental practice. Students learn these skills during simulated clinical activities designed to ensure that they achieve a satisfactory level prior to proceeding to direct patient care. These simulated activities have associated high costs in terms of staffing and facilities (Tedesco, 1995; McNally et al., 2002; Glickman et al., 2005). To optimise learning in
these settings, the design of relevant learning activities needs to be informed by theory and based on evidence.

However, there has only been limited research conducted in relation to the design of the most effective and efficient methods for learning the complex cognitive and fine motor skills required for patient care in dentistry (Boyd et al., 1980; Feil et al., 1994; Knight et al., 1994; Tedesco, 1995; Knight et al., 1997; Quinn et al., 2003; Wierinck et al., 2007). Similarly, there are few publications discussing the rationale and design of simulation and clinical endodontic learning activities (Abou-Rass, 1974b; 1974a; Qualtrough and Dummer, 1997; Qualtrough et al., 1999; Petersson et al., 2002; Sonntag et al., 2008; Friedlander and Anderson, 2011; Koedijker et al., 2011).

Furthermore, there is limited explicit use of learning theories to inform the design of these activities. Other than investigation of the design and diameter of hand file handles and the effect of the fit of gloves on performance (Chandler and Bloxham, 1990; Treble et al., 1993; Chandler et al., 1996; Chandler et al., 2004; Min et al., 2007). There is only limited research investigating factors that affect performance during root canal instrumentation. Thus, further investigations are indicated regarding the design of approaches for supporting students’ learning of fine motor skills required for root canal preparation that are informed by contemporary learning theories.

2.2 Learning endodontic skills

It is well established that learning endodontic theory and techniques can be challenging for undergraduate dental students (Burrell and Rasmussen, 1977; Friedlander and Anderson, 2011; Seijo et al., 2013; Murray and Chandler, 2014). Students are required to gain essential knowledge and develop related practical skills
in a relatively short period of time. Specifically, they need to integrate their theoretical knowledge and motor skills and show improvement in performance to achieve the competencies required to provide patient care.

Learning endodontic skills often begins with simulated practice of the different stages of root canal treatment on extracted human teeth. Biomechanical cleaning and shaping of the root canal space is an essential step (Schilder, 1974; Peters, 2004; Peters and Peters, 2010), aimed at eliminating or minimising the number of microorganisms causing infection in the root canal system. This includes removing debris and microorganisms from the root canal system, and shaping root canal spaces to facilitate cleaning and subsequent filling of the canal space (see Appendix 9.2). When using extracted human teeth, variable external and internal anatomy, as well as the condition of the root, make the biomechanical preparation of root canal systems a challenging and sometimes discouraging task. Therefore, a recent recommendation for the simulation stage of learning endodontic procedures is to use simulated plastic models of canals and teeth prior to the use of extracted human teeth (Australian Society of Endodontology, 2007).

Using simulated root canals permits standardisation of the root canal hardness, length, width (diameter), location and degree of canal curvature. This standardisation allows reproducibility of outcomes (Lim and Webber, 1985). Consistent with the recommendations of learning using simulated root canals, simulated plastic blocks and teeth have been found to be a valuable adjunct for learning how to determine root canal working lengths (Tchorz et al., 2014b), and how to carry out preparation techniques (LaTurno et al., 1984; Nassri et al., 2008). Studies have used simulated root
canals (e.g. resin blocks, plastic teeth, and artificial dentine) to investigate and compare the shaping ability of instruments, to compare different root canal instrumentation techniques, and to identify possible procedural errors during root canal preparation (Weine et al., 1975; Lim and Webber, 1985; Alodeh et al., 1989; Hülsmann et al., 2005). However, how realistically simulated canals in resin teeth or blocks mimic canals in natural teeth is unclear. For example, differences in properties between resin and dentine may be an issue. Microhardness of root canal dentine has been reported to be 35–40 kg/mm² compared to 20–22 kg/mm² for clear resin endodontic blocks, and 25–26 kg/mm² for artificial resin teeth (Weine et al., 1976; Lim and Webber, 1985; Nissin Dental, 2013). Moreover, it has been reported that the size of shavings resulting from resin and dentine is different, leading to more canal blockages in resin simulated root canals (Weine et al., 1976). Despite these concerns, simulated root canal models have been reported to be a suitable alternative for natural teeth in learning root canal preparation procedures (Nassri et al., 2008; Tchorz et al., 2014a).

The blinded nature of endodontic procedures adds further complication for novice students. They do not have visual cues to support their linking and transferring their theoretical knowledge of root canal morphology and root canal preparation techniques to produce appropriately-shaped and cleaned root canal spaces that are ready to be filled. In response, recommendations from Australian Society of Endodontology (2007) and guidelines from the European Society of Endodontology, support the use of visual demonstrations (observation) of simulated root canal procedures and techniques during learning (Australian Society of Endodontology, 2007; De Moor et al., 2013).
Success of root canal treatment relies mainly on effective cleaning and shaping of the root canal. This involves using a range of instrumentation procedures. The correct and safe application of these procedures and techniques can also prevent iatrogenic procedural errors from occurring. The following sections (2.2.1 and 2.2.2) summarise key aspects of instruments, procedures, and outcomes used in endodontics that are relevant to both Study 1 and 2.

2.2.1 Root canal preparation instruments

Root canal preparation includes mechanical (i.e. debridement and shaping of root canal space) and chemical procedures (i.e. cleaning root canals using irrigants and medications to minimise bacterial presence). Learning to mechanically prepare root canals requires the use of instruments, such as hand files and engine-driven rotary files. While nickel-titanium (NiTi) rotary files may be considered the gold standard for root canal preparation (Schafer and Zapke, 2000; Tan and Messer, 2002; Schafer et al., 2004), the use of traditional hand files remains of critical importance (Peters and Peters, 2010). Hand files are recommended for initial canal negotiation and preparation, prior to use of rotary files to further enlarge the canal (Saunders, 2005; Abbott, 2012). If rotary instrumentation techniques are used, it is also recommended that hand files should be used in between rotary files applications to help prevent any blockage of the canal system with debris created by a rotary file systems (Cailleteau and Mullaney, 1997; Ingle et al., 2002; Peters and Peters, 2010).

In addition, hand files are essential for the correction of procedural errors (e.g. by-passing ledges or blockages), preparation of large canals (e.g. maxillary central
incisors, canines), and in cases where the use of rotary files may be limited (e.g. in cases of apical resistance and anatomical variations in the canal system) (Ingle et al., 2002; Blum et al., 2003). Therefore, learning the fundamental skills of hand file manipulation is a crucial step prior to learning the use of other advanced armamentarium (i.e. rotary files) for root canal instrumentation procedures (Saunders, 2005).

2.2.2 Root canal instrumentation techniques

Mechanical root canal preparation using hand instruments involves the adaptation of relevant techniques to enable the instrument to properly clean and shape the root canal system to the full length of the canal. The objective of mechanical preparation is to remove infected soft and hard tissues, to facilitate the delivery of root canal irrigants and medicaments to the apical area of the root canal system, and to preserve the integrity of the root canal structure (i.e. prevent weakening of the root structure by removing too much dentine) (Peters and Peters, 2010).

This objective can be achieved by cleaning and shaping the root canal from a reference point (i.e. a point on the sound tooth structure) to slightly short (0.5-1mm) of the canal terminus, i.e. the foramen (Peters and Peters, 2010). This length is referred to as the working length of the root canal. Working length is estimated using a pre-operative radiograph of the tooth, often established with the use of an electronic apex locator and confirmed radiographically after inserting a small file in the root canal to the predicted working length (Carrotte, 2004). Maintenance of working length can be achieved by using copious amounts of irrigation and frequent insertions of a small
file to the full working length to clear and loosen accumulated debris and dentine shavings from the apical portion of the canal. Many different instrumentation techniques (e.g. standardized, circumferential filing and step-down) have been discussed in the literature (Clem, 1969; Roane et al., 1985; Hülsmann et al., 2005). The choice of root canal preparation technique is dictated somewhat by the design and shape of the instrument (Ingle et al., 2008). K-type hand instruments are most commonly used during root canal preparation procedures (Peters and Peters, 2010). This is mainly due to their safety during cleaning and shaping of root canals (Svec, 2008). In the following section, the focus will be on techniques that are relevant to K-type hand instruments that are used during the Adelaide Bachelor of Dental Surgery pre-clinical endodontic program (see Section 3.2.1).

2.2.2.1 Crown-down

The crown-down technique prepares the root canal by starting from the coronal part of the root canal system and then progressing to the apical region (Morgan and Montgomery, 1984). This technique relies on flaring the coronal part (see Figure 2.1) of the root canal (i.e. progressing from large to small hand instruments) which enables removal of infected soft tissue, reduces the risk of blockage of the apical portion of the root canal, and minimises extrusion of canal contents beyond the apical area (Hülsmann et al., 2005). By commencing with the coronal section of the root canal, this technique improves access to the full length of the canal, enhances tactile sensation to the apical portion of the canal, and reduces the risk of fractures (Silveira et al., 2008). The crown-down technique has been reported to be superior to the step-back technique in the preparation of curved root canals ranging from 10 to 35 degrees of curvature (Morgan and Montgomery, 1984).
2.2.2.2 Step-back

The step-back technique, presented by Clem (1969), relies on preparing the root canal starting from the apical part and progressing to the coronal part. It incorporates a stepwise reduction in the working length (i.e. 1mm steps), but with progressively larger instruments, producing a flared and tapered root canal. This technique is one of the traditional root canal preparation techniques and is believed to be effective in minimising procedural errors (Peters and Peters, 2010).

2.2.2.3 Hybrid (modified double-flared)

The double-flared technique was first introduced by Fava (1983). This technique was then improved and referred to as the ‘modified double-flared’ technique (Saunders and Saunders, 1992) or ‘hybrid’ technique (Ingle et al., 2002; Peters and Peters, 2010). It commences by negotiating the root canal with a hand instrument until it reaches the end of the root canal. This is followed by preparation of the coronal part of the canal using the crown-down technique, then enlarging the apical part of the root canal (refer to Figure 2.1). Finally, the middle part of the root is prepared using a step-back technique (Saunders and Saunders, 1992). This technique combines the benefits of both the crown-down and step-back techniques. Therefore, this technique is used at the Adelaide School of Dentistry when learning root canal hand instrumentation (see Appendix 9.2). The learning and testing trials in both Study 1 and 2 are focused on the first stage of root canal preparation (i.e. crown-down technique).
2.2.3 Hand instrument manipulation: balanced force technique

To complete the instrumentation procedure, there are a range of hand instrument manipulation strategies to mechanically remove canal contents and infected dentine, e.g. reaming, filing, watch-winding, circumferential root canal filing, and the balanced force technique (Peters and Peters, 2010). The balanced force technique (BFT), reported by Roane et al. (1985), involves a series of rotational movements (see Figure 2.1) that enable hand instruments to advance in the root canal. BFT has been shown to be a favourable hand instrument manipulation technique compared with other instrumentation techniques, due to its superior maintenance of canal curvature and prevention of iatrogenic procedural errors (Royal and Donnelly, 1995; Saunders, 2005; Peters and Peters, 2010). It provides adequate apical control of the tip of the hand instrument and good centring of the instrument in the root canal (Hülsmann et al., 2005). Hence, it is used in Adelaide School of Dentistry when learning root canal hand instrumentation (see Appendix 0) and used by participants in both Study 1 and 2 for manipulation of hand instruments during root canal preparation.

The balanced force technique involves introducing the instrument into the root canal with a quarter-clockwise motion with light pressure to engage the hand instrument with the canal walls. This is followed by maintaining the pressure while completing a three-quarter counter-clockwise turn thereby cutting the dentine of the canal, resulting in enlargement of the canal. The final step involves a quarter clockwise motion, without pressure, to collect the shavings from the canal walls, and removal of the hand instrument from the root canal (see Figure 2.1). The incorrect use of any of
the previously mentioned techniques or failure to maintain working length could lead to procedural errors such as blockage and ledge formation in the root canal (Carrotte, 2004; Hülsmann et al., 2005).

Figure 2.1. A diagram summarising the three key movements in the balanced force technique. 1= Insert file and engage the file in the canal wall with a quarter-clockwise rotation turn, 2= Maintain pressure and turn the file in a three-quarters counter-clockwise direction to cut the dentine of the canal wall, 3= Turn the file clockwise without pressure, and 4= Remove the file from the canal.

2.2.4 Endodontic measures of success

Success of root canal treatment depends on accessing the apical part of the root canal during root canal preparation, and maintaining this access during chemomechanical preparation (Ng et al., 2008). Clinical outcome measures for root canal preparation procedures involve assessing the quality of canal instrumentation including accuracy of the preparation and the presence or absence of procedural errors during shaping of the root canals (Hülsmann et al., 2005). The following sections (2.2.4.1 and 2.2.4.2) will be reviewing the quality of canal preparation and procedural errors relevant to root canal hand instrumentation.
2.2.4.1 Quality of root canal preparation

As mentioned earlier (see Section 2.2), success of root canal preparation relies mainly on effective cleaning and shaping of the root canal system. This can be achieved through chemo-mechanical preparation of the canal from a coronal reference point (i.e. a point on the incisal or occlusal surface of the tooth) to the apical end of the root canal (Peters and Koka, 2008). Assessment of the quality of the root canal preparation can be achieved clinically and radiographically (Ingle et al., 2008). Clinically, accuracy of canal preparation can be determined via tactile digital sense by inserting the hand instrument in the root canal, checking that the instrument can smoothly reach to the full working length of the canal (see Section 2.2.1) (Peters and Koka, 2008). This then can be confirmed radiographically by measuring the distance from the tip of the instrument to 0.5 to 1mm short of the radiographic end of the root canal (Peters and Peters, 2010) (see Figure 3.10). These assessment criteria were incorporated while evaluating root canal instrumentation following learning and testing trials in both Study 1 and 2.

Instrumentation to a shorter length can result in the accumulation of debris, leading to procedural errors. These errors include canal blockage, ledge formation, canal transportation, and fracture of the hand instrument.

2.2.4.2 Root canal preparation errors

As mentioned previously, procedural errors can occur during root canal instrumentation using hand instruments. This section will outline some of the common iatrogenic errors that may occur.
Blockage of the root canal involves obstruction in a previously patent canal, resulting from the accumulation and retention of dentine chips or residual tissues at the apical part of the canal (Lambrianidis, 2006). Canal blockage can be identified by an inability to advance an instrument to the full working length of the canal. A blockage can be associated with the instrumentation technique used. In a study that compared eight preparation techniques, it was found that canal blockage occurred least when the balanced force technique was used (Al-Omari and Dummer, 1995).

Ledge formation has been shown to be associated with the degree of canal curvature and the design of the selected hand instrument (Jafarzadeh and Abbott, 2007). For example, ledging of a root canal can result from preparing the canal using an inflexible instruments (e.g. a large files that have reduced flexibility). A ledge usually occurs on the outer-side of the canal curvature as a step (platform) that can then be challenging to bypass and can ultimately lead to an inability to negotiate past the root canal ledge (Hülsmann et al., 2005). Ledges can be differentiated from canal blockage by the characteristics of tactile sensation and radiographically (Lambrianidis, 2006). Specifically, advancing an instrument in the canal, will feel like the file is hitting a solid wall, while radiographically, the image would show the tip of the instrument directed away from the true canal path.

Canal transportation results from a tendency of the instrument to straighten a curved canal, as a result the main path of the canal is deviated from its original canal pathway (Hülsmann et al., 2005). Canal transportation can be detected radiographically as straightening of a curved canal compared with the original path of
the root canal (Weine et al., 1975). It has been reported that using NiTi files results in less canal transportation compared with stainless steel files (Gambill et al., 1996).

Fracture of hand instruments can result from torsion stress (i.e. an overload of force during twisting) or fatigue through flexure and repeated use of the instrument (Patino et al., 2005). Hand-instrument fracture can be associated with the radius and angle of the canal curvature, instrumentation technique, rotational forces applied on the instrument, and experience of the operator (Patino et al., 2005). Fracture of hand instrument can also be related to the type of hand instrument used. For example, H-type hand instruments are more likely to fracture compared with k-type instruments due to the manufacturing process and reduced cross sectional area (Peters and Peters, 2010). The use of NiTi instruments during root canal preparation can result in reduced procedural errors compared with stainless-steel hand instruments (Peters, 2004). This can be explained by the flexible nature of NiTi files and their ability to conform within curved root canals, therefore being less susceptible to fracture (Tepel et al., 1997). Therefore, it was decided to use NiTi hand instruments for root canal preparation during learning and testing trials for both Study 1 and 2.

Fractures of a tooth usually occur in the crown and/or root. Cracked or fractured root canals are frequently difficult to diagnose and treat. In relation to root canal preparation, root canal fracture can occur when the forces used during canal preparation are beyond the elastic limit of the root canal wall (Rivera and Walton, 2009). However, there is limited evidence that root fractures are associated with forces generated during root canal preparation procedures (Tamse, 2006; Adorno et al., 2010).
In summary, effective root canal treatment involves cleaning and shaping of root canals using a range of instrumentation procedures and techniques. The hybrid technique is a commonly-used approach that combines the benefits of both the crown-down and step-back techniques (Peters and Peters, 2010). Hand-instrument manipulation using the balanced forced technique is also favoured as it rapidly and safely permits removal of canal contents allowing irrigants and medications to reach deep inside canal spaces (Carrotte, 2004). The correct and safe application of these techniques can prevent iatrogenic procedural errors from occurring.

These hand instrumentation procedures and techniques require tactile feedback (i.e. feeling the canal walls with the hand instruments) involving somatosensory input through the fingertips (see Section 2.3.1), neuromuscular mediation processes (see Section 2.3), and the use of correct decisions regarding the forces applied on the hand instrument during these procedures (i.e. cognitive processes).

### 2.3 Neurophysiology of fine motor skill learning and control

Motor skill learning involves continuous interaction between cognitive, sensory and neuromuscular processes (Mulder and Hochstenbach, 2002). Specifically, learning a fine motor skill, as in endodontics, requires control as well as the integration of posture, motion, and muscle stimulation that, in turn, allows the performer to execute a variety of motor behaviours that are controlled by a range of task requirements (Newell, 1991).
To understand how motor skills are acquired and retained, it is important to identify the mechanisms of motor activity in the human brain. Many attempts have been made to understand and determine the specialised areas of the brain responsible for motor activity (Gerloff et al., 1998; Watson, 2006). The use of advanced techniques to monitor brain activity (including functional magnetic resonance imaging (fMRI), repetitive transcranial magnetic simulation, and electroencephalography (EEG) power spectral analysis) have allowed scientists to observe brain activity during motor tasks (Toni et al., 1998; Zhu et al., 2011b). Using these techniques, these authors have identified six areas of the brain that play major roles in fine motor movement, including the primary motor cortex, premotor cortex, presupplementary cortex and basal ganglia, supplementary cortex, posterior parietal cortex and the cerebellum (Figure 2.2). Specifically, the primary motor cortex is involved in force initiation, task-specific muscle movement and the automated nature of learned movements. The premotor cortex is essential in the initial phase of learning psychomotor skills. It has an important role in movement planning, limb movement execution and recognition. It has been demonstrated that during non-automated voluntary movements, the basal ganglia are active and the presupplementary motor area is functional when learning new sequences (Toni et al., 1998).
Figure 2.2. Parts of the brain involved in fine motor movement (modified from Watson, 2006).

The supplementary motor area facilitates self-initiation of movements, sequencing of previously memorised movements, two-handed coordination and planning of complex movements. Visual response of limb movements is achieved through the posterior parietal cortex and the premotor cortex. The coordination, timing and accuracy of movements are controlled by the cerebellum, which also is understood to play a further critical role in motor learning. In particular, mediation of the voluntary movement program is achieved by the lateral cerebellum, however, motor commands are reorganised during performance by the intermediate part of the cerebellum (Seitz and Roland, 1992). While these areas have individual roles, as noted, they function together in harmony to enable completion of a motor task.

Brain activity of particular areas in the brain is related to an individual’s level of proficiency. EEG studies have shown that high levels of proficiency (i.e. expert) were associated with increased alpha power in the left temporal region of the brain (T3) (Zhu et al., 2010; Zhu et al., 2011b). Communication between different regions of the brain (coherence or co-activation) are reflective of verbal analytic processing during
performance of a motor task (Zhu et al., 2011b). For example, coherence between the left temporal region (T3) and the frontal midline region (Fz) of the cerebral cortex was used to evaluate differences between low and high skilled performers. The degree of activity varies depending on whether the performer is learning, training or retaining expertise (Deeny et al., 2003). For example, changes in the degree of activity also relate to the difficulty of the task and the individual’s level of automaticity (Duong et al., 2010). Studies have also reported on T3 alpha power to be associated positively with training and practice (Zhu et al., 2010; Zhu et al., 2011b). T3 is associated with verbal-analytical processes, a stage that involves conscious attempts by the learner to test hypotheses about the best approach to achieve the target of a motor task (Zhu et al., 2010). The Fz region is responsible for movement planning. Results from EEG T3-Fz coherence have shown that verbal-analytical processes are less involved in motor planning by experts than in novice performers (Deeny et al., 2003). In other work, greater verbal-analytical involvement in a motor task has been shown to be related to higher coherence or co-activation between the T3 and Fz areas, potentially reflecting increased attention demands, which may result in deterioration of motor performance (Zhu et al., 2011b).

Another important role of the premotor cortex involves gaining benefit following observation of actions completed by another performer (Magill and Anderson, 2013a). This role involves planning of eye movements and orientation of the visual-spatial attention. The premotor area is also involved in the planning of movements prior to the commencement of the movement and control and coordination during movement (Toni et al., 1998). The above-mentioned studies related to brain activities during motor skill learning provide valuable objective
measures that can assist in identifying different patterns of neural activation in experts compared with novices (Zhu et al., 2010; Zhu et al., 2011b). They can also provide objective markers of hypothesis testing during motor skills learning and performance (Masters and Maxwell, 2008). Hypothesis testing (i.e. error detection and correction) was suggested to result in conscious access and overload of working memory resources leading to deterioration of motor skill performance (Maxwell et al., 2001). Therefore, it is important to be able to identify and prevent hypothesis behaviour during motor skill learning to optimise learning outcomes (see Section 2.5.4).

2.3.1 Sensory input during fine motor skill learning

Brain activity related to learning fine motor skills is triggered mainly by visual and tactile sensory input systems (Magill and Anderson, 2013d). Root canal preparation, using hand instruments principally involves tactile (i.e. digit-sense) sensory input, rather than visual input as occurs in routine cavity preparation tasks. This involves the ability to recognise and distinguish the form of an object through exploration (touch) using indications about the texture, size, spatial properties and temperature of the object (Boehm, 1941; Lederman and Klatzky, 1993). It includes a mixture of somatosensory perceptions of patterns on the skin surface (e.g. edges, curvature, and texture) and proprioception of hand position and conformation (Streri and Spelke, 1988). In human physiology, touch and proprioception are considered as senses in the somatic sensory system and are classified into ‘deep sensation’ related to subdermal muscles, tendons, joints, and ‘cutaneous sensation’ that involves receptors on the surface of the skin (Hayashi and Takahata, 2005). Deep sensation occurs due to activation of receptors existing in joints and muscles, and provides motion-related
information like position sensation, sensation of speed and haptic sensation (Lederman and Klatzky, 2009).

Other information generated during gross and fine motor activities includes kinesthesia (i.e. movement sensitivity), which relates to the specialised sensor groups that can provide details on the length of muscles, the angles of joints, the degree of muscle tension, and the rates of change in these values (Gallagher and O’Sullivan, 2012). Kinesthetic information is extracted mainly from the body’s physical activity, which might be auto-generated or externally reinforced. As reviewed in Gallagher and O’Sullivan (2012), kinesthesia is associated with essential abilities such as walking, stretching and grasping. It is also essential for fine motor activities (e.g. root canal hand instrumentation motion) which involve specific control over the movement and position of body parts. Kinesthetic receptors are located in muscles, tendons and the linings of joints. These receptors react to mechanical force (e.g. rotations and pressure forces during hand instrumentation), which might be produced by stretching a muscle, pulling a tendon, or bending a joint (Gallagher and O’Sullivan, 2012).

Tactile sensory information plays an important role in improving motor skill control and performance (Magill and Anderson, 2013d). Researchers have found that tactile feedback from fingertips is essential for defining characteristics of movement, including movement accuracy (i.e. grip precision and movement sequence) (Fisher et al., 2002; Goebl and Palmer, 2008), movement consistency, ongoing movement force adjustment, and aiding proprioceptors to estimate the beginning and end of a movement (Magill and Anderson, 2013d). For example, it is expected that tactile feedback is critical to improve hand-instrument grasp, judge the amount of pressure
and force to be applied on hand instruments during instrument rotations, and estimate the start and the end points of each of the rotations.

### 2.4 Factors affecting motor skill learning

Dental clinical practice is complex (Elani et al., 2014) and the design and application of an appropriate motor learning strategy are often multi-factorial. Therefore, it is important to identify factors that can influence the choice of motor learning strategy and how to translate clinical theory into practical actions. Many factors have been found to facilitate motor skill learning. These factors include instructions, type and timing of feedback, type of task, stage of learning, abilities related to the learner (e.g. working memory), repetition and variation of practice, and manual guidance (Kleynen et al., 2014; Kleynen et al., 2015). This section will only focus on the role of instructions, abilities related to the learner, and variation in practice in fine motor skill learning during root canal preparation. These factors have specific implications for the designs of implicit and explicit motor skill learning of relevance to Study 1 and Study 2.

#### 2.4.1 Instructions

There is strong evidence that supports the value of verbal instructions in shaping motor skill learning (Magill and Anderson, 2013c; Kleynen et al., 2015). To optimise learning outcomes, it is suggested that the quantity of verbal instructions is minimal and should not exceed the learner’s attentional capacity (see Section 2.4.2). Instructions during motor skill learning often include descriptions of the movements of
a particular part(s) of the body (e.g. hand or fingers) in relation to other body parts in space and time (Wulf et al., 2010). This type of instruction, focusing on specific body movements, is referred to as having an ‘internal focus’. In contrast, instructions that direct a learner’s attention to the effect of the movement are referred to as having an ‘external focus’ (Wulf and Prinz, 2001). Studies on attentional focus effects have shown that minor alterations in the wording of instructions can have a major effect on learning and performance (Wulf et al., 2010). Applying this in the context of the current study, it seems that providing instructions characterised by an external focus of attention (e.g. cleaning and shaping root canal space, and advancing the instrument) has more learning advantages in contrast with an internal focus of attention (e.g. angulation of the hand instrument inside the canal, movement or grasp on a hand instrument).

The advantage of an external focus can be explained by the utilisation of unconscious and automated processing of information related to the task (Wulf et al., 2010). Use of this automated information can accelerate the learning process and shorten the initial stage of learning. In contrast, using an internal focus, learners tend to get confused due to the incompatibility of the information provided with their movement planning and desired outcome, resulting in conscious concentration on the control of movement (Wulf and Prinz, 2001). However, Poolton et al. (2006) examined the effect of attentional focus on learning and performance of a complex motor task and suggested that deterioration of performance in the internal focus of attention group was related to generating greater attentional demands on working memory compared to the instruction based on an external focus of attention. This factor was considered when designing instructions provided to the experimental groups in Study
Instructions provided were limited and made as simple as possible to minimise load on working memory.

2.4.2 Abilities of the learner

Memory plays an important role during learning (Cowan, 2014). The structure of memory consists of two memory function systems, namely working memory (i.e. short-term memory) and long-term memory (Baddeley, 2003). During motor skill learning, visual, auditory, proprioceptive, and tactile sensory forms of information are temporarily stored in working memory. These types of information are made available to be used for assessment of outcomes and performance (Magill and Anderson, 2013b). When processing novel information, the duration and capacity of working memory are limited. It has been shown that movement information stored in working memory tends to be lost (i.e. forgotten) after about 20-30 seconds (Cowan, 2014). The scope of short-term working memory is also limited. This limitation can affect the amount of information that can be received, processed, and stored in working memory (Magill and Anderson, 2013b). Based on Miller’s (1956) suggestion, the capacity of working memory is about seven items, plus or minus two items. For example, in relation to motor skill learning working memory can hold 7±2 procedural instructions or rules related to movements and movement sequences (Magill and Anderson, 2013b).

The second component of the memory system is long-term memory. Long-term memory functions as a permanent store for information. Procedural memory is the part of long-term memory which stores and retrieves motor skill information (Magill and Anderson, 2013b). These skills are difficult to be described verbally, but rather are
expressed by means of performance (ten Berge and van Hezewijk, 1999). Procedural memory is essential for performance of a motor skill as a learned procedure is evaluated based on the produced actions rather than verbalisation of the actions (Magill and Anderson, 2013b). As reviewed by Magill and Anderson (2013b), both working and long-term memory systems interact with each other, and distinctions in the functions of each system depends on level of performance and stage of learning during motor skill acquisition and performance.

During motor skill acquisition, the learner progresses through three stages of development: the cognitive (declarative) stage; the associative (knowledge compilation) stage; and the autonomous (procedural) stage (Anderson, 1982). In the declarative stage, execution of a motor skill relies on an unintegrated collection of rules stored in working memory that are used to control and guide performance (Anderson, 1982). This process is dependent on working memory such that working memory capacity is reduced relative to rules in use which leads to a reduction in the capacity to interpret and process other information related to performance of the task. During the associative and procedural stages, further prolonged application of these rules occurs until the motor skill is acquired, resulting in automation of the motor skill (Fitts and Posner, 1967; Maxwell et al., 2003). In relation to root canal preparation, the cognitive stage is represented by a student’s reliance mainly on verbal instructions provided to clean and shape the root canal space. Following initial practice, students will interpret these instructions to improve their performance. During the procedural stage, students would be familiar with the instructions and rules, resulting in performing the root canal preparation procedure without reliance on these instructions.
2.4.3 Variation in practice

Research in the motor learning domain have highlighted the importance of practice variables on motor learning (e.g. practice schedule) (Kleynen et al., 2015). Studies comparing a blocked (i.e. repetitive) practice schedule (i.e. AAA, BBB, CCC) to a random (i.e. unpredictable) practice schedule (i.e. ABC, BCA, CAB) during learning trials have found that blocked practice results in superior performance to random practice (Li and Wright, 2000). In contrast this study also showed that, random practice results in superior retention of performance compared with blocked practice. Random practice is suggested to create an episodic retention loss during practice and subsequent reconstruction, which disadvantages performance relative to blocked practice but is beneficial to retention of learning following practice. However, these findings were only applicable to relatively simple tasks (e.g. key-press sequence) but not complex tasks (Akizuki and Ohashi, 2013). When performing a complex task (e.g. root canal hand instrumentation), random practice would result in increasing attentional demands on working memory resources due to hypothesis-testing to correct unsuccessful attempts. This overload on working memory disrupts the automated execution of some of the motor skill components, resulting in the loss of flexibility of the movement, and thereby potentially causing deterioration of performance. Therefore, it is suggested that blocked practice (i.e. practicing the entire skill) would be more beneficial where the task is complex (Akizuki and Ohashi, 2013; Kleynen et al., 2015). This suggestion informed a blocked practice design for learning root canal hand instrumentation in both Study 1 and Study 2.
This section has focussed on some of the factors affecting motor skill acquisition. To further clarify how motor skills occur and develop, it is important to review relevant theories to explain how these factors influence motor skill learning.

2.5 Motor skill learning theories

As noted in Section 2.3, fine motor skill learning requires the control and integration of a range of stimuli and responses to be able to perform the desired motor task. But how can we explain, support, or predict how people learn these skills? Several learning theories have been developed to explain how learning motor skills occurs and what stimulates individuals to learn and change. In dentistry, understanding relevant learning theories is essential for dental educators to be able to design effective learning activities, with a clear rationale that supports their dental students’ learning. In the following sections, four key learning theories that have relevance to learning procedural skills and declarative knowledge related to learning motor skills will be discussed. Specifically, these are Schema theory, Cognitive Load theory, the Novice-Expert continuum, and Reinvestment theory.

2.5.1 Schema theory

Theories of motor skill acquisition were initially conceptualised by behavioural psychologists based on the associations between stimuli and responses (Miller, 1956). The role of cognition in motor skill acquisition was first emphasised by Adams (1971). Adams postulated that motor skill learning included a combination of motor behaviour
with a variety of cognitive processes in addition to the development of strategies that can be used to complete a motor task.

The way in which feedback and error detection affects learning were fundamental elements of Adams’ (1971) closed-loop theory of motor control. According to this theory, learners usually hold a reference of accuracy that determines a desired outcome of the movement and a feedback process that perceives error between the learner’s desired movement and the actual movement produced (Adams, 1971). Research findings suggested that Adams’ views were true for movements that are relatively slow (Schmidt, 1975). Slow movements provided learners with a chance to evaluate their performance and to detect any error between the desired movement and the actual movement by way of a feedback mechanism. This form of processing has been termed ‘closed-loop processing’ (Schmidt and Lee, 2005a). Adams (1971) suggested that movements create internal feedback which produces a perceptual trace of the movement that is located in the central nervous system. The strength of the perceptual trace in subsequent trials is dependent on the accuracy of the achieved movement. The feedback produced by the movement is compared to the accumulated perceptual trace through a feedback mechanism, and errors between the actual and expected feedback are detected (Adams, 1971).

However, Adams’ theory has a number of limitations (Schmidt, 1975). It does not explain how rapid (open-loop) movements are learned and controlled. To achieve rapid movements, a motor plan needs to be structured in advance, which does not allow for feedback during the movement. Another reported limitation is the effect of variable practice on the strength of the perceptual trace (Schmidt, 2003). Despite
these limitations, Adams’ theory represented a step forward in understanding motor skill learning and paved the way for newer theories.

Schema theory, first proposed by Schmidt (1975), suggested that a motor program (i.e. stored muscle commands) contains general rules that may be applied to different environmental or situational contexts through the contribution of an open-loop control process and generalised motor programs (GMP). The schema contain the common rules that generate the spatial, temporal muscle behaviour designed to achieve a specified movement (Schmidt and Lee, 2005a). Therefore, when learning new movements, a person may produce a new GMP based on the choice of parameters (e.g. to reduce issues with the novel movement), or improve an existing GMP (which helps minimise the storage problem of multiple GMP), depending on previous experience with the movement and task context.

Schema theory proposed that, after generation of a movement, four components are usually stored in memory: (a) the initial conditions (i.e. the proprioceptive information of the limbs and body); (b) the response specifications for the motor program, which are the parameters used in the generalised motor program (e.g. speed and force); (c) the sensory consequences of the response produced, which consist of information about how the movement felt, looked and sounded; and (d) the outcome of that movement with knowledge of the results (Schmidt, 1975). Schema theory proposes that motor learning involves ongoing processes that update the recall and recognition schemas with every movement that is performed (Schmidt and Lee, 2005a). Despite its deficiencies, schema theory has triggered the development of alternative ideas and provided a model from which new theoretical positions have
been proposed. Schema theory is the most commonly used theory, either explicitly or implied that has been used to explain procedural skill development in dentistry (Wierinck et al., 2007; Hauser and Bowen, 2009; Hendricson, 2012).

However, for many scholars, including Schmidt himself, Schema theory no longer provides a satisfactory theoretical basis for understanding motor skill learning. In particular, more recent findings cast doubt on the cognitive-based assumptions of Schema theory and it can only provide incomplete explanations of how motor skills are acquired (Schmidt, 2003; Sherwood and Lee, 2003). For example, this theory is unable to describe how people are capable of learning through observation in the absence of cutaneous sensory feedback or movement (Rose and Christina, 2006).

Another issue related to Schema theory is the theoretical role of augmented feedback, when retention and transfer tests are conducted (Schmidt and Lee, 2005c). Feedback about motor movement can be divided into inherent (intrinsic) feedback, and augmented (extrinsic) feedback (Schmidt and Lee, 2005c). Specifically, inherent feedback is related to information about a motor task gained by the performer through various sensory channels during or after the execution of a motor movement, depending on the nature of the task. Augmented feedback, on the other hand, is related to information provided about a movement task that is supplementary to, or that reinforces, the inherent feedback (Schmidt and Lee, 2005c). Augmented feedback can have a number of dimensions (or categories); among these categories are knowledge of results (KR) and knowledge of performance (KP). KR relates to verbalisable post-movement information about the outcome of a movement. In contrast, KP relates to verbalisable post-movement information about the nature of a
movement pattern and the possible ways to correct and improve improper movement patterns. Both of these dimensions are fundamental factors for learners. According to the theory, high levels of KR occurrences are critical for initiation of error detection through recognition and recall of schemata of the motor program. Studies conducted by Lai and Shea (1998; 1999) showed that manipulation of feedback on performance results under different practice conditions did not result in consistent improvement in skill. Specifically, reducing the frequency of KR achieved better performance stability and enhanced the learning of the motor tasks during variable practice (e.g. using a mixture of variable motor tasks during a practice session). In contrast, conditions of constant practice (e.g. repetition of a single task during a practice session) motor task learning was improved. Therefore, Schema theory is not able to explain the effect related to manipulations of frequency of feedback on performance outcomes on motor task variables. In addition, this theory is limited in regards to the kind of characteristics in a motor program that are affected by manipulations of feedback about results of performance (e.g. timing, pattern and movement sequence), and the influence of variability and order of practice on the acquisition of the motor skills (Sherwood and Lee, 2003).

2.5.2 Cognitive load theory

Many contemporary theories on motor skill learning have identified the importance of cognitive processes during motor skill acquisition, particularly in the initial stages of learning (Hendricson et al., 2006; Lam et al., 2010a). The initial stage of motor skill learning (i.e. cognitive stage/ declarative stage) involves cognitive
processing of verbal/visual instructions related to the task and rehearsal of the task in working memory. This cognitive processing, facilitates the interpretation of these instructions required to perform the task (Anderson, 1982). Cognitive load theory (CLT) is related to working memory characteristics and instructional design (de Jong, 2010). It was developed to provide guidelines to assist in presenting instructional material in a way that facilitates learning motor activities and optimises performance (Sweller et al., 1998). The history of this theory goes back to 1950s when George Miller (1956) first described the limited nature of working memory and noted that humans are only able to hold seven, plus or minus two, pieces of information in their short-term memory. Subsequently, John Sweller (1988) further developed cognitive load theory to inform instructional design principles and strategies supported by a model of human cognitive architecture.

CLT is based on the assumption that the human cognitive system has limited working memory (i.e. short-term memory) that can only store and process a small amount of information for a few seconds (Robertson, 2002). This limitation in capacity and duration is restricted to new information retrieved through sensory memory (Sweller et al., 2011). However, if information is obtained from long-term memory, these limitations do not exist. As reviewed by Sweller et al. (2011), long-term memory is believed to store information as cognitive schemas, which may vary in complexity and automation. Expertise in humans is achieved by knowledge built up by these schemas. Careful and gradual combining of simple ideas to become more complex can result in the development of expertise in novice learners. The organisation of knowledge by schemas can extensively reduce working memory load as highly complex
schemas can be processed as a single element in working memory (van Merrienboer and Sweller, 2010).

Limitation in the capacity of memory arises when handling completely new and unorganised information (Cowan, 2014). This limitation might be related to the increased number of elements to be organised, which increases the number of possible combinations of elements required to be tested during any problem solving process (van Merrienboer and Sweller, 2010). This combinatorial explosion problem can be compensated for by limiting the number of information units that are processed at the same time. This can be achieved by organisning information in long-term memory using schema construction processes, thereby reducing the extraneous cognitive load (van Merrienboer and Sweller, 2010). During problem-solving processes, schemas can be built up by putting elements together (i.e. chunking), and/or combining new elements with already existing schemas in long-term memory (Chase and Simon, 1973). Schemas can then be handled as a single element in working memory, which can significantly reduce cognitive load related to the performance of future tasks. Properly designed instructions should support schema construction, as well as encourage schema automation, which can help free working memory capacity for other activities.

2.5.2.1 Types of cognitive load

The load on working memory may be influenced by the intrinsic environment of the learning tasks (intrinsic load), by the way tasks are presented (extraneous load), and by the actual learning that occurs (germane load) when handling intrinsic load (van Merrienboer and Sweller, 2010). Intrinsic cognitive load is the fundamental level
of difficulty related to instructional materials. It depends on the number of elements that need to be processed at the same time in working memory (Chandler and Sweller, 1991). Intrinsic load may not be altered by instructional interventions unless the task to be learned is altered. This alteration in the task (simplification) may occur when schemas are broken into pieces termed ‘subschemas’ and taught individually, then joined together and described as a whole unit (Kirschner et al., 2006).

*Extraneous cognitive load* is induced when instructional materials are presented to the learner in a particular way that imposes a high level of cognitive load and can lead to the overloading of working memory (Chandler and Sweller, 1991). This overloading might be related to the use of multiple sources of information causing the ‘split attention effect’ (Mousavi et al., 1995). The partially independent nature of visual and auditory working memory might be useful when multiple sources for understanding are required. Therefore, effective working memory can be increased by presenting material in a mixed format, instead of a single format. For example, visual forms of presentation (e.g. a written text and a diagram) alone are more likely to overload the visual processor but, if the written material is presented in spoken form, some of the cognitive load can be moved to the auditory processor (Mousavi et al., 1995).

*Germane cognitive load* is the load dedicated to the processing, construction and automation of schemas using working memory resources to handle intrinsic cognitive load and achieve actual learning (Sweller et al., 1998). These methods of dealing with intrinsic cognitive load consist of elements associated with previous tasks or knowledge already existing in long-term memory. Learners therefore need working
memory resources for germane cognitive load that is necessary for learning (van Merrienboer and Sweller, 2010).

Based on cognitive load theory, both intrinsic and extraneous cognitive loads are added and related when learners are presented with a task (van Merrienboer and Sweller, 2010). If intrinsic load is low, a high extraneous load resulting from poor instructional design might not be detrimental to learning as the total cognitive load is within the limits of the working memory. When teaching complicated tasks (e.g. root canal preparation) involving greater interaction between elements involved in a task (i.e. motion, sequence, force and tactile sensation in root canal preparation), the combined intrinsic and extraneous loads are likely to exceed working memory capacity and result in overload. The more that extraneous cognitive load is reduced, the more working memory resources can be dedicated to intrinsic cognitive load which enables easier induction of a germane cognitive load for learning (van Merrienboer and Sweller, 2010).

Cognitive Load theory has had a major impact on educational research and instructional design (Paas and Ayres, 2014). However, some critical questions have been raised concerning its conceptual clarity, validity of instruments used to measure cognitive load, and generalisability of its outcomes in different contexts and populations (de Jong, 2010). For example, there remains a lack of clear distinction between intrinsic, extraneous and germane cognitive load. Moreover, measurement of cognitive load using self-reported questionnaires is often presented with no standard format and with differences in the number of items used for the survey.
However, these measures cannot be utilised to measure cognitive overload (i.e. when working memory capacity is exceeded) (de Jong, 2010).

2.5.3 **Novice-Expert continuum**

To develop the capacity of expert understanding and skilful performance, Dreyfus et al. (1987) suggested a five-stage development continuum beginning with novice level, moving through advanced beginner, to competent, proficient, and expert. A learner in training for a professional role develops from a true novice (a beginner) through a sequence of stages where capacities are gradually improved by trial and error learning and continual approximation supported by appropriate supervision. Dreyfus and colleagues (1987) identified that the safe practitioner stage (competent) is a stage where the learner can perform the basic tasks related to a professional role and resolve common problems without assistance. This stage is the starting point for obtaining smooth, consistent, and accurate performance that is a characteristic of true expertise (Hendricson et al., 2006).

The development of a graduate from a professional education programme to become competent, proficient or even hold some aspects of expertise, depends on many factors (Hendricson et al., 2006). These factors include the difficulty of the skills to be acquired, practice frequency, prospects for gradually increasing levels of challenge and responsibility for the task, and mentor availability to act as an instructor and role model (Hendricson and Kleffner, 1998). Dental school graduates will generally not have the ability to perform as experts immediately after graduation, but hopefully can perform at a competent level for the essential skills associated with general
dentistry (Hendricson et al., 2006). With further practice and progress it is anticipated they will become experts.

Differences between experts and novices are often related to how they structure, analyse, and utilise information (Abernethy et al., 2008). Expert practitioners have integrated neural networks that enable instant recovery of information related to task performance or assessment of a problem (Robertson, 2002). Novice learners, on the other hand, find it difficult to bring together isolated pieces of information. Novices utilise an ineffective trial and error method because of the deficiency in pre-existing networks to facilitate fast recovery of relevant information (Hendricson et al., 2006). Students may possess some information (i.e. from text books or manuals), but this information is isolated and often not related to other topics. To develop problem-solving ability, students need to convert their disorganised acquired information (i.e. pieces of data) from textbooks and lectures into connected chains of networked knowledge, which have meaning, significance, and recognised value that can be described in an individual’s own words (Hendricson and Kleffner, 2002).

Research studies have highlighted that novices can benefit from learning motor skills with minimal conscious involvement as performance is maintained when high levels of cognitive effort are required (Masters and Poolton, 2012). Furthermore, it is evident that novices who learn without attending and monitoring their movements demonstrate characteristics that are similar to the performance of professionals with comprehensive knowledge and skills (i.e. experts) (see Section 2.5.4). The development of activities and schedules that enable novices to demonstrate
characteristics similar to experts, without the reported long period of ‘deliberate practice’, is clearly of value (Abernethy et al., 2008).

### 2.5.4 Reinvestment theory

The general distinction between conscious and non-conscious features of motor learning processes is considered a starting point to explain a variety of motor learning models (Kleynen et al., 2014). Recent research into motor skill acquisition has demonstrated that motor skill learning is often disrupted by distraction and self-focus, especially under stressful conditions (Malhotra et al., 2012). When distracted, the attention of the performer becomes focused on stimuli that are not related to the motor task. Self-focus, on the other hand, can direct attention in a way that involves self-regulation and self-evaluation in an attempt to match the required standard of performance (Masters and Maxwell, 2008). Masters (1992) grouped the range of views of self-focus control behaviours under the term ‘reinvestment’ (Masters, 1992; Masters et al., 1993; Masters and Maxwell, 2008).

Reinvestment theory relates to the conscious attempts by performers to ensure the quality of their performance, by observing (i.e. movement self-consciousness) and controlling (i.e. conscious motor processing) their own movements using explicit processes involving working memory (Masters and Maxwell, 2008). As a result of this observation and control, disruption of the automated execution of some of the motor skill components occurs, resulting in the loss of flexibility of the movement, and subsequent breaking down of performance (Masters et al., 1993).
The propensity to reinvest and the impact of reinvestment seems to vary depending on the amount of task-related declarative knowledge available and the ease of cognitive access to that knowledge by performers (Masters and Maxwell, 2008). For example, the effect of reinvestment might be more disruptive for skilled performers who depend more on automated behaviours associated with procedural knowledge rather than novices who rely on task-related knowledge to perform non-automated behaviours (Masters and Maxwell, 2008). The difficulty of the task also influences the level of disruption from reinvestment. Propensity to reinvest has been suggested to be associated with more complex tasks rather than simple tasks (Jackson et al., 2013). This is relevant to learning how to prepare root canals, as this is a complex task involving different procedures requiring cognitive access to both procedural knowledge (related to stages of treatment, sequence of instruments and materials, and different mechanical techniques used) and declarative knowledge (related to the anatomy of the root canal system, diagnosis of the case, and choice of the most suitable material and instrument in relation to the tooth/patient condition). Therefore, the impact of reinvestment during root canal preparation might be more disruptive for performance.

To assess the propensity for reinvestment, Masters and his team (1993) developed a psychometric tool referred to as the ‘Reinvestment Scale’ (see Appendix 9.11.1). This scale consists of 20 yes/no questions related to self-focus of attention. These questions were anticipated to predict propensity for conscious monitoring and control behaviour particularly under stressful and pressured conditions. The Reinvestment Scale was later followed by the ‘Movement Specific Reinvestment Scale (MSRS)’ (Masters et al., 2005) (see Appendix 9.11.2). The MSRS
consists of 10 questions. These questions were designed to assess a performer’s susceptibility to skill breakdown and movement disruption. More recently, a ‘Decision-Specific Reinvestment Scale (DSRS)’ has been developed (see Appendix 9.11.3), adapting items from the Reinvestment Scale to apply to the decision-making component of skilled performance (Kinrade et al., 2010). The DSRS consists of 13 questions to assess for individuals with a greater predisposition for making poor decisions under pressure (see Section 5.2 for further details about the surveys).

2.5.4.1 Implicit and explicit learning

The negative effect of reinvestment can be prevented by emotion control training, training performers to avoid conscious control of their behaviour, distraction techniques, or directing performers to an external focus of attention (Masters and Maxwell, 2008). Another possible way to prevent reinvestment is by utilising implicit methods for learning motor skills. Implicit learning of motor skills includes learning skills without the accumulation of expressed verbal knowledge (e.g. rules) of motor task performance such that these “implicitly learned skills are (unconsciously) retrieved from implicit memory” (Kleynen et al., 2014). Therefore, by learning implicitly, the aim is to limit the accumulation of movement-specific knowledge, decrease dependence on declarative knowledge structure during motor task performance, and minimise testing of hypotheses related to movements that are aimed at improving performance (Masters, 1992; Masters and Maxwell, 2004). Studies have found that the value of implicit motor learning in novices exceeds the expected objective of acquiring motor skills by also showing robust performance under conditions of stress conditions, fatigue and when high levels of cognitive effort are
required, e.g. when performing an additional or secondary task (Masters, 1992; Liao and Masters, 2001; Masters et al., 2008c).

An implicit approach contrasts with the conventional approach for learning motor skills in dentistry and surgery, namely, learning explicitly by consciously following detailed textual, visual, and/or verbal instructions related to carrying out a motor skill task (Feil et al., 1994; Dubrowski et al., 2012). An explicit learning process consists of cognitive (declarative) stages and depends on involvement of working memory (Kleynen et al., 2014). Research on motor skill learning during laparoscopy procedures has indicated that using explicit learning approaches disrupts neural efficiency of the brain compared with implicit approaches (Zhu et al., 2011a). While this explicit framework of instruction is routine, it was proposed recently that a shift to more implicit (less explicit) training strategies might be beneficial, particularly in the initial stages of learning (Poolton et al., 2005).

2.5.4.2 Implicit and explicit learning approaches

In a study using the Delphi technique to explore opinions by experts regarding descriptions for implicit and explicit learning methods, there was a lack of agreement among experts regarding the application of explicit and implicit motor skill learning (Kleynen et al., 2015). However, there was agreement that certain methods can promote more implicit or more explicit motor learning depending on instructions, limitations in the environment, type of motor task, and personal abilities (see Section 2.4). Various implicit and explicit motor skill learning strategies have been reported in the literature (Kleynen et al., 2014; Kleynen et al., 2015). Methods for learning more implicitly include learning motor skills under secondary task conditions
(e.g. golf putting: Masters, 1992); learning without errors (e.g. golf putting: Maxwell et al., 2001; Poolton et al., 2005; Lam et al., 2010b); learning with physical ‘guidance’ (skiing: Wulf et al., 1998; e.g. suture and knot tying: Masters et al., 2008b); learning by analogy (e.g. table tennis: Liao and Masters, 2001); or learning from observation (e.g. suture and knot tying: Masters et al., 2008a). The efficacy of these various approaches for learning motor skills has been demonstrated. For example, learning using a procedure to reduce the production of errors, i.e. errorless learning, has been shown to result in significantly higher levels of performance during both learning and testing phases compared with learning via increasing errors (explicitly) (Maxwell et al., 2001; Lam et al., 2010b).

Implicit learning tends to avoid hypothesis testing by participants (Seger, 1994). Indeed, a core principle of implicit learning approaches is to develop learning protocols that minimise hypothesis testing and prevent participants learning from their errors (Maxwell et al., 2001). Subsequently, learning with reduced errors is associated with limited development of ‘declarative’ knowledge (Poolton et al., 2005). This outcome has been proposed to result from a reduction in the use of working memory for error detection and correction (Poolton et al., 2005). A recent study provides evidence of the impact of errors on cognitive processing (Lam et al., 2010a). This study demonstrated that cognitive processing increased, as evidenced by increased reaction times to audio prompts, following golf putting errors associated with unsuccessful putts, compared with reaction times following successful putts (Lam et al., 2010a).

As noted, another implicit learning approach involves learning from observation. For example, observation combined with guidance, i.e. *guided-observation*, involves
learning motor skills via a non-verbal method with limited conscious awareness of what is learnt and how a motor task is executed. As a result, it is difficult for the learner to provide verbal details on how a motor task is carried out and therefore this is considered to be an implicit way of learning (Masters et al., 2008a). Guided-observation reduces performance errors by using physical guidance to direct the movements, thereby reducing the need for conscious correction of mistakes by the performer. Studies have shown that guided observation encourages more stable performance under stressful conditions and multi-tasking (Maxwell et al., 2001; Poolton et al., 2005; Masters et al., 2008a). In contrast, learning from observation in combination with instructions, i.e. instructed-observation, involves the acquisition of motor skills with supplementary verbal instructions and high conscious awareness by the performer about how a motor task is executed. As a result the learner can provide detailed verbal steps about a motor task that has been learnt explicitly (Masters et al., 2008a).

In general, motor skill learning strategies that result in high conscious awareness about how the motor task is articulated are used to promote motor learning that is more explicit, for example, by learning motor skills by increasing errors (errorful), trial-and-error learning, and learning by observation combined with instruction (Kleynen et al., 2015). However, for other motor learning strategies, it is unclear whether they promote more implicit or more explicit motor learning, e.g. learning by observation alone (Kleynen et al., 2014).
2.5.4.3 Impact of stress on motor skill learning

These features of implicit motor learning are of importance in dentistry because working under stressful conditions (e.g. physiological or psychological) is a consistent characteristic, either during undergraduate studies (Pöhlmann et al., 2005; Gorter et al., 2008; Alzahem et al., 2011; Schéle et al., 2012) or in practice (Kay and Lowe, 2008). The most common stressors for practitioners include patient demands, fear of complaints and non-clinical administrative tasks (Kay and Lowe, 2008). Likewise, patient demands are stressors for dental students, in addition to stressors related to their clinical and academic performance, course workload and requirements, fear of failing or falling behind, and lack of time for study and relaxation (Alzahem et al., 2011). These stressors are of significance as they can compromise the performance of dental students (Alzahem et al., 2011) and can negatively impact on their learning experiences when they are stressed (Murray and Chandler, 2014). Moreover, the finding of a limited relationship between surgical performance in theatre to that achieved under simulation conditions may be due to the stress associated with operating on a live patient compared with completing a similar but simulated task (Prabhu et al., 2010). Therefore, further investigation of learning dental fine motor skills under conditions that result in robust performance, under stressful conditions (Masters, 1992; Liao and Masters, 2001; Lam et al., 2009) is indicated.
2.6 Summary

In summary, learning endodontics is a complex task involving the development of fine motor skills (Seijo et al., 2013; Murray and Chandler, 2014). The reported use of theories and/or evidence for designing learning activities to develop the fine motor skills needed for root-canal preparation is limited. Recent evidence from studies investigating motor skill learning highlights the negative impact of self-focus and self-regulation on learning outcomes, particularly during the early stages of learning (see Section 2.5.4) (Masters et al., 1993). Learning implicitly, so that minimal conscious involvement is required (e.g. approaches that minimise errors or involve observation with physical guidance), has been shown to limit the effect of self-focus and self-regulation on subsequent performance. This can result in positive and sustained outcomes, even under multi-tasking or stressful conditions, in comparison to commonly-used explicit approaches (e.g. approaches that increase error production or involve observation with instructions) (see Section 2.5.4.1). It has also been shown that novices who learn implicitly demonstrate characteristics that are similar to the performance of professionals with comprehensive knowledge and skills (i.e. experts). For example, expert performance is maintained under stressful conditions, and their movements are consistent and efficient (Zhu et al., 2010). The development of activities and schedules that enable novices to demonstrate characteristics similar to experts, without the reported long period of ‘deliberate practice’, is clearly of value (Abernethy et al., 2008) (see Section 2.5.3).

Outcomes of learning implicitly are important in dentistry because working under stressful conditions (e.g. physiological or psychological) is a consistent
characteristic, either during undergraduate study or in practice (Alzahem et al., 2011). Stressors related to dental students’ transferring from simulation to clinical settings can result in deterioration of performance. It is suggested that learning implicitly in the simulation stage can reduce loss of performance with the move to clinical settings (Malhotra et al., 2012). Therefore, further investigation of effective methods for learning dental fine motor skills is indicated, using conditions that result in robust performance, even under stressful conditions (Masters, 1992). The findings from this study will also be relevant to current and planned investigations in other areas of dentistry that require fine motor skills e.g. cavity preparation, crown preparation, and minor surgical skills. Furthermore, the outcomes of this thesis should aid in the design for activities based on future simulation/haptic systems.
2.7 Aims and hypotheses

The main aim of this study is to evaluate the effect of different learning approaches (specifically approaches that are consistent with implicit and explicit learning (Kleynen et al., 2014) on the acquisition of fine motor skills associated with root canal hand instrumentation in simulated endodontic tasks. This involves using different learning strategies, with subsequent tests to establish how well performance of dental students is maintained (i.e. when multi-tasking and when stressors are present). Two learning approaches that are consistent with implicit learning, namely errorless (Study 1) and guided-observation (Study 2) approaches are used, in comparison to explicit related approaches, namely errorful and instructed-observation approaches. Recent evidence proposes that learning implicitly results in the maintenance of performance under multi-tasking or stressful conditions, in contrast to learning explicitly, as a result of a reduction in the attentional demands of the learning approach (Liao and Masters, 2001; Lam et al., 2009; Poolton et al., 2011). Moreover, as part of Study 2, it is sought to investigate the impact of stress (i.e. the combined effect of time pressure and evaluation stressors) on the performance of pre-clinical dental students using subjective (psychological, i.e. self-report questionnaires) and objective (physiologic, i.e. heart rate) measures of stress.

It is hypothesised that attention loads will be reduced when manipulation skills are learnt by limiting errors or observation with guidance. This will allow learners to process critical information required for completing the task more readily and complete complex root canal treatment procedures accurately while maintaining performance under multi-tasking conditions. In contrast, it is expected that learning
through increasing errors or observation with instructions and observation alone will lead to a reduction in performance under these pressered conditions.

Another aim was to investigate the impact of reinvestment on performance in the same sample of dental students (Study 3). Three reinvestment surveys (i.e. RS, MSRS, and DSRS) designed to explore a propensity to reinvest were used. Scores derived from the surveys are then used to divide the samples from Study 1 and 2 into low and high reinsters.

It is hypothesised that individuals with a high propensity for conscious monitoring during root canal preparation would not perform as well as low reinsters. It is proposed that the reduction in performance results from high reinsters allocating working memory resources to monitoring and controlling their movements.
3 Study 1: Errorless vs errorful learning

3.1 Introduction

As noted previously, procedural and cognitive skills are essential abilities for clinical dental practice. Students learn these skills during simulated clinical activities designed to ensure that they achieve a satisfactory level of competence prior to proceeding to direct patient care. To optimise learning, the design of relevant learning activities needs to be based on evidence. However, limited research has been conducted on the rationale and design of pre-clinical and clinical endodontic courses, and only a limited number of studies have investigated factors that affect performance during root canal instrumentation (see Section 2.1). Generally, endodontic courses have been designed on a foundation of feasibility and practicality in each dental school (e.g. use of human extracted teeth rather than plastic teeth) and have not been consistently based on ‘contemporary practices’ (Feil, 1992; Tchorz et al., 2014b). Moreover, current methodologies for learning motor skills associated with root canal preparation are based mainly on providing detailed textual and verbal instructions for each procedure (i.e. explicit learning). Thus, investigation using contemporary learning theories to inform the design of approaches to support students’ learning of the fine motor skills required for root canal preparation is indicated (see Section 2.1).

Among the various endodontic instruments available, the use of traditional hand instruments remains of critical importance. Hand instruments are recommended for initial root canal preparation, for use in between rotary instruments, and for the correction of procedural errors (see section 2.2.3). Therefore, learning the
fundamental skills of hand-instrument manipulation remains essential and should occur prior to learning the use of other advanced systems (i.e. rotary instruments) for root canal preparation procedures.

As discussed previously (see Section 2.5.4), the propensity to reinvest and the impact of reinvestment can vary depending on the amount of task-related declarative knowledge and the ease of cognitive access to that knowledge by performers (Masters and Maxwell, 2008). For instance, the effect of reinvestment might be more disruptive for skilled performers depending more on automated actions linked with procedural knowledge rather than novices relying on task-related knowledge to perform non-automated behaviours (Masters and Maxwell, 2008). As noted previously, reinvestment is also proposed to be more detrimental to complex motor tasks involving many components that must be coordinated (Masters, 1992). This is applicable to learning root canal preparation, as this is a complex task involving different procedures requiring cognitive access to both procedural knowledge (related to sequence of instruments, and manipulation of mechanical techniques used) and declarative knowledge (related to the anatomy of the root canal system, and decision to progress with hand instrument or shift to another instrument during canal preparation).

As discussed in Section 2.5.4.1, there are various approaches that can reduce the effect of reinvestment on performance. Studies have found that the importance of implicit motor learning in novices exceeds the expected objective of learning motor skills. These studies showed that learning implicitly provides robust performance under stressful conditions, fatigue and when high levels of cognitive effort are required
(e.g. when performing a secondary task) (see Section 2.5.4) (Masters, 1992; Liao and Masters, 2001; Masters et al., 2008c). The main objective of implicit learning is to provide learning protocols that minimise hypothesis testing and reduce the use of working memory for error detection and correction. Various effective implicit motor skill learning approaches have been tested. For example, learning using a procedure to reduce the production of errors, i.e. errorless learning, resulted in significantly greater levels of performance during both learning and retention phases compared with an errorful approach that increased production of errors (Maxwell et al., 2001; Lam et al., 2010b; Capio et al., 2013) (see Section 2.5.4.2).

In summary, learning endodontics is a difficult task involving the development of fine motor skills. To date, there are no published studies to provide theory-informed and/or evidence-based approaches for learning these skills. Recent evidence from studies investigating motor skill learning highlight the negative impact of self-focus and self-regulation on learning. To limit the effect of self-monitoring on learning and subsequent performance, implicit approaches for learning skills have resulted in positive and sustained outcomes by comparison with more routine/explicit approaches.

**Aim and hypothesis**

Therefore, the aim of this study was to investigate the effect of learning via an errorless approach (implicit) or via an errorful approach (explicit) on the acquisition of root canal preparation hand skills. It was hypothesised that root canal preparation skills learnt with reduced errors would not deteriorate during multi-tasking.
3.2 Methods

3.2.1 Curriculum context: Adelaide pre-clinical endodontic component

The current Bachelor of Dental Surgery (BDS) curriculum at the Adelaide School of Dentistry consists of a single course (stream) for each year level. This stream is designed to integrate theory related to clinical, biodental, population health and behavioural sciences, and the required skills for subsequent provision of patient-centred care (Kaidonis et al., 2013). Dental Science and Practice 3 (DSP 3) is the single stream in the third-year of the Adelaide Bachelor of Dental Surgery (BDS) program.

The DSP 3 course runs over 28 weeks and involves case-based integrated learning activities, a series of interactive class meetings, simulated clinical sessions, and direct patient care. Simulation activities in endodontics are part of the DSP 3 stream and start in the second semester of the BDS 3 program. The program consists of 11 one-hour interactive class meetings (weeks 1-11) and seven 3-hour simulated clinical sessions in semester 2 (weeks 7-13). In DSP 4, the endodontic component starts with a two-week commencement term that consists of five one-hour interactive class meetings and six 3-hour simulated clinical sessions. Students are required to successfully complete the learning activities in the commencement term before they can progress to providing endodontic care for patients. These clinical sessions start in semester 1 of the DSP 4 program. The total number of hours spent during endodontic interactive lectures is 16 hours distributed over the DSP 3 and DSP 4 programs (see Table 3.1), while, the total number of hours spent during simulated clinical sessions is 39 hours distributed over the DSP 3 and DSP 4 programs (see Table 3.1).
Table 3.1. Number of hours spent during endodontic interactive lectures and simulated clinical sessions

<table>
<thead>
<tr>
<th>Year</th>
<th>Interactive lectures</th>
<th>Simulated clinical sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second semester, DSP 3</td>
<td>11 hours (weeks 1-11)</td>
<td>21 hours (weeks 7-13)</td>
</tr>
<tr>
<td>Commencement term, DSP 4</td>
<td>5 hours</td>
<td>18 hours</td>
</tr>
</tbody>
</table>

DSP = Dental Science and Practice

Pre-clinical endodontic simulation activities are designed and set up to simulate the clinical situation, i.e. working with an adjustable manikin head that simulates the patient’s actual head position in the clinic. During these sessions, students work with natural human teeth (e.g. incisors, premolars and molars, including both maxillary and mandibular teeth) that are set in a plastic model and placed in the manikin head. Endodontic simulation exercises are carried out under rubber dam isolation and involve access cavity preparation, followed by working length determination of the root canal, root canal preparation and subsequent root canal filling. Mechanical root canal preparation includes instrumentation of the root canal using hand instruments and rotary instruments. Root canal instrumentation activities during the DSP 3 course are practised using stainless-steel K-type hand instruments with NiTi rotary instruments being used in commencement term of the DSP 4 course. Stainless-steel hand files are commonly used in simulated endodontic programmes due to their lower cost compared with NiTi hand files. At the beginning of each simulated endodontic session, the course coordinator reviews each procedure and the required outcomes of each task supported with slides. These techniques have been discussed in interactive class meetings and made available online for students before the simulation clinic sessions. During these sessions, groups of 9-12 students practise under the supervision of a tutor. Tutors are academic staff members, private practice clinicians,
or postgraduate endodontic students. A range of methods is used by tutors to improve skill learning during simulation clinic sessions, e.g. the tutor previews tasks and instruments required during the session with their group and then gives instructions relevant to the procedures and/or techniques. Teaching approaches and learning contexts vary from one tutor to the other (e.g. including use of descriptive drawings, diagrams, and multimedia). Tutors provide formative feedback to their students during sessions, and students fill out self-assessments on the completion of each procedure and discuss their performance with their tutors. Assessment criteria used in the clinical simulation sessions are similar to those used for clinical assessment for all BDS year levels. These criteria include knowledge base, clinical skills, patient management and professional behaviour. These criteria are used as part of self-assessments and summative assessment of endodontics simulation clinic and clinic performance.

3.2.2 Research design for Study 1

Ethical approval was obtained from the Human Research Ethics Committee of the University of Adelaide (Protocol H-2012-117, see Appendix 9.3). Following a pilot study, participants performed fundamental root canal hand instrumentation tasks during learning and testing phases. These tasks focused on the first stage of root canal preparation, namely, the crown-down stage (see Section 2.2.2.1). There was no pre-test of baseline dexterity levels to avoid accumulation of verbalisable technical knowledge by learners (Maxwell et al., 2000). Instead, the aim was to achieve matched ability between groups based on a random group allocation of participants.
The learning phase in this study involved either an errorless (E less) learning approach or an errorful (E ful) learning approach (see Figure 3.1). To elevate and maintain motivation levels throughout practice, all participants were informed about the later testing phase, and were encouraged to do their best. Immediate retention/transfer tests were used to establish the learning achieved after completion of learning trials and to assess the effect of increasing process demands on performance. Specifically, the transfer tests included simulated canal instrumentation in a plastic tooth. The second transfer test involved a multi-tasking activity during completion of the simulated root canal preparation (Koedijker et al., 2011). The addition of a secondary task was designed to increase cognitive demands for participants. In this latter test it was expected that the performance of participants in the E less (implicit) group would be maintained while that of the E ful (explicit) group would deteriorate. A digital video/audio record of participants’ time spent on enlarging the canal, participants’ responses to the secondary task, and recall of instructions were produced. Participants completed three reinvestment surveys after learning/testing phases (see Section 5.2).
**Pilot Study:** novice participants, i.e. no previous experience/ knowledge in endodontics (n=8)
Used to determine the time frame for each task, essential instructions for using hand instruments to minimise provision of explicit procedural knowledge, type and order of learning blocks, choice of relevant hand instruments for errorless (implicit) and errorful (explicit) groups, and the number of learning trials needed to show improvement.

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**Experimental Groups n=42**

**Comparative Group n=17**

- **Comparative group:** students who had completed the usual pre-clinical endodontics activities (15-20 hours of hand instrument use for initial canal preparation) provided comparative performance data (for comparison with performance achieved by errorless and errorful learning groups).

**Errorless (Implicit) Group n=21**

- **Learning phase:**
  - Estimated time: 60 min/session: range 60-90 min
  - Task: endodontic preparation of canals in plastic blocks from simple to complex canals (see Figure 3.4)

**Errorful (Explicit) Group n=21**

- **Learning phase:**
  - Estimated time: 60 min/session: range 60-90 min
  - Task: endodontic preparation of canals in plastic blocks from complex to simple canals (see Figure 3.4)

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**Resting period:** 10-15 minutes break with refreshments provided, and general discussion unrelated to experiment.

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**Testing phase: (15-30 minutes)**

- **Immediate retention/ Transfer test 1:** Primary task
  - Estimated time: 12 min/session: range 7-15 min
  - Task: endodontic preparation of canal in plastic tooth in a manikin (see Figure 3.5)

- **Transfer test 2:** Primary and secondary task
  - Estimated time: 12 min/session: range 7-15 min
  - Task: endodontic preparation as for retention/ transfer test 1 with secondary task, i.e. while an auditory tape played a series of dentally relevant words, participants were instructed to repeat the word immediately prior to the target word.

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**Reinvestment Survey:** 3 weeks later, participants completed the three reinvestment surveys. This was used to evaluate participants’ focus of attention behaviours on learning and performance in general, i.e. not related to study activities (see Section 5.2).

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Figure 3.1. Summary of Study 1 plan
3.2.3 Pilot study

Since there are no studies that have investigated the outcomes of implicit learning conditions for endodontic skills, pilot testing was carried out to determine the type/number and sequence of learning blocks and relevant hand instruments, the number of learning trials, essential instructions, and the time frame for each task. The pilot study involved eight participants with no previous experience or knowledge in endodontics. The following sections indicate the procedure and decisions made. Results for each component of the pilot study are given at the end of this section (see Table 3.2).

3.2.3.1 Type, number and sequence of learning blocks

Eight clear resin simulated root canal practice blocks were selected for the pilot test (wide straight: S1-U1; wide/curved: S1-L6, S4-U1 10°, S4-U1 20°, S4-U1 30°; narrow straight: S8-BS2-U; and narrow/curved: S8-BC2-U, Nissin Dental™, Japan; Profile practice block, 0.02 taper, Dentsply™, Australia) (see Appendix 9.4.1). Selection was based on the variation in root canal shape, diameter, and curvature. The manufacturer provided information on simulated root canal curvature of the blocks. The reported curvature was then confirmed via the measurement technique described by Pruett et al. (1997). For the pilot trials, the plastic blocks were embedded in silicon material (Z-DUPE, duplication silicon, Italy) in plastic cups, to be consistent with the ‘blind’ aspect of completing root canal preparation in natural teeth. The test involved two phases. The first phase aimed to find out the appropriate sequence of plastic blocks from the simplest to most difficult canal in terms of manipulation of root canal preparation. During the first phase, eight participants were asked to enlarge and
shape simulated root canals in eight randomly ordered standardised plastic blocks. Participants were informed that there were possible differences between the blocks. Following each trial, participants were asked to place the prepared blocks in order of difficulty (see Appendix 9.4.2). Completion time for each trial was recorded and their response to the instructions for root canal instrumentation was observed (i.e. hand movements, rotation of the instrument in the root canal, torque and pressure applied in the canal). Following completion of the eight trials, participants were asked to review and comment on the order of the plastic blocks. Selection of the simulated root canal blocks for the subsequent study pilot was based on feedback from participants, completion time and procedural errors. Four blocks were selected to be used during the learning phase, with the order for the E less group being wide/straight; wide/ curved 20°; narrow/ straight; and narrow/ curved 20° (S1-U1, S4-U1-20°, S8-BS2-U, S8-BC2-U, Nissin Dental, Japan). The sequence of E full groups was in the reverse order (see Table 3.2).

3.2.3.2 Selection of hand instruments and working length

Nickel titanium (NiTi) K-type (25mm length) hand instruments (KFNT25, ADAM Dental, Australia) were selected to be used for learning and testing phases. This selection was based on a review of the endodontic literature (see Section 2.2.3). Selection of relevant hand instrument sizes was based on the diameter (i.e. wide or narrow) of the root canal and the fit of the hand instrument in the canal. For example, the instrument that fitted the wide canals (i.e. the tip of the file reached to one to two millimetres from the end of the canal and had a tight fit at that part of the canal) was size 40. Accordingly, instrument sizes selected for the wide canals (wide/ straight, wide/ curved 20°) were 50, 45, and 40. For the narrow canals (narrow/ straight and
narrow/ curved 20°) sizes 40, 35, and 30 were selected (see Table 3.2). The sequence of using the hand instruments was based on the chosen hand-instrumentation technique of the crown-down technique (see Section 2.2.2).

The working length of the simulated root canal (i.e. from the top surface of the block to the end of the canal) was determined visually on sample blocks by inserting a small hand instrument (e.g. size 15) until the tip of the instrument reached the end of the canal. Then the rubber stopper was set to the top surface of the block (i.e. reference point), and the instrument was removed. The working length was measured from the tip of the instrument to the rubber stopper using a metallic millimetre ruler (Stainless Steel Ruler 150mm, Kincrome, Australia). Measurements were obtained to the nearest 0.5mm. The recorded working lengths for wide/ straight, narrow/ straight and narrow/ curved 20° canals was 17.5 mm, and was 18.5mm for the wide/ curved 20° canal. For standardisation of working length conditions, it was decided to fix the working length of all learning blocks at 17.5mm. The working lengths were also fixed for all hand instruments used during learning trials. This was achieved by using Super Glue (UHU Super Glue, UHU GmbH & Co. KG, Germany) to fix the rubber stopper for each hand instrument.

3.2.3.3 Number of trials

The aim of the second phase of the pilot study was to identify the number of learning trials required for participants to show improvement in performance as well as provide an estimation of the time frame required for the learning phase. The second phase was separate from the first phase (i.e. after three hours on the same day, or on a different day). During the second phase, five of the eight participants
were asked to enlarge and shape simulated root canals in two of the eight standardised plastic blocks: the wide/ curved (20° curvature) canal block (S4-U1-20°, Nissin Dental, Japan), and the narrow/ curved (20° curvature) canal block (S8-BC2-U, Nissin Dental, Japan). Completion time for each trial was recorded and their response to the instructions for root canal instrumentation was observed again (i.e. hand movements, rotation of the instrument in the root canal, torque and pressure applied in the canal). Participants had five repeats for each of the two types of blocks (see Appendix 9.4.4). These repeats were based on the maximum allocated time (i.e. 60 minutes) for the pilot test. The number of trials for each block was determined based on improvement in completion times, improvement in the quality of canal preparation, and reduction in procedural errors. Three trials were selected for each of the four learning blocks (see Table 3.2).

3.2.3.4 Instructions

Following completion of the pilot trials, participants viewed a diagram (see Figure 3.2) illustrating the key movements in the balanced force technique. They were asked to provide comments on the possible essential instructions needed to explain the technique. For the direction of rotations, five out of the eight participants preferred the use of terms “turns” for the rotations, and “clockwise” and “counter clockwise” to indicate the direction of the rotation. They indicated the presence or absence of pressure by using the terms “with” or “without pressure” following the rotation direction, for example, a quarter-clockwise turn to the right with pressure for the first movement. The other three participants referred to the direction as “screw-in” and “screw-out”. Participants’ comments were reviewed and refined to minimise provision of explicit procedural knowledge (see Section 3.2.5.3).
Figure 3.2. Illustration of the three key movements in the balanced force technique. A diagram used to develop essential instructions for the key movements.

3.2.3.5 **Time frame**

The average completion time recorded for learning blocks was about five minutes. In addition, the average completion time for the most difficult block among the selected learning blocks (i.e. narrow/ curved 20°) was also about five minutes (see Appendix 9.4.3). Based on these results and the number of trials in the learning phase (i.e. three trials x four types of blocks), it was decided to allow 60 minutes as an average completion time for the learning trials (see Table 3.2).

<table>
<thead>
<tr>
<th>Learning conditions</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of resin blocks selected</td>
<td>Four blocks were selected according to canal curvature and width: wide/ straight, wide/ curved 20°, narrow/ straight and narrow/ curved 20° (S1-U1, S4-U1-20°, S8-BS2-U, S8-BC2-U, Nissin Dental, Japan)</td>
</tr>
<tr>
<td>Sequence of learning blocks</td>
<td>E less: wide/ straight, wide/ curved 20°, narrow/ straight and narrow/ curved 20°; E ful: reverse order</td>
</tr>
<tr>
<td>NiTi hand instruments to be used</td>
<td>Wide blocks: K-type # 50, 45 &amp; 40, narrow blocks: K-type # 40, 35 &amp; 30. All instruments were measured and fixed to the full working length of the canal (17.5mm)</td>
</tr>
<tr>
<td>Number of learning trials</td>
<td>Three learning trials for each of the four blocks</td>
</tr>
<tr>
<td>Essential instructions for using hand instruments in balanced force technique</td>
<td>Balanced force technique: ¼ turn to the right with pressure, then turn ¾ to the left with pressure, and finally, a ¼ turn to the right while you are removing the instrument (i.e. minimum key instructions)</td>
</tr>
<tr>
<td>Maximum time frame for each task</td>
<td>Five minutes for each plastic block</td>
</tr>
</tbody>
</table>
3.2.4 Participants

3.2.4.1 Recruitment procedures

Academic staff introduced the main investigator and the project to the participants during a class meeting, then left before further explanation about the recruitment procedure was provided by the main investigator. Students were provided with information sheets and consent forms to support the explanations provided and subsequent questions were answered. Details of the project were explained and students were formally invited to participate. Students were asked to respond on a voluntary basis.

3.2.4.2 Inclusion and exclusion criteria

Participants were volunteer third-year dental students enrolled in the 5-year Bachelor of Dental Surgery programme in School of Dentistry at the University of Adelaide during 2013. Dental students were selected for the study and not university students from other courses, as previous research has shown that innate abilities reported to influence motor skill learning are higher in dental students than the general population (e.g., cognitive and perceptual speed) (Suksudaj et al., 2012). As a result, the results of the current study are not generalisable to the general population (Willson, 1990), however, the focus of the study was to investigate learning approaches for use with dental students. To test the effect of different learning conditions, it was important that participants were novices in the activities to be learnt. This was necessary so that they did not bring any previously-acquired explicit or prior knowledge to the task that might influence outcomes (Masters, 1992; Maxwell et al., 2001). Therefore, the participants in the experimental groups were in their first
semester of third-year, having successfully completed their second-year dental course but with no previous endodontic knowledge or working experiences. Students were excluded if they had previous endodontic knowledge or working experiences, if they were repeating the third-year dental program at the time when data were collected; and/or if they did not complete all experimental trials. To be able to compare performance levels for E less (implicit) and E ful (explicit) learning groups, dental students who had successfully completed the normal pre-clinical endodontic activities (completed in second semester of third-year (2012) and the commencement term in fourth-year (2013) provided comparative performance data. This group is referred to as the ‘comparative group Study 1 (COM1)’. Forty-two (50%) third-year students and 17 (21%) fourth-year students were included as participants based on the inclusion and exclusion criteria.

3.2.4.3 Sample size

Sample size calculations for this study were based on previous endodontic studies about factors affecting performance of undergraduate dental students during root canal instrumentation (e.g. hand-instrument handle design, diameter and fitting of gloves (Chandler and Bloxham, 1990; Chandler et al., 1996)), and the effect of sequence and amount of training on pre-clinical endodontic students (Abou-Rass, 1974a; 1974b). From these studies, likely minimal differences that would be statistically significant between experimental groups for measures of completion time and accuracy were calculated. In calculating the sample size, significance was set at 0.05 and beta at 0.2, with a power of 80%. From the analyses for each of these measures, based on minimum differences, estimated sample sizes ranged from seven to 15 per learning group. Due to a lack of previous studies related to endodontics and
the anticipated possible loss of consenting participants, it was decided to assign a minimum of 20 participants per learning group.

3.2.5 Research materials and methods

3.2.5.1 Preparation of blocks for the learning phase

For the learning phase, the clear plastic blocks that were selected (see Section 3.2.3.1) were embedded in silicon material (Z-DUPE, duplication silicon, Italy) in plastic cups, to be consistent with the ‘blind’ aspect of completing root canal preparation in natural teeth. This also resulted in participants being unable to observe the canal shape and instrument movement/ path in the canal with the aim to minimise hypothesis testing (see Figure 3.3).

Figure 3.3. Setup for learning trials. (I) light, (II) instrument tray with irrigation syringes and tweezers, (III) hand instruments presented in sequence (1-3) for (A-B) blocks (wide), (IV) Hand instruments presented in sequence (1-3) for (C-D) blocks, (V) working area, and (VI) 3 sets of plastic blocks embedded in blue silicon and arranged in their sequence (A-D) of different canal widths and curvatures.
3.2.5.2 Learning phase procedure

Prior to trial commencement, participants were asked to wear protective glasses and gloves, and to adjust the chair, and light positions for comfort. Participants prepared root canals with hand instruments using the balanced force technique (see Section 2.2.3) during learning and testing phases. Participants were asked to enlarge and shape standardised canals (crown-down stage only) in plastic blocks with different canal diameters and curvatures (see Figure 3.4). This training programme simulated the difficulty levels of practice such that errors would occur at varying rates for the E less and E ful groups. The E less group (implicit) enlarged and shaped the canals in Figure 3.4 to minimise creation of errors, namely commencing with the simplest task (wide/straight canal) and progressively moving toward the most difficult task (narrow/curved canal) (Maxwell et al., 2001). As a result, it was anticipated that as there should be no need to correct performances that were successful, participants would generate limited movement strategies that would result from feedback associated with error detection and correction. The E ful group (explicit) enlarged and shaped the canals in the reverse order, with training beginning with the most difficult task (Zhu et al., 2011a). It was expected that this sequence of learning tasks would be associated with creation of frequent errors and subsequent active hypothesis testing behaviours by participants with resultant accrual of explicit knowledge about how to do the task (Poolton et al., 2005).
3.2.5.3 Instructions provided

The amount of information provided to both E less and E ful groups was limited and made as simple as possible to minimise load on working memory (Miller, 1956) (refer to Section 2.5.1). For example, channel was used instead of canal. Therefore, participants were provided the following verbal instructions.

1. You are required to complete a series of three trials for each of the four types of blocks on the tray.

2. For each block, use the instruments in front of you in the sequence from left to right (1-3), and prepare the channel as efficiently and as quickly as possible: you have around five minutes per block.

3. The target is that when you reach instrument number 3, it feels loose inside the channel, and the rubber stopper is touching the upper surface of the block. The loose fit of the instrument and that the stopper touches the upper surface of the block only applies to instrument number 3.

4. To get the instrument down in the channel you need to use a specific technique: pick up the hand instrument by the plastic handle like a pin, and imagine that you
are inserting the instrument with a one-quarter turn to the right with pressure, then turn three-quarters to the left with pressure, and finally, a one-quarter turn to the right while you are removing the instrument from the channel.

5. Between each of your instruments clean the channel by inserting the small purple-handled instrument and move it in and out frequently. Make sure that the instrument goes all the way down until the rubber stopper touches the top of the block.

6. Then wash out the channel using the syringe by inserting the needle into the channel as far as possible, and using copious amounts of water.

3.2.5.4 Preparation of teeth for testing phase

Tooth/ root canal selection

The mandibular left first molar tooth (B22X-END#36, Nissin Dental, Japan) had features similar to the equivalent natural human tooth, namely an accurate simulation of the canal systems, anatomical features, and physical properties (e.g. microhardness, see Section 2.2.1). Both transfer test 1 and 2 were performed on the distal canal of plastic mandibular first molar teeth as this canal was of a medium degree of difficulty compared to the tasks in the learning phase for both E less (implicit) and E ful (explicit) groups. Specifically, the beginning of the canal was wide and straight, then the canal curved (about 20 degrees) and narrowed towards the end of the root. This variation from the practised tasks during the learning phase for both groups was necessary to evaluate the effect of learning on performance in isolation from any degrading or enhancing factors related to the practice condition particularly in terms of similarity to the final blocks from the learning phase (Wulf et al., 2010). It has also been reported
that this variation is important for generalisation of the learnt motor skill (Anderson, 1982). Teeth were inspected visually and radiographically for any manufacturing defects and variations in canal length, curvature and diameter.

**Access cavity preparation**

Access to the root canal was gained according to ideal access cavity guidelines (Peters and Koka, 2008; Wilcox, 2009) thereby providing straight line access to the canals. This was achieved using a high-speed tapered diamond bur (see Figure 3.5, a). To ensure root canal patency of all teeth, a size 10 NiTi K-type hand instrument was inserted into the root canal and advanced about 1mm through the apical foramen (i.e. root end opening).

![Figure 3.5. Testing phase: plastic tooth (mandibular left first molar). (a) occlusal view with access opened and reference point (■) marked distal to the cavity, (b) buccal view, and (c) distal view showing distal canal.](image)

**Canal length determination**

After ensuring patency of the distal canal, a size 15 NiTi K-type hand instrument was inserted in a sample tooth for determination of the distal canal working length (i.e. from the reference point to the apical end of the root canal) (see Figure 3.5, a).
Viewed through an operating microscope (OPMI pico, Carl Zeiss, Germany), the instrument was advanced in the canal until its tip was visually flush at the apical foramen. The rubber stopper on the hand instrument was then adjusted and positioned on the reference point (i.e. distal side of the access opening). The working length was determined as described in the pilot study (see Section 3.2.3.2) such that the recorded working length for the distal canal was 19.5 mm. This working length was fixed for all hand instruments used during the testing trials as per the pilot study. The canal length was confirmed radiographically (bucco-lingual direction) using digital radiography (Intraoral x-ray unit, Prox, Planmeca, USA) with an intraoral phosphor storage plate (Size#2 PSP, Air Techniques, USA) and digital imaging system (ScanX duo, Air Techniques, USA). Radiographs were screened and analysed using digital radiographic imaging software (Exact V10, Software of Excellence, Australia).

Simulated root canal curvatures of teeth were recorded on radiographic images using the technique described by Pruett et al. (1997) and the imageJ software package (ImageJ v1.47, National Institutes of Health, USA).

**Hand instruments selection and sequence**

The same files used in the learning phase (NiTi K-type hand instruments) were used in the testing trials. Using the same criteria for instrument sizes that were used in the pilot (see Section 3.2.3.2), the sequence of files for the distal root canal preparation selected were 50, 45, 40, 35, and 30 (see Figure 3.6). As noted in the learning phase, this sequence of hand instruments was based on using the crown-down technique (see Section 3.2.3.2).
**Manikin model preparation**

Simulated jaw model bases were customised from acrylic to fit a bench-mounted manikin head (Frasaco™, USA) (see Figure 3.6). A layer of periphery wax (Surgident, USA) was placed at the base of the model to hold the teeth in place. Vaseline (Vaseline petroleum jelly, Unilever, USA) was rubbed on to the roots of each tooth to facilitate subsequent removal and cleaning of wax. In each model, two plastic teeth were positioned in the lower left quadrant of the mouth. Placement of teeth was adjusted to the correct anatomical orientation in the lower arch. After placement of teeth, a layer of beauty hard wax (Ultrafilm, Mancine Cosmetics, Australia) was melted with a wax heater (Adina wax, Le Chat, Australia) and poured around the teeth to the level of the cervical area of the teeth. Following setting of this wax (see Figure 3.6), teeth were labelled (i.e. according to tooth position, participant number, and test number) and the reference point was marked on the occlusal surface of each tooth using a permanent black marker. The models were then placed in the manikin head with rubber dam (Hygenic Dental Dam, Coltene/Whaledent, USA) applied on the test teeth using a clamp (W8) (see Figure 3.6).

**Instrument tray preparation**

The instruments used during the transfer tests included three irrigation syringes filled with water with side-vented 27 gauge needles (Henry Schein-Halas, Australia), a dental mirror, tweezers to hold cotton pellets and dry the access cavity, a plastic cup for dispensing used cotton pellets and blue sponge squares to clean and hold the K-type hand instruments (see Figure 3.6).
Figure 3.6. A: Setup for transfer test. (I) light, (II) instrument tray with irrigation syringes, mirror, tweezers, and cotton pellets (III) hand instruments in sequence (1-5), and (IV) plastic teeth in manikin head simulating patient clinical setting. B: setup of plastic teeth in the manikin model.

3.2.5.5 Transfer test phase procedures

Before starting the retention/transfer tests in the testing phase, participants had a 10-15 minute rest. During this break refreshments were provided and general discussion occurred unrelated to the experiment. Between each transfer test, participants also had further 1-2 minute rest periods.

Transfer test 1: Primary task condition

Prior to trial commencement, participants were asked to wear protective glasses and gloves, and to adjust the chair, manikin head and light positions for comfort. For this first task condition, participants completed one trial which involved the crown-down stage preparation of the distal canal of a plastic tooth (36). This was
completed within a set timeframe of 12 minutes (see Figure 3.6). At the beginning of the trial, participants were instructed that: they needed to complete this trial on the distal canal of a plastic tooth and prepare the canal using the instruments provided in a similar manner to what they had done during the learning phase; the black marking on the tooth (see Figure 3.5, a) was similar to the top of the plastic blocks used in the learning phase; they needed to work as accurately and as fast as possible and had a maximum of 12 minutes to complete the task, and they needed to indicate when the task was completed or they would be stopped after 12 minutes. Following instructions and prior to starting the task, participants were provided with a digital radiographic image of the tooth and the distal canal (see Figure 3.7). This radiographic image provided visual information related to canal length, width and curvature and is considered as part of standard procedures prior to commencement of root canal treatment (Sherwood, 2012). Completion time was recorded from when the participant inserted the first instrument into the canal until completion of the task was reported or when the time was up.

![Digital radiographic image of plastic teeth in the manikin model.](image-url)
Transfer test 2: Primary and secondary task condition

In this condition, participants were instructed to perform the same primary task as in transfer test 1 (canal shaping on the plastic tooth) within a set timeframe as accurately as possible while they completed a secondary task. The secondary task involved listening to an auditory tape playing six ‘dentally-relevant’ words (i.e. open, wider, light, irrigation, mirror, and suction) sequenced randomly at two-second intervals (see Appendix 9.5.3). This was produced using an audio editing software program (WavePad V5.46, NCH Software, USA). Participants were required to recall and repeat loudly the word previous to the target word (e.g. suction) (Koedijker et al., 2011).

Following completion of the transfer tests, participants were asked to report “rules, knowledge or instructions” related to the technique that they had used in order to prepare root canals during the learning and testing trials. These rules were audio recorded. Records were then transcribed, coded and de-identified by an independent professional transcriber.

Three weeks after completing the experiment, participants completed the three reinvestment surveys (see Section 2.5.45.2). This procedure was used to evaluate the effect of participants’ focus of attention on their learning and performance in general, i.e. not specific to dentistry.

3.2.6 Sequence and timing of data collection

Data collection for the COM1 group was completed at the end of the 2013 commencement term of the pre-clinical endodontic course for fourth year dental students. For the experimental groups, the data collection period commenced at the
middle of the 2013 first semester of the third year dental program and was completed before participants started their pre-clinical endodontic course in the second semester.

3.2.7 Data analysis

All data were coded, de-identified and randomly sequenced prior to data analysis. Audio/video recordings and information sheets obtained during experiments were coded, de-identified, and stored on a protected external hard drive.

3.2.7.1 Assessment of performance

A total of 504 blocks (252 E less, and 252 E ful) and 112 plastic teeth (40 E less, 40 E ful, and 32 COM1) were available for analysis. Specifically, data were available for 20 participants each in the E less and E ful groups and 16 participants for the COM1 group. A further two participants fractured instruments during a transfer test, one each from the E less and E ful groups. Therefore, these specimens were not available for assessment. One participant from the COM1 group failed to attend the transfer tests and an alternative time could not be arranged. However, other data (e.g. learning trials and/or reinvestment surveys) were collected from these three participants and were included in the relevant analyses.

Accuracy of canal preparation

The accuracy of the root canal preparations was assessed by checking the extent/fit of the last instrument in the prepared canal in relation to the working length (see Section 3.2.5.4) and its tightness/looseness. This was achieved by inserting a NiTi
K-type hand instrument in the canal that matched the last instrument used during root canal preparation (i.e. size 40 for the wide-canal blocks and size 30 for both the narrow-canal blocks and distal canal of plastic teeth). The angle of hand instrument insertion was parallel to the long access of the canal. To standardise pressure (weight) applied on the instrument during insertion, the average weight applied during assessments on 10 canals in sample plastic blocks by two experienced dentists was measured on a digital scale (Model BSK200, Breville, Australia). The average applied weight on the hand instrument was 95 grams. For blocks used in the learning phase, prepared canals with inserted instruments were then radiographed using digital radiography with an intraoral phosphor storage plate (Size#2 PSP) and digital imaging system. Radiographic exposure was set at 70 KV, 6 mA, and a time of 0.160 seconds. These parameters were determined following pilot tests. A paralleling technique was used with the distance from the x-ray tube head to the film set at 4 centimetres and the angle of the tube head was 90 degrees to the long axis of the canal and the phosphor plate (see Figure 3.8, a). A 6-millimetre metal reference was placed on the radiographic film to calibrate the digital radiographic image measurement scale during assessments (see Figure 3.8, b). Radiographs were screened and analysed using digital radiographic imaging software (see Figure 3.8, c). Canal preparations were measured using ImageJ software package by calculating the difference between the prepared canal (i.e. length from tip of the hand instrument to the top surface of the block) and the full working length (i.e. 17.5mm). For each participant the accuracy of the canal preparation of all learning blocks in learning trials was assessed as the mean distance in millimetres (mm) that the last instrument reached within the canal compared to the
target distance (17.5 mm) for the canal. This applied to each of the endodontic learning blocks for both experimental groups.

Figure 3.8. Learning block radiographic assessment. (a) x-ray tube head set position in relation to learning blocks and film. (b) image of blocks (wide/ curved 20°) following insertion of assessment hand instruments size 40. (c) digital radiographic image of image (b) blocks with metal reference on the left side if the image.

Plastic teeth for the testing phase were carefully removed using a wax knife heated via a heat induction machine (Heat Zone, Whip Mix, USA) and roots were cleaned with gauze and 95% ethanol (Methylated Spirit, Diggers, Australia). Two putty keys were prepared using vinyl polysiloxane laboratory modelling putty Key impression (Lab-Putty, Coltene/ Whaledent, USA) to standardise tooth position on the digital scale (see Figure 3.9, a & b) and during radiographic exposures (see Figure 3.9, c). For the digital scale, each tooth was positioned in the putty so that its long axis was perpendicular to the scale surface (see Figure 3.9, b).
Prepared teeth with inserted instruments were then placed on the second putty key (see Figure 3.9, c) and radiographed using digital radiography with an intraoral phosphor storage plate and digital imaging system as described in Section 3.2.7.1. Radiographic exposure was set at 70 KV, 6 mA, and time of 0.200 seconds. A 6-millimetre metal reference was placed in the putty key at the same level of the distal canal for calibration of the digital image (see Figure 3.10). Radiographs were reviewed and analysed using ImageJ such that the canal preparation was measured from the tip of the hand instrument to the radiographic apex or end of the root in relation to the full working length of 19.5mm. Accuracy of canal preparations in transfer tests 1 and 2 was determined by calculating the distance in millimetres (mm) that the last instrument reached compared to the target distance (19.5 mm) for the prepared distal canal.
Figure 3.10. An example of a digital radiograph of plastic teeth for assessment. Instruments were inserted parallel to the long axis of the root with 95 grams pressure. The measured distance was from the tip of the hand instrument to the radiographic apex. A metal reference length was positioned between the teeth at the same level of distal canals. Rubber stoppers were fixed at the full working length of 19.5mm.

Since all radiographic images were obtained under the same conditions (i.e. x-ray tube distance and angulation from the film), it was decided to standardise the measurement scale for all radiographic images (i.e. pixels per millimetres). The standardised measurement scale was based on a series of measurements of a random selection of radiographic images (i.e. 20 learning blocks and 20 transfer tests teeth radiographs) in which the measurement of a metal reference (6mm) was obtained in each radiographic image. The average distance in pixels was set to be 49 pixels/mm for testing radiographs (plastic teeth) and 47 pixels/mm for learning radiographs (plastic blocks). Differences in the pixels/mm between plastic blocks/teeth were related to differences in the position of the metal reference in relation to the canal in plastic block/tooth.
Completion time

Time taken to complete the canal preparations for each group was measured in minutes (min) from the moment the participant inserted the hand instrument in the canal until canal preparation was reported to be completed by the participant. The digital video/ audio record (Handycam DCR-SX43, Sony, Japan) of participants’ hands provided data for time spent preparing the canal, plus verbal reports of the secondary task activity.

Procedural errors

Procedural errors included some common canal preparation errors, for example canal blockages, ledges, canal transportation and instrument fracture (see Section 2.2.4). Procedural errors and accuracy of the preparations were evaluated visually under an operating microscope and radiographically on digital radiographic images.

Reported rules related to the task

The number of reported rules was then calculated for each participant. Mean values and standard deviations were calculated for E less and E ful groups. Unpaired t-tests were used to assess differences between the two groups.

3.2.7.2 Errors of measurement

Systematic and random errors of measurement are two important types of measurement error (Harris and Smith, 2009). In the current study, systematic errors may have occurred from errors in radiographic image magnification related to the use of different x-ray machines to obtain the radiographs. A systematic overestimation of measurements as a result of uncorrected magnification error can lead to a bias in the
comparison between the obtained radiographs. Random errors, on the other hand, can occur due to variations in the position/angulation of teeth/blocks and the x-ray machine during the process of taking the radiographs, which can lead to variation in the magnification of the radiographic image. Furthermore, the quality of the radiographic image can be affected during the processing of the radiographs (i.e. resolution of the scanner), which could result in inaccurate identification of anatomical landmarks (e.g. radiographic apex) and thus cause random error.

Measurement error of the various outcomes was computed by repeated measurements on a random selection of 15-20% of the trials. Specifically, these outcomes included accuracy of the canal preparation from learning trials and teeth in transfer tests; and type and number of procedural errors made during the canal preparations. Teeth and blocks were sampled systematically from a random selection of teeth/blocks based on the order of the radiographic images. This resulted in the assessment of 82 teeth, and 88 plastic blocks.

To assess procedure repeatability, measures of distance in millimetres (mm) that the last instrument reached compared to the target distance for the prepared canal were repeated for plastic teeth and blocks on new radiographs after repeating the assessment procedures (i.e. reapplying the hand instrument in the canal using digital scale and re-taking the radiograph). To assess repeatability, measures of the prepared canal were repeated two times for the canal length for plastic teeth and blocks on the same radiograph. A minimum time gap of 1-2 weeks separated the initial measurement and the repeated measurement. For the intra-rater procedures, the main investigator was involved in repeating the measures on the same radiographs.
and repeating the assessment procedures and measurements on new radiographs. For the inter-rater procedures, an expert dentist (i.e. endodontist) was involved in repeating the measurements on the radiographs. All measurements for radiographic images were carried out using (ImageJ v1.47) software package.

To assess intra- and inter-rater reliability, paired t-tests were used to assess systematic errors of the measures from the two sets of scores for continuous data (accuracy of canal preparation), with a p-value of 0.05 as the minimal level of statistical difference. Kappa statistics were used for categorical data (procedural errors) (Cohen, 1960). Levels of agreement were adapted from Landis & Koch (1977) guidelines. Dahlberg statistics ($\delta \varepsilon$) were used to quantify the magnitude of random errors by assessing the Technical Error of Measurement (TEM) ($\delta \varepsilon = \sqrt{\sum d^2 / 2n}$) where $d$ is the difference between the first and the second measures, and $N$ is the number of pairs (Harris and Smith, 2009). There is no consensus regarding a cut-off value for the Dahlberg error. However, researchers have reported the amount of error empirically to be small or large (Kim, 2013). Intraclass correlation coefficients (ICC) were used to determine the level of agreement between raters (McGraw and Wong, 1996). ICC was interpreted as follows: 0-0.2 indicated poor agreement; 0.3-0.4 indicated fair agreement; 0.5-0.6 indicated moderate agreement; 0.7-0.8 indicated strong agreement; and >0.8 indicated almost perfect agreement (Shrout and Fleiss, 1979).

3.2.7.3 Comparison of performance between groups

For the continuous outcome measures (e.g. measures of canal preparation accuracy and time spent during activities), tests of normality were performed using normal probability plots (Wilk and Gnanadesikan, 1968) and equal variance tests
(Shapiro and Wilk, 1965). Mean values and standard deviations were calculated for each outcome measure across each set of trials for each group and for both learning and transfer phases.

Repeated measures analysis of variance (ANOVA), with post-hoc analyses as appropriate, were used to assess the effect of learning method on the outcome measures; differences in the outcome measures between learning trials and transfer tests within E less and E ful learning groups; and differences in performance between groups for the transfer tests. A Bonferroni post-hoc test was used when comparing groups or conditions with equal sample sizes. This test was preferred over Tukey’s test because it has more power when the number of comparisons is small, while Tukey is more powerful when testing large numbers of means (Field, 2009c). A Games-Howell post-hoc test was performed when comparing unequal variances and/or unequal sample sizes (Field, 2009c). Categorical data (e.g. error type) were analysed using Wilcoxon Rank Sum Test (W₁) for comparisons between the E less and E ful groups during the learning phase and the two transfer tests during the testing phase. Kruskal-Wallis Test (H) was used for comparisons between the four learning blocks during the learning phase and the E less, E ful and COM1 groups during the testing phase (Field, 2009b). This was achieved by comparing error percentage (i.e. number of participants with procedural errors divided by total number of participants in each group) for E less and E ful across the four types of learning blocks and across the three groups during transfer tests 1 and 2. Z-tests (z) were used to assess for differences between proportions in the experimental and comparative groups (Moore et al., 2009). Effect size (r) were used to estimate the difference between the population proportions and were calculated by converting z-score into the effect size (r) using the formula \( r = \frac{z}{\sqrt{N}} \),
where $Z$ is the z-score, $N$ is the total sample size (Field, 2009b). An $r$ value of 0.1 was considered to have a small effect, medium from 0.3, and large effect size if equal or larger than 0.5 (Rosenthal, 1991).

All data analyses were conducted using SPSS (version 20.0; SPSS Inc, Chicago, IL), and statistical significance for quantitative and categorical data was set at $p<0.05$. Standardised mean difference (SMD) was indicated using Cohen’s $d$, a $d$ value of 0-0.2 was considered to have a small effect, medium from 0.2-0.5, and large effect size if larger than 0.5 (Cohen, 1988a; Borenstein, 2009). Effect size (Cohen’s $d$) were calculated using the method described by Durlak (2009).
3.3 Results

3.3.1 Demographic data of participants

Data from 59 participants (26 males and 33 females) were available for analyses. As noted in Table 3.3, the majority of participants in all groups were right handed (86%). Across the groups, the number of students with normal vision was 18, compared with 41 students with corrected vision. Participants’ ages ranged from 19-34 years with a mean age of 22.0 ± 2.8 years.

Table 3.3. Summary of demographic data for the two experimental and comparative groups for Study 1

<table>
<thead>
<tr>
<th></th>
<th>Errorless Group (n=21)</th>
<th>Errorful Group (n=21)</th>
<th>Comparative Group (n=17)</th>
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<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
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<td>Gender</td>
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<tr>
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<td>3</td>
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<tr>
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<td>9</td>
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<tr>
<td>Corrected Contacts</td>
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<td>6</td>
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<td>17</td>
</tr>
<tr>
<td>&gt;24</td>
<td>1</td>
<td>04.8</td>
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</tr>
</tbody>
</table>

3.3.2 Error of measurements

3.3.2.1 Intra-rater measures of prepared canals lengths

Results from repeated measurements of prepared canals lengths for plastic blocks and teeth (see Table 3.4) showed that the mean differences (M1-M2) in measurements of the prepared canals lengths were small, ranging from -0.02 to
0.03mm. Results showed no systematic differences between measurements (p>0.05). The Dahlberg statistics (\(\delta \varepsilon\)) technical error of measurement (see section 3.2.7.1) were small, ranging from 0.05 to 0.14mm, which demonstrated that random errors were small and unlikely to bias the results. Average Intraclass Correlation Coefficient (ICC) results indicated an almost perfect intra-rater level of agreement (>0.8) (McGraw and Wong, 1996).

Table 3.4. Intra-rater repeated measures of prepared canal length of the plastic blocks and teeth from learning and testing trials

<table>
<thead>
<tr>
<th></th>
<th>Learning Phase</th>
<th>Testing Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repeated Measures</td>
<td>Repeated Procedure</td>
</tr>
<tr>
<td></td>
<td>(Plastic Blocks)</td>
<td>(Plastic Teeth)</td>
</tr>
<tr>
<td>N (%)</td>
<td>60 (12%)</td>
<td>24 (21%)</td>
</tr>
<tr>
<td>M1-M2 (mm)</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>Paired t-test (p value)</td>
<td>0.10^</td>
<td>0.69^</td>
</tr>
<tr>
<td>TEM ((\delta \varepsilon))</td>
<td>0.09</td>
<td>0.14</td>
</tr>
<tr>
<td>ICC</td>
<td>0.989</td>
<td>0.976</td>
</tr>
</tbody>
</table>

M1 = measurement 1, M2 = measurement 2 (same rater at two different times)

^No significant difference (p>0.05)

TEM = Technical error of measurement (Dahlberg’s)

ICC = Intraclass Correlation Coefficient

Cohen’s kappa (K) was used to determine if there was agreement between two ratings performed by the main investigator on the presence or absence of procedural errors in 21 randomly selected learning blocks and 20 teeth used in the testing phase. There was a strong level of agreement for the learning and testing phases ratings, (K = 0.717, 95% CI [0.027-0.063], p = 0.001) and (K = 0.694, 95% CI [0.119-0.260], p = 0.002), respectively.
3.3.2.2 Inter-rater measures of prepared canals lengths

Results from repeated measurements using plastic blocks and teeth (see Table 3.5) showed that the mean differences (A1-A2) in measurements of the prepared canals lengths were small, ranging from -0.10 to 0.03mm. Results showed no systematic differences between measurements (p>0.05). Dahlberg statistics values ($\delta\varepsilon$) were also small, ranging from 0.03 to 0.22mm, which demonstrated that random errors were small and measurement bias in the results was unlikely. Average ICC indicated an almost perfect inter-rater level of agreement (>0.8) (McGraw and Wong, 1996).

Table 3.5. Inter-rater repeated measures of prepared canal length of the plastic blocks and teeth from learning and testing trials

<table>
<thead>
<tr>
<th></th>
<th>Learning Phase</th>
<th></th>
<th>Testing Phase</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repeated Measures</td>
<td>Repeated Procedure</td>
<td>Repeated Measures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Plastic Blocks)</td>
<td>(Plastic Teeth)</td>
<td>(Plastic Teeth)</td>
<td></td>
</tr>
<tr>
<td>N (%)</td>
<td>28 (5.5%)</td>
<td>16 (14%)</td>
<td>18 (16%)</td>
<td></td>
</tr>
<tr>
<td>A1-A2 (mm)</td>
<td>0.03</td>
<td>-0.10</td>
<td>-0.03</td>
<td></td>
</tr>
<tr>
<td>Paired t-test (p value)</td>
<td>0.18^</td>
<td>0.20^</td>
<td>0.11^</td>
<td></td>
</tr>
<tr>
<td>TEM ($\delta\varepsilon$)</td>
<td>0.08</td>
<td>0.22</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>ICC</td>
<td>0.989</td>
<td>0.960</td>
<td>0.996</td>
<td></td>
</tr>
</tbody>
</table>

A1= measurement 1 (assessor 1, principal researcher), A2= measurement 2 (assessor 2, supervisor)
^No significant difference (p>0.05)
TEM= Technical error of measurement (Dahlberg’s)
ICC= Intraclass Correlation Coefficient
3.3.3 Learning trials

3.3.3.1 Accuracy of preparation

For the E less group, the mean distances for each of the four groups of learning blocks ranged between 15.64mm and 17.45mm (M= 16.71mm, SD= 0.43) (Figure 3.11). For the E ful group, the mean distances for each group of the learning blocks ranged between 15.56mm and 17.56mm (M= 16.68mm, SD= 0.44) (Figure 3.11). A group X learning block (2 X 4) repeated measure ANOVA revealed no significant difference in accuracy of canal preparation between the E less and E ful groups, F (1, 40)= 0.26, p= 0.613. Differences in accuracy of preparation between the groups of learning blocks were statistically significant, F (1, 40)= 108.19, p< 0.001. A Bonferroni post-hoc test revealed significant differences in accuracy of preparation between blocks. Specifically, preparation accuracy for wide/ straight (W0°) was significantly higher than wide/ curved (W20°) (p< 0.001, d= 1.42), and narrow/ curved (N20°) blocks (p< 0.001, d= 2.86). Accuracy of preparation for W20° was significantly higher than narrow/ curved (N20°) block (p< 0.001, d= 1.62), narrow/ straight (N0°) block was significantly higher than N20° (p< 0.001, d= 1.73). However, differences between learning blocks W0° compared with N0°, and W20° with N0° were not significant, (p= 0.140 and p= 0.062 respectively).
Figure 3.11. Mean distance (millimetres) that the last instrument reached compared to the target distance (17.5 mm) for the prepared canal in each of the endodontic learning blocks for E less and E ful groups. E less=errorless, E ful=errorful, W0°=wide/ straight canal block, W20°=wide/ 20° curved canal, N0°=narrow/ straight canal, and N20°=narrow/ 20° curved canal. Sequence of learning trials for E less group was from block W0° to block N20°, and from block N20° to block W0° for E ful group. Decrease in length = reduced accuracy, error bars= +1 standard error mean. *** significant difference between learning blocks, p< 0.001.

3.3.3.2 Completion time

For the E less group, the mean completion times for each of the four learning blocks ranged between 1.72min and 10.55min (mean (M)= 4.29min, SD= 1.75) (Figure 3.12). For the E ful group, the mean completion times across the four groups of learning blocks ranged between 1.38min and 10.77min (M= 4.39min, SD= 1.81) (Figure 3.12). A group X learning block (2 X 4) repeated measure ANOVA revealed no significant difference in completion times between E less and E ful groups, F (1, 40)= 0.19, p= 0.663. Completion times between learning blocks across the groups were significant, F (1, 40)= 48.18, p< 0.001 (Figure 3.12). A Bonferroni post-hoc test revealed significant differences in completion time between blocks. Specifically, W0° took significantly shorter time than N0° (p= 0.024, d= 0.54), and N20° (p< 0.001, d= 1.45) blocks. Time spent to prepare N20° was significantly longer than W20° (p< 0.001, 1.45).
$d = 1.07$), and $N0^\circ$ ($p < 0.001$, $d = 0.93$) blocks. Differences between learning blocks $W0^\circ$ compared with $W20^\circ$, and $W20^\circ$ with $N0^\circ$ were not significant, ($p = 0.99$ and $p = 1.00$ respectively).

Figure 3.12. Mean time (minutes) taken to complete canal preparation for each type of the endodontic learning blocks for E less and E ful groups. E less=errorless, E ful=errorful, W0\''=wide/ straight canal block, W20\''=wide/ 20\° curved canal, N0\''=narrow/ straight canal, and N20\''=narrow/ 20\° curved canal, sequence of learning trials for E less group was from block W0\'' to block N20\'', and from block N20\'' to block W0\'' for E ful group, error bars= +1 standard error mean. *** significant difference between learning blocks ($p < 0.001$). * significant difference between learning blocks $W0^\circ$ & $N0^\circ$ ($p < 0.05$).

### 3.3.3.3 Procedural errors

During the learning trials, procedural errors included root canal blockages ($n = 32$, 91% of errors), ledges ($n = 2$, 6% of errors), and a fractured hand instrument ($n = 1$, 3% of errors). The total number of errors made by both experimental groups was 35 errors by 30 participants (7% of the learning blocks) (refer to Figure 3.13). Wilcoxon Rank Sum Test ($W_s$) showed that the number of errors made by the E less and E ful groups during learning was not significantly different ($W_s = 17.5$, $z = -0.15$, $p = 0.97$). Z-test results in the E less group showed that $N0^\circ$ learning block had significantly lower
number of errors compared with N20° (95% CI [-0.43 to -0.04], z= -2.40, p= 0.02, r= -0.5), and W20° (95% CI [-0.56 to -0.11], z= -2.90, p= 0.004, r= -0.6) blocks. It also showed that E less group had significantly fewer procedural errors in block N0° compared with E ful group (95% CI [0.01 to 0.37], z= 2.10, p= 0.04, r= 0.3).

<table>
<thead>
<tr>
<th>Type of learning blocks</th>
<th>Number of participants with errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>W0°</td>
<td>E less: 3, E ful: 2</td>
</tr>
<tr>
<td>W20°</td>
<td>E less: 4, E ful: 5</td>
</tr>
<tr>
<td>N0°</td>
<td>E less: 5, E ful: 6</td>
</tr>
<tr>
<td>N20°</td>
<td>E less: 4, E ful: 3</td>
</tr>
</tbody>
</table>

Figure 3.13. Number of procedural errors made by E less and E ful groups during the learning phase. E less=errorless, E ful=errorful, W0°=wide/straight canal block, W20°=wide/20° curved canal, N0°=narrow/straight canal, and N20°=narrow/20° curved canal. * significant difference between learning blocks (p< 0.05).

### 3.3.4 Transfer tests

#### 3.3.4.1 Accuracy of preparation

The mean length of prepared canal achieved in transfer tests for the E less, E ful, and COM1 groups ranged between 16.88mm and 19.35mm (M= 18.19mm, SD= 0.59), 16.16mm and 19.61mm (M= 18.33mm, SD= 0.69), and 15.90mm and 19.00mm (M= 17.81mm, SD= 0.65), respectively (Figure 3.14). A group X transfer test (3 X 2) repeated measure ANOVA revealed a significant difference in accuracy of preparation between the three groups, F (2, 53)= 4.83, p= 0.012. A Games-Howell post-hoc test showed that the E ful group was significantly more accurate than the COM1 group at
transfer test 1, F (2, 53)= 4.83, p= 0.012, d= 1.54. Results showed a significant
deterioration in preparation accuracy for the E ful learners under multi-tasking
conditions, between transfer test 1 and 2, F (1, 19)= 6.69, p= 0.018, d= -0.76, i.e. the
average (mean) length of preparation was shorter than the target distance (19.5mm)
and so was less accurate. In contrast, the accuracy of preparation for the E less and
COM1 groups remained stable when multi-tasking (F (1, 19)= 3.73, p= 0.069) and (F (1,
15)= 0.91, p= 0.356), respectively. (Figure 3.14).

![Accuracy of Preparation](image)

Figure 3.14. Mean distance (millimetres) that the last instrument reached compared to the target
distance (19.5 mm) in transfer tests 1 and 2 for E less, E ful, and COM1 groups.
E less=errorless, E ful=errorful, COM1= comparative, decrease in length = reduced accuracy, error bars= +1 standard error. * significant difference between transfer tests 1 & 2 within E ful group, and between
E ful & COM1 groups at transfer test 1 (p< 0.05).

3.3.4.2  Completion time

For the E less, E ful, and COM1 groups, the mean completion time during
transfer test 1 and 2 ranged between 3.08min and 15.55min (M= 8.59min, SD= 3.03),
4.38min and 16.00min (M= 8.59min, SD= 3.05), and 3.45min and 12.17min (M=
7.91min, SD= 2.65), respectively (Figure 3.15). A group X transfer test (3 X 2) repeated
measure ANOVA revealed no significant difference in completion time between the three groups, $F(2, 53)= 0.38$, $p= 0.687$. There were no significant differences in completion times between transfer tests 1 and 2 within each of the three groups.

![Figure 3.15](image)

Figure 3.15. Mean time (minutes) spent to complete the task during transfer tests 1 and 2 for E less, E ful, and COM1 groups.

E less=errorless, E ful=errorful, COM1= comparative, error bars= +1 standard error mean.

3.3.4.3 Responses to secondary task

Both experimental and comparative groups achieved high scores for the correct responses during the secondary task condition. The percentage of correct responses in the E less group was 95% (SD= 0.11) compared with 90% (SD=0.09) for the E ful group, and 95% (SD= 0.08) for the COM1 group. Although the E ful group scored the lowest percentage, chi-squared ($\chi^2$) test results showed no significant differences between groups, $\chi^2(38)= 48.99$, N= 58, $p= 0.11$.

3.3.4.4 Procedural errors

During the transfer tests, procedural errors included root canal blockages (n= 3, 27% of errors), development of ledges (n= 3, 27% of errors), fractured files (n= 3, 27%
of errors), and fractured roots (n= 2, 18% of errors). A total of 11 errors were made by both experimental and comparative groups by 11 participants (i.e. 10% of the transfer teeth). The E less group made fewer errors than the E ful group during test 1 (primary task only), and 50% fewer errors during test 2 (the multi-tasking condition), compared with three errors in the E ful group in both tests and one error in the COM1 group for both tests (refer to Figure 3.16). Wilcoxon Rank Sum Test (W_s) was used to compare the percentage of errors produced during transfer tests 1 and 2, across the three groups. Results showed no significant differences in the number of procedural errors made during transfer test 1 and 2 (W_s = 9.0, z= -0.67, p= 0.80). Kruskal-Wallis Test (H) results showed no significant differences in the number of procedural errors made by each of the three groups (H (2)= 3.64, p= 0.20). Z-test results showed that there were no significant differences between transfer tests between and within groups (p>0.05).

![Diagram](image_url)

**Figure 3.16.** Number of procedural errors made by E less, E ful and COM1 groups during the testing phase.
E less=errorless, E ful=errorful, COM1= comparative.
3.3.4.5 Reported rules

For the E less (n= 13) and E ful (n= 14) groups, the average number of rules related to the balance force technique ranged between 3-8 rules (M= 6.62, SD= 1.39), and 7-8 rules (M= 7.71, SD= 0.47), respectively (Figure 3.17). An unpaired t-test revealed that the E less group had significantly fewer retained rules than the E ful group (t (25)= 2.80, p= 0.010, d= 1.11).

![Bar chart showing the number of reported rules for E less and E ful groups.](image)

Figure 3.17. Mean number of reported rules from instructions related to the preparation technique provided to E less and E ful groups. E less=errorless, E ful=errorful. * significant difference between E less and E ful groups (p< 0.05).
3.4 Discussion

This study examined hand instrumentation skills in preparing root canals under either errorless or errorful conditions. Participants prepared root canals during both learning and testing phases. The comparative group provided comparative performance data during the testing phase.

During learning, accuracy of preparation and completion times in the errorless and errorful groups were similar over the course of learning blocks. However, the errorless group made significantly fewer procedural errors in the narrow/straight canal than the errorful group. The errorless group also produced fewer errors in this block compared with the curved canals (i.e. either wide or narrow canals). Overall, both groups showed improvement during the learning trials and, based on the similar level of performance achieved in both errorless and errorful groups, it is considered that participants working under each condition were equally competent in performance. These results are consistent with findings from Lam et al. (2010b) and Poolton et al. (2005) who examined performance of golf putting tasks. In these studies, the errorless groups progressed from distances closer to the hole to distances further from the hole, whereas the errorful groups carried out the task in the reverse order. These studies also reported similar performance of both experimental groups at the end of the learning phase.

As expected, given the differences in complexity of different blocks, there were significant differences in accuracy of canal preparation and completion times between the learning blocks in each experimental group. Specifically, preparations of the curved canals, both wide and narrow, were less accurate than the straight canals, with
the narrow/ curved canal being associated with the least accurate preparation. Completion times varied, with a decrease in time between the wide/ straight and narrow/ straight blocks, while the final block (narrow/ curved) took the longest time to complete for both experimental groups.

The four learning blocks, were sequenced in order of difficulty, based on pilot testing involving feedback from participants, completion times and procedural errors (see Section 3.2.3.1). According to guidelines provided by the American Association of Endodontics (AAE, 2005), an increase in canal curvature and/ or reduction in canal size can lead to an increase in the difficulty of endodontic treatment. However, these guidelines are not clear about which of these factors is more significant (i.e. the curvature of the canal or the size of the canal). These differences in accuracy and completion times between the blocks for both experimental groups suggest the level of difficulty across the blocks did not increase sequentially as expected. Performance on the wide/ curved and narrow/ straight canals, in terms of accuracy of canal preparation and completion times, was similar. However, fewer procedural errors were produced with narrow/ straight canals compared with wide/ curved canals. This suggests that the narrow straight canal might have been simpler to prepare than the wide/curved canal.

The high number of participants producing procedural errors when preparing the wide/ curved canal might be explained by the larger size of hand instruments used with the wide canals compared with the narrow canals. For example, forceful use of large inflexible hand instruments has been reported to be associated with root canal blockages and ledges (Lambrianidis, 2006). Participants in the errorless groups
produced more errors in the wide/curved canal, which may have resulted in them learning explicitly, through hypothesis-testing. These findings suggest that the sequence of simplest to the most complex block should be straight canals, (i.e. wide, then narrow) followed by the curved canals (i.e., wide, then narrow). Further investigation of accuracy and error production are needed to confirm this order. It is also possible that using the balanced force technique may have contributed to the production of procedural errors due to the complexity of the technique. BFT was selected over other instrumentation techniques due to its superior clinical outcomes (see Section 2.2.3). It is also the technique used in the endodontic programme in the University of Adelaide, such that the comparative group learnt their endodontic skills using this technique, therefore, the same technique was used for the experimental groups to enable comparisons of outcomes between these groups.

During the testing phase, two transfer tests were used for the errorless, errorful and comparative groups. Transfer test 1 involved root canal preparation of the distal canal of a mandibular first molar plastic tooth (i.e. primary task). Transfer test 2 involved the same task as in test 1 but, in addition, participants were required to recall a ‘target’ word from a random series of words (i.e. multi-tasking). The plastic tooth root canal that was selected in transfer tests 1 and 2 was chosen deliberately to be different to the final blocks of the learning phase for both errorless and errorful groups. It presented a task with a medium degree of difficulty when compared to the tasks in the learning phase (i.e. similar to the wide/ straight and narrow/ curved learning blocks). This variation from the tasks practised during the learning phase for both groups was necessary to evaluate the effect of learning on performance in isolation from any degrading or enhancing factors related to the practice condition,
particularly in terms of similarity to the final blocks used in the learning phase (Wulf et al., 2010). It has also been reported that this variation is important for generalisation of the learnt motor skill (Anderson, 1982).

In transfer test 1, accuracy of canal preparation, completion times and procedural errors for the errorless and errorful groups were similar. Both experimental groups achieved comparable or significantly higher levels of performance accuracy as the comparative group who had completed usual simulated endodontic learning activities (15-20 hours).

For the primary task condition (transfer test 1), it was expected that the accuracy of preparation in the errorless group would be significantly better than in the errorful group. It was hypothesised that a reduction in correction of errors during learning in the errorless group would be maintained during the primary task condition (Maxwell et al., 2001). However, similar levels of accuracy were achieved by the errorless and errorful groups for primary task. This may have been due to the difficulty of the learning blocks not being ordered consistently from simple to complex, resulting in the production of more procedural errors and associated hypothesis testing than expected. However, the errorless learning group did report significantly fewer 'root canal instrumentation rules' than the errorful group.

In transfer test 2, accuracy of preparation for errorless group remained stable when multi-tasking. In contrast, learners in the errorful group showed a significant deterioration in preparation accuracy under the multi-tasking condition. Maintenance of performance of the errorless group under these multi-tasking condition may be explained by a reduction in error production during learning, resulting in a reduced
need to correct errors through hypothesis-testing. This decreased need to correct errors reduces the requirement to conscious processing of rules (i.e. instructions) to acquire relevant hand instrumentation skills, meaning that working memory capacity is not used for processing and correcting errors. Maxwell et al. (2001) also suggested that when errors are reduced during motor task learning, creation and testing of hypotheses will not be required. These findings of maintenance of performance are consistent with results from Poolton et al. (2005), Masters et al. (2008c), and Lam et al. (2010b) who reported higher levels of performance for errorless than errorful participants during golf putting trials. Similar to the current study, they also found that errorless participants reported significantly fewer rules than the errorful participants.

Despite the possibility that the order of the learning blocks may have affected the number of errors produced during learning, participants in the errorless group started their learning on the wide/straight block which displayed the highest accuracy measures, the lowest completion times, and the fewest procedural errors. These results indicate that this block was the simplest block. Poolton et al. (2005) have suggested that implicit learning is most critical at the beginning of practice and a brief exposure to an errorless learning condition at the beginning of practice can remain unaffected by subsequent errorful practice when tested under multi-tasking conditions. In other words, even if there is some doubt about the order of difficulty related to the wide/curved and narrow/straight learning blocks, the errorless group did experience features of an errorless learning condition. This conclusion is supported by significant fewer verbalisable rules reported by the errorless group.
Errorless learning is thought to result in motor skill performance that does not require working memory resources (Maxwell et al., 2001; Poolton et al., 2005). In contrast, deterioration of performance in the errorful group might be related to an extra load on working memory resources, that was needed by participants for completing the root canal procedure and also to respond to the target word during the multi-tasking condition. This finding is similar to that of Poolton et al. (2005) who tested the effect of loading working memory with multi-tasking (tone counting) on golf putting performance. They found that performance of an errorful group deteriorated due to demands on working memory related to trying to control putting and also carry out cognitive (i.e. tone counting) tasks.

Accuracy of preparation of the comparative group was not affected by the multi-tasking condition. This maintenance of performance in the comparative group during multi-tasking may be explained by their previous experience. Specifically, the comparative group had been exposed to a longer simulated practice time (20 hours) compared with 1.5 hours for the experimental groups. This finding is consistent with the opinion of Ericsson et al. (1993) who suggested that the amount of practice accumulated over time has an important impact on an individual’s performance of motor skills.

The implementation of the secondary task (i.e. multi-tasking) was effective. This was indicated by the high percentage of correct words identified during multi-tasking in both the experimental and comparative groups, suggesting that all participants were using their working memory resources. Consistent with these findings, Maxwell et al.
and Poolton et al. (2005) found that both implicit and explicit groups scored high percentages for tone-counting accuracy (multi-tasking).

3.5 Study limitations

An important component in evaluating permanent changes in motor skill performance (learning effect) includes assessing a delayed retention test (Schmidt and Lee, 2005b; Sanli and Lee, 2014). This was not feasible in the present study due to the limited time available for data collection between commencement of third-year and completion of the third-year simulation endodontic course. While non-dental students could have been invited, the involvement of participants for whom the tasks are realistic is important particularly for translating learning design into actual learning situations (de Jong, 2010).

Other limitations that should be considered are the nature of the motor task undertaken in this study. As discussed previously, root canal hand instrumentation is a complex motor task that involves the development and integration of both cognitive and fine motor skills. In contrast, previous studies conducted in relation to errorless and errorful learning have been focused mainly on sporting activities and complex gross motor skills (Maxwell et al., 2001; Poolton et al., 2005; Masters et al., 2008c).

3.6 Implications for practice

ASE guidelines for undergraduate education in endodontics (Australian Society of Endodontology, 2007) recommend the use of simulated plastic blocks/ teeth prior to the use of extracted natural teeth, particularly during the early stages of learning root
canal preparation. When using extracted human teeth (even an anterior single rooted tooth), variable external and internal anatomy, as well as the condition of the root, make the root canal preparation task challenging which can be discouraging for novice learners. The use of simulated root canals, on the other hand, permits standardisation of the root canal hardness, length, width (diameter), location and degree of canal curvature. However, it is recognised that the high cost of these simulated plastic blocks/teeth may preclude their routine use in dental schools. As noted below, this standardisation is important in the design of learning activities.

Additional recommendations should focus on the design of activities that aim to enable an errorless (implicit) learning approach. Learning from simple to complex (step-by-step) might seem to be a logical choice for learning motor skills but selecting a simple enough task to begin with can be difficult. For example, in root canal preparation tasks, starting with an anterior tooth (single canal) and moving to a premolar or molar (multiple canals) might seem appropriate. However, the focus of the design of the task should consider standardising the curvature and size of the selected root canal and minimising the anatomical variation in the root canal system. Based on results from the current study, it is recommended to start with a wide/straight canal, followed by narrow/straight, wide/curved, and finishing with a narrow/curved canal. Furthermore, these recommendations should emphasise the importance of providing simplified instructions related to root canal procedures. As mentioned, the amount and timing of instructions play an important role in the learning process. These implicit activities are critical for optimising learning, especially in the initial stages of learning a novel motor task.
3.7 Future research

Future research should focus on conducting experiments to examine the effect of errorless learning on delayed retention and transfer tests. Future studies could also address testing an alternate order of blocks that may align better with an errorless learning approach (i.e. straight then curved canals) as indicated by the results. Further evaluation of the robustness of motor skill learning under errorless learning conditions when pressured and under stressful conditions, specifically, retention of the skill would confirm the implicit nature of this approach would also be valuable. Investigation of alternative implicit motor learning paradigms (e.g. learning by observation, physical guidance and using analogy) is also recommended. Investigation of alternative approaches to learning other fine motor tasks in dentistry, including access cavity preparation, crown preparation, cavity preparation in restorative dentistry, and other surgical procedures that involve fine motor skills are also needed. Findings from this study would also transfer to virtual reality simulators used in dental education (Suebnuakarn et al., 2014) and other surgical professions in medicine. These findings would help guide the future development of effective teaching strategies that can be incorporated in these simulators. Further consideration of future research in the field of motor skill development in dentistry is provided in the General Discussion (see Section 6.4).
3.8 Conclusions

Accuracy of preparation and completion times in the errorless and errorful groups were similar during learning. These results indicate both experimental groups were equally competent in their performance at that time.

The errorless and errorful groups both achieved levels of performance that were comparable to those displayed by students who had completed the BDS undergraduate endodontic programme in Adelaide. However, the accuracy of preparation was maintained when multi-tasking by the errorless group, whereas accuracy deteriorated significantly in the errorful group. Performance of skills learned via an errorless approach may place fewer demands on working memory than performance of skills learned via an errorful approach. This is likely to limit the number of errors during learning, reducing the chances for error correction through hypothesis-testing, and thereby reducing reliance on working memory resources to perform the hand instrumentation task (Poolton et al., 2005). This was supported by the limited number of verbalisable rules reported by the errorless group, which related to a reduced need for hypothesis-testing during root canal preparation tasks.

The deterioration of performance in the errorful group might be explained by an overload on working memory resources, which was needed by participants not only for the root canal procedures but also for responding to the target word during the multi-tasking condition. The present findings provide the first evidence that learning endodontic skills under conditions that limit errors can result in more stable performance in terms of accuracy of preparation when multi-tasking.
The stable performance of the comparative group under multi-tasking conditions in terms of accuracy may be explained by a longer time spent practising hand instrumentation procedures as part of their conventional endodontic course. Specifically, this includes a deliberate practice (practice and time) effect and a longer simulated practice time (20 hours) compared with that for the experimental groups (1.5 hours).
4 Study 2: Learning by observation

4.1 Introduction

Observational practice is considered to be an effective method for learning simple and fine motor skills (Poolton et al., 2011). It is defined as “learning by observing a person performing the key spatial and/ or temporal features of a task, thereby creating a cognitive representation of the action pattern” (Kleynen et al., 2014). Observation (in the context of demonstration by an expert) is a common tool for supporting procedural knowledge development for simulated and clinical activities in dentistry (Fugill, 2005; 2012; Suksudaj et al., 2015). Visual demonstrations of simulated root canal procedures and techniques during teaching have been promoted by the Australian Society of Endodontology (Australian Society of Endodontology, 2007). Therefore, it was considered important to investigate how to promote motor skill learning using observational learning strategies.

Observational practice might not be as effective as physical practice, but it has a significant impact on the processes of learning, especially when combined with physical practice (Shea et al., 2000). This impact has been noted at both neurological and behavioural levels (Zhu et al., 2011b). It is suggested that the processing mechanisms associated with physical movement and observation are mediated via similar processes (Wulf et al., 2010). Observational practice can help the learner to extract vital information related to the requirements and coordination of a motor task, which offers the learner the chance to process and evaluate the task cognitively prior to physical performance of the task. This additional processing can be represented
when learners take turns in physical and observational practice in pairs (Wulf et al., 2010) (e.g. a student/assistant situation in four-handed dentistry). This form of practice has been found to contribute significantly to the motor skill learning processes in addition to being relatively cost-effective (Shea et al., 1999).

Although demonstration is a very common method of providing information about how to perform a motor task, there has been limited research on the best way to utilise demonstrations as an effective instructional strategy for motor skill learning (Magill and Anderson, 2013c). However, there has been a growing interest shown by researchers in using observational learning as an implicit learning approach (Masters et al., 2008a; Poolton et al., 2011; Kleynen et al., 2015). As mentioned earlier, implicit approaches, requiring minimal conscious involvement, have been shown to limit the effect of self-focus and self-regulation on learning and subsequent performance, resulting in positive and sustained outcomes, even under stressful conditions, in comparison to commonly used/explicit approaches (Masters, 1992; Liao and Masters, 2001; Masters and Maxwell, 2008). Outcomes of learning implicitly are of importance in dentistry because working under stressful conditions (e.g. physiological or psychological) is a consistent characteristic, either during undergraduate study or in practice (Pöhlmann et al., 2005; Gorter et al., 2008; Kay and Lowe, 2008; Alzahem et al., 2011; Schéle et al., 2012) (see Section 2.5.4.3). These stressors are of significance as they can compromise the performance of dental students (Alzahem et al., 2011) and can negatively impact on their learning experiences when they are stressed (Al-Saleh et al., 2010). It is suggested that learning implicitly in the pre-clinical stage can minimise loss of performance with the move to clinical settings (Poolton et al., 2011).
As noted above, another implicit approach for learning involves learning from observation. For example, observation combined with guidance, i.e. guided-observation (GO), involves learning motor skills via a non-verbal method with limited conscious awareness of what is learnt and how a motor task is executed (Kleynen et al., 2014). As a result it is difficult for the learner to provide verbal details on how a motor task is carried out and therefore is considered to be an implicit way of learning (Masters et al., 2008a). Guided-observation reduces performance errors by using physical guidance to the direct movements, thereby reducing the need for conscious correction of mistakes by the performer. In contrast, learning from observation in combination with instructions, i.e. instructed-observation (IO), involves the acquisition of motor skills with supplementary verbal instructions and high conscious awareness by the performer on how a motor task is executed. As a result the learner can provide detailed verbal steps about a motor task, having learnt explicitly (Masters et al., 2008a). Studies have shown that guided observation encourages more stable performance under stressful conditions and multi-tasking (Maxwell et al., 2001; Poolton et al., 2005; Masters et al., 2008a) than learning by instructed observation. Therefore, further investigation of effective methods for learning dental fine motor skills is indicated, using conditions that result in robust performance, even under stressful conditions (Masters, 1992; Liao and Masters, 2001; Lam et al., 2009).
Aim and hypothesis

The aim of this study was to evaluate the effect of observational learning via guided-observation (GO), instructed-observation (IO), or observation-only (OO) on the acquisition of fine motor skills associated with root canal hand instrumentation (Poolton et al., 2011). In addition, this study examined the impact of a combination of sources of stress commonly experienced in learning settings (time constraints, evaluation and presentation conditions) on the performance of pre-clinical dental students. Both subjective (psychological, i.e. self-report questionnaire) and objective (physiologic, i.e. heart rate) measures of stress were assessed. It was hypothesised that learners who used a guided-observation approach would experience minimal deterioration in performance under multi-tasking, pressured or stressful conditions. In contrast, it was expected that learners who completed instructed-observation and observation-only tasks would demonstrate a significant reduction in performance under multi-tasking, pressured or stressful conditions.
4.2 Methods

4.2.1 Research design for Study 2

The following research design was based on the literature and findings from a pilot study (see Section 4.2.2). Ethical approval for this study was obtained from the Human Research Ethics Committee of the University of Adelaide (Protocol H-2012-117, see Appendix 9.6).

Participants performed fundamental root canal hand instrumentation tasks during learning and testing phases (see Section 4.2). The learning phase involved learning by observation (Masters et al., 2008a) followed by completion of 12 learning trials (3 sets of 4 trials), in which they enlarged and shaped standardised canals in clear plastic blocks (see Section 4.2) (see Figure 4.3). Specifically, participants were divided randomly into three experimental learning groups: guided-observation (GO), instructed-observation (IO), and observation-only (OO) groups. The video that demonstrated a simulated root canal preparation (crown-down stage only) using the balanced force technique was viewed twice by all groups. Three key movements in the balanced force technique were represented in the video/image demonstration (see Section 4.2). In the GO group, participants observed the video demonstration with no verbal or written instructions, but with physical guidance, i.e. performing the key movement of hand instrumentation with the researcher’s hand guiding the movement direction and pressure (Figure 4.4). In the IO group, participants were provided with detailed verbal instructions while they observed the video demonstration. Verbal instructions included information about the sequence and direction of hand instrument rotations, and direction and amount of force/pressure to be applied.
Participants in this group were encouraged to ask for guidance and were provided with verbal reminders (Masters et al., 2008a). The OO group observed the video demonstration without verbal/ audio or written instructions or physical guidance. To elevate and maintain motivation levels throughout practice, all participants were informed about the later testing phase, and were encouraged to do their best.

Immediate retention/ transfer tests were used to establish the learning achieved after completion of learning trials and to assess the effect of increasing processing demands and effects of stress on performance. Specifically, the transfer tests included preparing a canal in a plastic tooth (distal canal of the mandibular left first molar). The second transfer test involved a multi-tasking activity during completion of the simulated root canal preparation (Koedijker et al., 2011). The addition of a secondary task was designed to increase cognitive demands for participants (see Figure 4.1). A third transfer test included completion of a root canal preparation task under pressured (time constraint) and stressful (evaluation and oral presentation) conditions (see Figure 4.1). A digital video/ audio record of participants’ hand movements for each set of learning and testing trials, time spent on enlarging the canal, participants’ responses to questions, recall of instructions, performance and other unrelated activities were all recorded. Participants completed three reinvestment surveys after learning/ testing phases (see Section 5.2).
### Experimental Groups

**n=59**

Volunteer third-year students: no previous endodontic learning or working experience

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#### Comparative Group  
**n=17**

Volunteer fourth-year students who had completed the usual pre-clinical endodontics activities (15-20 hours of hand instrument use for initial canal preparation) provided comparative performance data; they completed transfer tests 1-3, and STAI and the PSS scales.

#### Guided-observation Group  
**n=23** (Implicit)

**Learning phase:** 60-90 min/session
Task: Observation of video demonstration of endodontic canal preparation with audio instructions, then 4 trials of endodontic preparation of canals in 3 plastic blocks (see Figure 4.3)

#### Instructed-observation Group  
**n=23** (Explicit)

**Learning phase:** 60-90 min/session
Task: Observation of video demonstration of endodontic canal preparation with audio instructions, then 4 trials of endodontic preparation of canals in 3 plastic blocks (see Figure 4.3)

#### Observation-only Group  
**n=13** (Explicit)

**Learning phase:** 60-90 min/session
Task: Observation of video demonstration without audio or written instructions of endodontic canal preparation, then 4 trials of endodontic preparation of canals in 3 plastic blocks (see Figure 4.3)

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**STAI scale:** participants completed the State-Trait Anxiety Inventory (STAI) after all trials.

**Resting period:** 10-15 min with refreshments, and unrelated discussion.

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**Figure 4.1. Summary of Study 2 plan**

**Testing phase:** (30-45 minutes)

**Immediate retention/ Transfer test 1:** Primary task
Estimated time: 7-12 min/session
Task: Endodontic preparation of canal in a plastic tooth in a manikin (see Figure 3.5)

**Transfer test 2:** Primary and secondary task
Estimated time: 7-12 min/session
Task: Endodontic preparation as for retention/transfer test 1 with secondary task, i.e. an auditory tape played a series of dentally relevant words, participants were instructed to repeat the word immediately prior to the target word

**Transfer test 3:** Primary and stressful task
Estimated time: 7-12 min/session
Task: Endodontic preparation as for retention/transfer test 1 under stressful conditions, i.e. time constraints (working faster), evaluation and presentation stressors (i.e. 3 min to prepare and 2 min to deliver a presentation about the importance of root canal preparation task for the patient that is videoed)

**Stress scales:** Between tests, participants completed the STAI and the Perceived Stress Scale (PSS). Heart Rate was monitored during learning and testing trials.

**Reinvestment Survey:** 3 weeks later, participants completed the three reinvestment surveys. These were used to evaluate participants’ focus of attention behaviours on learning and performance in general, i.e. not related to dentistry or the study activities (see Section 5.2)
4.2.2 Pilot study

Since there are no studies that have investigated the outcomes of learning endodontic skills by observation, pilot testing of the observation learning paradigms was completed. Tests were used to determine the type/number and sequence of learning blocks and relevant hand instruments, the number of learning trials, essential instructions, images and video demonstration for learning hand file manipulation skills for each experimental group, and the time frame for each task. Tests were also completed to inform the assessment of subjective and objective stress measurement tools needed. The pilot study involved six participants with no previous experience or knowledge in endodontics. The following sections indicate the procedure and decisions made. Results for each component of the pilot study are summarised at the end of this section (see Table 4.1).

4.2.2.1 Type, number and sequence of learning blocks

Four clear resin simulated root canal practice blocks (from study 1) were selected for the pilot test (wide straight: S1-U1; wide/curved: S1-L6, S4-U1 10°, S4-U1 20°, S4-U1 30°; narrow straight: S8-BS2-U; and narrow/curved: S8-BC2-U, Nissin Dental™, Japan) (see Section 3.2.3). Selection was based on the variation in root canal shape, diameter, and curvature (see Section 3.2.3.1). As for study 1, the plastic blocks were embedded in silicon material (Z-DUPE, duplication silicon, Italy) in plastic cups. The test aimed to find out the completion time for each trial. Following completion of the trials, participants were asked to review and comment on the order of the plastic blocks in terms of difficulty. Selection of the simulated root canal blocks was based on results from study 1, completion time and procedural errors. Due to manufacturer inconsistencies related to standardisation of the wide straight canal diameter and length (S1-U1, Nissin Dental,
Japan), this block was excluded from the final block selection and three blocks were selected to be used during the learning phase. The order for all groups was; wide/ curved 20° (S4-U1-20°); narrow/ straight (S8-BS2-U); and narrow/ curved 20° (S8-BC2-U), Nissin Dental, Japan) (see Table 4.1).

4.2.2.2 Selection of hand instruments and working length

Similar to Study 1 (Section 3.2.3.2), NiTi K-type hand instruments were selected for use in learning and testing phases. Accordingly, instrument sizes selected for the wide/ curved 20° canal were 50, 45, and 40. For the narrow canals (narrow/ straight and narrow/ curved 20°) sizes 40, 35, and 30 were selected. The sequence of using the hand instruments and determination of the simulated root canal working length were based on the methodology described in Section 3.2.3.2. The recorded working length for narrow/ straight and narrow/ curved 20° canals were 17.5 mm, and was 18.5mm for the wide/ curved 20° canal. For standardisation of working length conditions, it was decided to fix the working length of all learning blocks at 17.5mm (see Section 3.2.3.2) (see Table 4.1).

4.2.2.3 Number of trials

As for Study 1 (see Section 3.2.3.3) the number of learning trials required for participants to show improvement in performance was three trials for each block type. To compensate for the exclusion of the straight wide canal block, it was decided to increase the number of trials for each block type to four trials. The number of trials for each block was determined based on improvement in completion times, improvement in the working length of canal preparation, and reduction in procedural errors.
4.2.2.4 **Time frame**

Based on study 1 (Section 3.2.3.5), the average completion time for learning blocks was about five minutes. In addition, the average completion time for the most difficult block among the selected learning blocks (i.e. narrow/curved 20°) was also about five minutes. Based on these results and the number of trials in the learning phase (i.e. 4 trials x 3 types of blocks), the average completion time of the learning trials was estimated to be 60 minutes. The average recorded time for each transfer test was estimated to be 12 minutes (i.e. 3 tests x 1 plastic tooth each), therefore, the average completion time of the testing trials was approximately 45 minutes allowing for rest periods after each test. These completion times were used to inform participants about the average allocated time for each learning block and each transfer test (see Table 4.1).

4.2.2.5 **Video demonstration**

A combination of video demonstration of the key movements and images showing the steps were presented in the video (video link on Appendix 9.7). Video demonstrations were edited using Windows Movie Maker © software (Windows movie maker, V16.4, 2012, Microsoft Corporation, USA). The video contained three sections. The first section was a video of all the steps in the balanced force technique using one hand instrument. This was repeated three times to show advancement of the instrument into the canal. The second section was a step-by-step demonstration, supported by images (see Figure 4.2) of the key movements and demonstrated cleaning the canal. The third section demonstrated the balanced force technique on one block using the last hand instrument used in preparing the full length of the canal. This section demonstrated that the rubber-stopper touching the top surface of the block, and the instrument was free
inside the canal, which was represented by three free insertions and removals of the hand instrument.

Figure 4.2. Diagram used in the second section of the video to indicate the progress of each instrument. Horizontal lines are shown on this diagram to indicate the difference in the depth of the hand instruments but were not shown in the video.

4.2.2.6 Verbal instructions

Following completion of the pilot trials, participants viewed a diagram (see Figure 3.2) illustrating the key movements in the balanced force technique. They provided comments on the possible essential instructions needed to explain the technique. Participants’ comments were reviewed and instructions refined to minimise provision of explicit procedural knowledge (see Section 3.2.5.3) and to inform the design and of the video demonstration.

4.2.2.7 Selection of stressors and measurement of stress levels

Various methods for the assessment of stress have been reported (Bryant and Harvey, 2000; Arora et al., 2010a; Everly and Lating, 2013). For example, heart rate, blood pressure, and salivary cortisol are used as physiologic indicators (objective measures), and self-reported questionnaires e.g. the State-Trait Anxiety Inventory (STAI) (Arora et al., 2010b; Poolton et al., 2011) and Perceived Stress Scale (PSS) (Cohen et al.,
are used as psychological and behavioural indicators (subjective measures). The STAI consisted of six statements relating to feeling calm, tense, upset, relaxed, content and worried and each requires a Likert scale response from 1 = “not at all” to 4 = “very much” (Arora et al., 2010b). PSS is a 10 item scale that is widely used instrument for measurement of stress perception. It measures the degree to which individuals may rate situations in their life as being stressful. Items were designed to indicate how unpredictable, uncontrollable, and overloaded participants find their lives (Cohen, 1988b). The PSS was used to indicate that there were no differences in the overall stress perception between the experimental and comparative groups. A combination of objective and subjective measures of stress, has been suggested as a requirement for constructing valid and reliable measures of stress (Arora et al., 2010a). Analysis of salivary cortisol is reported to be used as an objective measure of stress (Arora et al., 2010a). However, cortisol levels are sensitive to variations in temperature, furthermore, changes in cortisol levels were reported to be a less sensitive as an indicator of stress compared to heart rate measures (Arora et al., 2010b). Therefore, participants’ heart rates were monitored with a heart rate monitor (Polar RS800; Polar Electro Oy, Finland) that records individual heartbeats per minute.
Table 4.1. Summary of pilot study results for Study 2

<table>
<thead>
<tr>
<th>Learning conditions</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of resin blocks selected</td>
<td>Three blocks were selected according to canal curvature and width: wide/ curved 20° (S4-U1-20°), narrow/ straight (S8-BS2-U) and narrow/ curved 20° (S8-BC2-U), Nissin Dental, Japan</td>
</tr>
<tr>
<td>Sequence of learning blocks</td>
<td>Wide/ curved 20°, narrow/ straight and narrow/ curved 20°</td>
</tr>
<tr>
<td>NiTi hand instruments to be used</td>
<td>Wide block: K-type # 50, 45 &amp; 40, narrow blocks: K-type # 40, 35 &amp; 30. All instruments were measured and fixed to the full working length of the canal</td>
</tr>
<tr>
<td>Number of learning trials</td>
<td>Four learning trials for each block</td>
</tr>
<tr>
<td>Essential instructions for using hand instruments in balanced force technique</td>
<td>IO group only: Balanced force technique: insert with ¼ clock-wise turn, maintain pressure with ¾ counter-clock-wise turn, and ¼ clock-wise turn without pressure then disengage and remove the instrument</td>
</tr>
<tr>
<td>Maximum time frame for each task</td>
<td>Five minutes for each plastic block (learning phase) and 12 minutes for each plastic tooth (testing phase)</td>
</tr>
</tbody>
</table>
| Stress measures                      | Objective: Heart Rate  
  Subjective: STAI and PSS surveys                                                                                                           |
4.2.3 Participants

4.2.3.1 Recruitment procedures

The main investigator and the project were introduced by academic staff to the participants during a lecture (refer to Section 3.2.4.1 for further details). Further explanation regarding recruitment procedure was provided by the main investigator.

4.2.3.2 Inclusion and exclusion criteria

Participants were volunteer third-year dental students enrolled in the 5-year Bachelor of Dental Surgery programme in School of Dentistry at the University of Adelaide during 2014. To test the effect of different learning conditions, it was important that participants were novices in the activities to be learnt (see Section 3.2.3). To be able to compare learning achieved by experimental groups, dental students who had successfully completed the normal pre-clinical endodontic activities (completed in second semester of third-year (2013), the commencement term in fourth-year (2014) and did not participate in Study 1) provided comparative performance data. This group is referred to as the ‘comparative group Study 2 (COM2)’.

Students who consented to participate were excluded if they had medical conditions that compromised their ability to participate and complete the study procedures (e.g. cardiovascular disease and history of anxiety), and/or had previous endodontic knowledge or work experience. Other students were excluded if they were repeating the third-year dental program at the time of data collection; and/or did not subsequently complete all experimental trials. Fifty nine (66%) third-year students and 16 (19%) fourth-year students were included as participants based on the inclusion and exclusion criteria.
4.2.3.3 Sample size

The sample size calculations were based on Study 1 repeated measures ANOVA results (see Section 3.3), in terms of minimal differences between experimental groups in terms of accuracy of preparation and completion times. In calculating the sample size, significance was set at 0.05 and beta at 0.2, with a power of 80%. Estimated sample sizes ranged from 23 to 25 per learning group.

4.2.4 Research materials and methods

4.2.4.1 Preparation of blocks for the learning phase

For the learning phase, the selected clear plastic blocks (see Section 4.2.2.1) were embedded in silicon material (Z-DUPE, duplication silicon, Italy) in plastic cups (see Figure 3.3).

4.2.4.2 Learning phase procedure

During the learning phase, participants used hand instruments to enlarge and shape standardised canals (crown-down stage only) in clear plastic blocks with different canal diameters and curvatures using the balanced force technique (see Section 2.2.3). Based on Study 1 results blocks were ordered in increasing levels of difficulty such that errors would occur at similar rates for all three experimental groups (see Figure 4.3). The heart rate monitor was used during the learning trials to familiarise participants with the device and to provide baseline data (refer to Appendix 9.10 for a sample of heart rate data during learning and testing trials).
Learning sequence:

Figure 4.3. Learning phase clear plastic blocks sequence. W20°= wide/ curved (S4-U1-20°), N0°= narrow/ straight (S8-BS2-U), and N20°= narrow/ curved (S8-BC2-U), Nissin Dental, Japan.

4.2.4.3 Instructions provided

Participants in experimental groups were provided with the following introductory instructions.

1. You will be required to complete a series of 4 trials on three different plastic blocks and you will receive 1-2 minute breaks between blocks.

2. For each block, using the instruments in front of you in the sequence from left to right, please prepare the channel as efficiently and as quickly as possible; each block should not take more than 5min/blocks.

3. Please watch the following video for information related to the task and the technique that you need to use. The video will be played once only for about 3 mins, so please keep focused during this time. If you have any questions after watching the video, I will refer you to think back to the video.

Each group then watched the video demonstration (Section 4.2.2.5, Appendix 9.7). While participants in the GO group watched the video, the researcher placed his hand over participant’s fingers to imitate the three key movements of the balanced force technique (see Figure 3.2). This was achieved using a large metal screw fitted with an
acrylic handle (hand instrument) placed in a plastic cup filled with periphery wax (Surgident, USA) (see Figure 4.4).

The IO group watched the same video as GO group supplemented with audio/verbal instructions. Verbal audio instructions provided (see Appendix 9.8) consisted of three sections. The first section contained instructions about the basic balanced force technique. The second section showed a diagram (Figure 4.2) indicating the progress of the three hand instruments down the canal. Instructions in this section consisted of a step-by-step description of the basic balanced force technique and the cleaning process between each hand instrument. The final section of the instructions included a repeat of the balanced force technique instructions including cleaning and ending with a description of the position and fit of the last instrument inside the canal. The OO group watched the same video as GO group without any form of physical guidance or audio or written instructions.
4.2.4.4 Preparation of teeth for testing phase

As for Study 1 (see Section 3.2.5.4), transfer test 1, 2 and 3 were performed on the distal canal of mandibular left first molar teeth. All test teeth were inspected visually and radiographically for defects and variations. Access to the dental canal was gained providing straight line access to the canals (see Figure 3.5, a) and patency of the canals was checked. The working length was determined as described in Study 1 (see Section 3.2.3.2) such that the recorded working length for the distal canal was 19.5 mm. Using the same criteria for instrument sizes and sequence, the sequence of files for the distal root canal preparation selected were 50, 45, 40, 35, and 30 (see Figure 3.6). Simulation jaw model bases with teeth were customised and instruments tray were prepared as described in Section 3.2.3.2.

4.2.4.5 Transfer test phase procedures

Before commencing the testing phase, participants had a 10-15 minute rest. During the break, refreshments were provided, with general discussion unrelated to experiment. Between each transfer test, participants in all experimental and comparative groups had 1-2 minute rest periods. A heart rate (HR) monitor was used by all participants in each transfer test, to provide a continuous measurement of heart rate during each test.

Transfer test 1: Primary task condition

As for Study 1 (see Section 3.2.5.5), participants completed the primary task of preparing the distal canal of a plastic tooth within a set timeframe. After completing the task, participants completed the STAI, focusing on their response to transfer test 1.
Transfer test 2: Primary and secondary task condition

In this condition, participants were instructed to perform the same primary task as in transfer test 1 within a set timeframe (canal shaping on the plastic tooth) as accurately and as fast as possible while they completed a secondary task as described in Section 3.2.5.5. Following completion of this task, participants completed the STAI, focusing on their response to transfer test 2.

Transfer Test 3: Primary and stressful condition

Finally, participants were asked to carry out the same task as for test 1 as accurately as possible under pressured and stressful conditions. Specifically, these were conditions of time constraints and public-speaking stressors (Saab et al., 1989; Liao and Masters, 2001; Poolton et al., 2011). The time constraint condition, required participants to complete the task as in test 1 a minute faster than the best time they were told they had achieved in the previous tests (Poolton et al., 2011). Data from the previous study indicated that the times for participants to complete the simulated root canal preparations ranged from 4 min to 12 min (maximum time allocated). Time pressures were achieved using countdown timer software (Versa Timer, version 1.02, Lux Aeterna Software, Sweden). Specifically, a timer displayed on the computer screen in front of the participant, was set up to call out the remaining time (minutes and seconds) every 30 seconds, and in the last 2 minutes, called out the remaining time every 15 seconds, finishing with counting down (audio) the last ten seconds. In addition, a ticking sound (each second, metronome) played in the background from the start until the end of the transfer test. The public-speaking stressor, involved participants being told prior to primary task that after this test, they had three minutes to prepare a speech describing their experiences during the learning and transfer tasks and two minutes to deliver the
speech in front of a video camera (Saab et al., 1989). They were informed that this presentation would be reviewed by an endodontic academic who teaches at another dental school in Australia and that they would use this presentation to develop materials explaining aspects of endodontics to future students.

Participants were also asked to include in their presentation some information about why it was important to perform the task effectively for patients who might be afraid or experiencing discomfort. They were informed that the level of discomfort patients might experience would be evaluated from the video recordings of their tests and that the focus of the presentation was about the importance of completing the task effectively. Following the completion of the final transfer test and before they prepared their presentations, participants were asked to complete the STAI and the PSS, particularly focusing on transfer test 3. After finishing the STAI and the PSS, participants were informed that there was no need to prepare a talk or be videoed, nor would there be any review by an endodontic academic. Participants also were instructed not to talk about the nature of the activities of these tests they performed with any other student.

As for Study 1 (see Section 3.2.5.5), following completion of transfer tests, participants were asked to report “rules, knowledge or instructions” related to the technique that they had used in order to prepare root canals. Three weeks after completing the experiment, participants completed the three reinvestment surveys (see Section 2.5.45.2).

4.2.5 Sequence and timing of data collection

Data collection for the COM2 group was completed at the end of commencement terms of the pre-clinical fourth year endodontic course for 6 participants in 2014 and 10
participants in 2015. For the experimental groups, the data collection period commenced at the middle of the first semester of the third year dental program in 2014 and was completed before participants started their pre-clinical endodontic course in the second semester.

4.2.6 Data analysis

All data were de-identified, coded and randomly sequenced prior to data analysis. Audio/video recordings and information sheets obtained during experiments were coded, de-identified, and stored on a protected external hard drive.

4.2.6.1 Assessment of performance

Data were available for 23 participants each in the GO and IO groups, 13 participants in the OO group and 16 participants for the COM2 group. A total of 708 blocks (GO= 276, IO= 276, and OO= 156) and 225 plastic teeth (GO= 69, IO= 69, OO= 39, and COM= 248) were available for analyses.

As for Study 1 (see Section 3.2.7.1), accuracy of the canal preparation was determined by calculating the distance in millimetres (mm) that the last instrument reached compared to the target distance of the canal. Time taken to complete the canal preparations for each group was measured in minutes (min) from the moment the participant inserted the hand instrument in the canal until canal preparation was reported to be completed by the participant. The digital video/audio record of participants’ hands provided data for time spent preparing the canal, plus verbal reports of the secondary task activity and retained procedural instructions. Procedural errors of
the preparations were evaluated visually under operating microscope and radiographically. Criteria and protocol for assessment of performance accuracy, completion time, and procedural errors were similar to those in Study 1 (see Section 3.2.7.1). Differences in the number of reported rules between the GO, IO, and OO groups were assessed by a one way ANOVA and post-hoc analyses.

Participants’ stress levels were measured using three measures. Two from the Imperial Stress Assessment Tool (ISAT, Arora et al., 2010b), namely heart rate (HR) and the State Trait Anxiety Inventory (STAI, Arora et al., 2010b; Poolton et al., 2011), plus the Perceived Stress Scale (PSS, Cohen et al., 1983; Cohen, 1988b). Validity of the STAI and PSS surveys were tested using Cronbach Coefficient Alpha (standardised) (α) and by means of regression of survey variables against HR at each transfer test (linear regression) and global p values were calculated. STAI test-retest reliability was calculated using Intraclass Correlation Coefficient (ICC) at the 3 time periods.

Participants’ HR data were transmitted at the end of each transfer test to a computer via bidirectional infrared interface using Polar ® professional training software (Polar ProTrainer 5, V 5.41.002, Polar Electro Oy, Finland) (see Appendix 9.10 for a sample of heart rate data during learning and testing trials). Heart Rate data were then corrected for all participants using Polar software (Essner et al., 2013). Correction of HR data was conducted to compensate for measurement errors that appeared as sudden peaks in the HR beats (Polar, 2014). Pearson product-moment correlations were calculated to test for associations between the three stress measures (i.e. STAI, PSS, and HR) and variations in accuracy of preparation and completion time (Arora et al., 2010a).
4.2.6.2 Errors of measurement

The assessment of measurement error of the various outcomes was computed by repeated measurements on a random selection of 7-12% of the trials. Specifically, these outcomes included accuracy of the canal preparation from learning trials and teeth in transfer tests; and type and number of procedural errors made during the canal preparations. Teeth and blocks were sampled systematically from a random selection of teeth/ blocks based on the order of the radiographic images. This resulted in the assessment of 27 teeth, and 51 plastic blocks. The intra-rater measurement repeatability was assessed as described in Section 3.2.7.2.

4.2.6.3 Comparison of performance between groups

For the continuous outcome measures (e.g. measures of canal preparation accuracy and time spent during activities), tests of normality were performed using normal probability plots (Wilk and Gnanadesikan, 1968) and equal variance tests (Shapiro and Wilk, 1965). Mean values and standard deviations were calculated for each outcome measure across each set of trials for each group and for both learning and transfer phases.

Repeated measures analysis of variance (ANOVA), with post-hoc analyses as appropriate, were used to assess the effect of learning method on the outcome measures; differences in the outcome measures within learning trials and within transfer tests for each of the three learning groups; and differences in performance between groups for the transfer tests. Categorical data (e.g. error type) were analysed using Kruskal-Wallis Test (H) (Field, 2009b). This was achieved by comparing error percentage (i.e. number of participants with procedural errors divided by total number of participants...
in each group) for GO, IO and OO across the three types of learning blocks and across the four groups for the transfer tests 1, 2 and 3. Z-tests ($z$) were used to assess for differences between proportions of participants with errors in the experimental and COM2 groups (Moore et al., 2009). Effect size estimates ($r$) were calculated using the method described by Rosenthal (1991) (see Section 3.2.7.3).

All data analyses were conducted using SPSS (version 20.0; SPSS Inc, Chicago, IL), and statistical significance for quantitative and categorical data was set at $p<0.05$. Standardised mean difference (SMD) was indicated using Cohen’s $d$ (Cohen, 1988a; Borenstein, 2009). Effect size estimates (Cohen’s $d$) were calculated using the method described by Durlak (2009). A $d$ value of 0-0.2 was considered to have a small effect, medium from 0.2-0.5, and large effect size if larger than 0.5 (Cohen, 1988a; Borenstein, 2009).
4.3 Results

4.3.1 Demographic data of participants

Data from 75 participants (35 males and 40 females) were available for analyses. As noted from Table 4.2, the majority of participants in all groups were right-handed (93%). The number of students with normal vision was 36, compared with 39 students with corrected vision across groups. Participants’ ages ranged from 20-32 years with a mean age of 22.8 ± 2.4 years.

Table 4.2. Summary of demographic data for the guided-observation (GO), instructed-observation (IO), observation-only (OO), and comparative (COM2) groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender</th>
<th>Handedness</th>
<th>Vision</th>
<th>Age Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Right</td>
<td>Normal</td>
<td>Corrected Glasses</td>
</tr>
<tr>
<td>GO Group (n=23)</td>
<td>15</td>
<td>23</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>IO Group (n=23)</td>
<td>10</td>
<td>21</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>OO Group (n=13)</td>
<td>5</td>
<td>12</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>COM2 Group (n=16)</td>
<td>5</td>
<td>14</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

4.3.2 Error of measurements

4.3.2.1 Intra-rater measures of prepared canals lengths

Results from repeated measurements for plastic blocks and teeth (see Table 4.3) showed that the mean differences (M1-M2) in measurements of the prepared canals lengths were small, ranging from 0.01 to 0.04mm. Results showed no systematic differences between measurements (p> 0.05). The Dahlberg statistics (δε) (see
section 3.2.7.2) were small, ranging from 0.04 to 0.11mm, which demonstrated that random errors were small and unlikely to bias the results. Average Intraclass Correlation Coefficient (ICC) results indicated an almost perfect intra-rater level of agreement (> 0.8) (McGraw and Wong, 1996).

Table 4.3. Intra-rater repeated measures of prepared canal length of the plastic blocks and teeth from learning and testing trials

<table>
<thead>
<tr>
<th></th>
<th>Learning Phase</th>
<th>Testing Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repeated Measures</td>
<td>Repeated Procedure</td>
</tr>
<tr>
<td></td>
<td>Plastic Blocks</td>
<td>Plastic Teeth</td>
</tr>
<tr>
<td>N (%)</td>
<td>51 (7%)</td>
<td>27 (12%)</td>
</tr>
<tr>
<td>M1-M2 (mm)</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>Paired t-test</td>
<td>0.63^</td>
<td>0.16^</td>
</tr>
<tr>
<td>(p value)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEM (Δε)</td>
<td>0.08</td>
<td>0.11</td>
</tr>
<tr>
<td>M1-M2 (mm)</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>ICC</td>
<td>0.981</td>
<td>0.985</td>
</tr>
</tbody>
</table>

M1= measurement 1, M2= measurement 2 (same ratter at two different times)
^No significant difference (p> 0.05)
TEM= Technical error of measurement (Dahlberg’s)
ICC= Intraclass Correlation Coefficient

Cohen’s kappa (K) was used to determine if there was agreement between two ratings performed by the main investigator on the presence or absence of procedural errors in 25 randomly selected learning blocks and 20 teeth used in the testing phase. There was a strong level of agreement between ratings for the learning (K= 0.759, 95% CI [0.025-0.054], p< 0.001) and testing (K= 0.694, 95% CI [0.061-0.154], p= 0.002) phases.
4.3.3 Learning trials

4.3.3.1 Accuracy of preparation

For the errorless GO group, the mean distances across the three learning blocks ranged between 15.76mm and 17.41mm (M= 16.72mm, SD= 0.38) (Figure 4.5). For the IO group, the mean distances for each of the learning blocks ranged between 15.64mm and 17.52mm (M= 16.80mm, SD= 0.37) (Figure 4.5). For the OO group, the mean distances for each of the learning blocks ranged between 15.68mm and 17.72mm (M= 16.82mm, SD= 0.40) (Figure 4.5). A group X learning block (3 X 3) repeated measure ANOVA revealed no significant differences in accuracy of canal preparation between the three experimental groups, F (2, 56)= 0.74, p= 0.484. Differences in accuracy of preparation within learning blocks across all the three experimental groups were statistically significant, F (1, 56)= 41.76, p< 0.001. A Bonferroni post-hoc test revealed significantly higher accuracy of preparation for the narrow/ straight (N0°) block compared with the wide/ curved (W20°) (p< 0.001, d= 2.87), and the narrow/ curved (N20°) (p< 0.001, d= -1.35) blocks. Results also showed a significant higher accuracy of preparation for the N20° block compared with the W20° block (p< 0.001, d= 1.33).
Figure 4.5. Mean distance (millimetres) that the last instrument reached compared to the target distance (17.5 mm) for the prepared canal in each of the endodontic learning blocks for GO, IO, and OO groups. GO= guided-observation, IO= instructed-observation, OO= observation-only, decrease in length = reduced accuracy, error bars= +/-1 standard error mean. W20°= wide/20° curved canal, N0°= narrow/straight canal, and N20°= narrow/20° curved canal. Sequence of learning trials for all groups was from block W20° to block N20°. *** significant difference between learning blocks, p<0.001.

4.3.3.2 Completion time

For the GO group, the mean completion times for each of the three learning blocks ranged between 1.27min and 12.78min (M= 5.72min, SD= 2.45) (Figure 4.6); for the IO group, they ranged between 1.90min and 10.73min (M= 5.68min, SD= 1.98) (Figure 4.6), and for the OO group, they ranged between 2.63min and 12.14min (M= 6.42min, SD= 2.33) (Figure 4.6). A group X learning block (3 X 3) repeated measure ANOVA revealed no significant difference in completion times between the three experimental groups, F (2, 56)= 0.17, p= 0.95. Completion times between learning blocks across all the groups was significant, F (1, 56)= 5.01, p= 0.010 (Figure 4.6). A Bonferroni post-hoc test revealed that participants spent significantly shorter time preparing the N20° blocks compared with the W20° block (p< 0.001, d= 0.50).
4.3.3.3 Procedural errors

During the learning trials, procedural errors ranged between root canal blockages (n= 47, 68% of errors), ledges (n= 2, 3% of errors), canal transfer (n= 2, 3% of errors), fractured hand instruments (n= 16, 23% of errors), and fractured roots (n= 2, 3% of errors). The total number of errors made by experimental groups was 69 errors by 62 participants (10% of the learning blocks) (refer to Figure 4.7). Kruskal-Wallis Test ($H$) showed no significant differences in the number of procedural errors between the three groups ($H (2)= 1.69, p= 0.51$). Z-test results showed that IO group had significantly fewer procedural errors in block N20° compared with OO group (95% CI [-0.03 to -0.50], $z= -2.20, p= 0.03$). Significant differences between blocks within each group are presented in Table 4.4.
Table 4.4. Comparisons of procedural errors between learning blocks within each experimental group

<table>
<thead>
<tr>
<th>Group</th>
<th>Comparison Block</th>
<th>Reference Block</th>
<th>n</th>
<th>Z-value</th>
<th>Z-test P value</th>
<th>95% confidence intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>GO</td>
<td>W20</td>
<td>N0</td>
<td>23</td>
<td>3.29</td>
<td>0.001</td>
<td>0.76 0.19</td>
</tr>
<tr>
<td>GO</td>
<td>W20</td>
<td>N20</td>
<td>23</td>
<td>3.63</td>
<td>&lt;0.001</td>
<td>0.81 0.24</td>
</tr>
<tr>
<td>IO</td>
<td>W20</td>
<td>N0</td>
<td>23</td>
<td>2.38</td>
<td>0.02</td>
<td>0.63 0.06</td>
</tr>
<tr>
<td>IO</td>
<td>W20</td>
<td>N20</td>
<td>23</td>
<td>4.09</td>
<td>&lt;0.001</td>
<td>0.84 0.29</td>
</tr>
<tr>
<td>IO</td>
<td>N0</td>
<td>N20</td>
<td>23</td>
<td>2.05</td>
<td>0.04</td>
<td>0.43 0.01</td>
</tr>
<tr>
<td>OO</td>
<td>W20</td>
<td>N0</td>
<td>13</td>
<td>1.99</td>
<td>0.047</td>
<td>0.76 0.01</td>
</tr>
<tr>
<td>OO</td>
<td>W20</td>
<td>N20</td>
<td>13</td>
<td>2.36</td>
<td>0.02</td>
<td>0.85 0.08</td>
</tr>
</tbody>
</table>

GO= guided-observation, IO= instructed-observation, OO= observation-only, W20°=wide/20° curved canal, N0°=narrow/straight canal, and N20°=narrow/20° curved canal.

Figure 4.7. Number of procedural errors made by GO, IO, and OO groups during the learning phase. GO= guided-observation, IO= instructed-observation, OO= observation-only, W20°=wide/20° curved canal, N0°=narrow/straight canal, and N20°=narrow/20° curved canal. Significant difference between learning blocks * = (p<0.05), ** = (p<0.01), *** = (p<0.001).
4.3.4 Transfer tests

4.3.4.1 Accuracy of preparation

The mean distance achieved in transfer tests for the GO, IO, OO, and COM2 groups ranged between 15.21mm and 18.93mm (M= 17.03mm, SD= 0.89), 15.61mm and 18.76mm (M= 17.05mm, SD= 0.85), 15.66mm and 19.11mm (M= 17.06mm, SD= 0.83), and 14.67mm and 18.97mm (M= 16.97mm, SD= 0.97), respectively (Figure 4.8). A group X transfer test (4 X 3) repeated measure ANOVA revealed no significant differences in accuracy of preparation between the three transfer tests for each group, F (1, 71)= 1.37, p= 0.25. Results also showed no significant difference in accuracy of preparation between the four groups at each transfer test, F (3, 71)= 0.11, p= 0.96 (Figure 4.8).

Figure 4.8. Mean distance (millimetres) that the last instrument reached compared to the target distance (19.5 mm) in transfer tests 1, 2 and 3 for GO, IO, OO, and COM2 groups. GO= guided-observation, IO= instructed-observation, OO= observation-only, COM2= comparative, decrease in length = reduced accuracy, error bars= +1 standard error.
4.3.4.2 Completion time

For the GO, IO, OO, and COM2 groups, the mean completion time during the three transfer tests ranged between 1.73 min and 12.00 min (M = 6.38 min, SD = 2.36), 2.05 min and 12.00 min (M = 6.26 min, SD = 1.75), 1.92 min and 13.38 min (M = 7.66 min, SD = 1.96), and 1.42 min and 12.30 min (M = 5.75 min, SD = 2.01), respectively (Figure 4.9). A group X transfer test (4 X 3) repeated measure ANOVA revealed a significant difference in completion time between each of the three transfer tests across the four groups, F (1, 71) = 342.16, p < 0.001. A Bonferroni post-hoc test revealed significant differences between transfer tests 1, 2, and 3 (refer to Table 4.5).

Table 4.5. Comparisons of completion times between transfer tests 1, 2, and 3 within each experimental and comparative groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Comparison Test</th>
<th>Reference Test</th>
<th>n</th>
<th>P value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>GO</td>
<td>1</td>
<td>2</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>0.60*</td>
</tr>
<tr>
<td>GO</td>
<td>1</td>
<td>3</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>1.47*</td>
</tr>
<tr>
<td>GO</td>
<td>2</td>
<td>3</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>0.81*</td>
</tr>
<tr>
<td>IO</td>
<td>1</td>
<td>2</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>1.11*</td>
</tr>
<tr>
<td>IO</td>
<td>1</td>
<td>3</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>2.72*</td>
</tr>
<tr>
<td>IO</td>
<td>2</td>
<td>3</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>1.11*</td>
</tr>
<tr>
<td>OO</td>
<td>1</td>
<td>2</td>
<td>13</td>
<td>0.022</td>
<td>0.58*</td>
</tr>
<tr>
<td>OO</td>
<td>1</td>
<td>3</td>
<td>13</td>
<td>&lt; 0.001</td>
<td>2.11*</td>
</tr>
<tr>
<td>OO</td>
<td>2</td>
<td>3</td>
<td>13</td>
<td>&lt; 0.001</td>
<td>1.11*</td>
</tr>
<tr>
<td>COM2</td>
<td>1</td>
<td>2</td>
<td>16</td>
<td>&lt; 0.001</td>
<td>1.61*</td>
</tr>
<tr>
<td>COM2</td>
<td>1</td>
<td>3</td>
<td>16</td>
<td>&lt; 0.001</td>
<td>2.44*</td>
</tr>
<tr>
<td>COM2</td>
<td>2</td>
<td>3</td>
<td>16</td>
<td>&lt; 0.001</td>
<td>0.85*</td>
</tr>
</tbody>
</table>

GO = guided-observation, IO = instructed-observation, OO = observation-only, COM2 = comparative group Study 2, transfer test 1 = primary task, transfer test 2 = primary task and multi-tasking, and transfer test 3 = primary task and under stressful condition. * d > 0.5 = large effect size.

Completion times between the four groups showed a significant difference, F (3, 71) = 2.69, p = 0.049. A Games-Howell post-hoc test showed that the COM2 group took significantly less time to complete the canal preparation than the OO group at transfer tests 2 (F (3, 71) = 4.85, p = 0.004, d = 1.44), and 3 (F (3, 71) = 4.20, p = 0.009, d = 1.51) (Figure 4.9).
Figure 4.9. Mean time (minutes) spent to complete the task during transfer tests 1, 2 and 3 for GO, IO, OO, and COM2 groups.

GO= guided-observation, IO= instructed-observation, OO= observation-only, COM2= comparative, error bars= +1 standard error mean. *** significant difference between transfer tests at each group (p< 0.001). * significant difference in transfer tests 2 & 3 between OO and COM2 groups (p< 0.05).

4.3.4.3 Procedural errors

During the transfer tests, procedural errors included root canal blockages (n= 15, 54% of errors), development of ledges (n= 8, 28% of errors), and fractured roots (n= 5, 18% of errors). A total of 28 errors were made by 28 participants of the three experimental and comparative groups (12% of the transfer teeth). While there were variations in the number of errors produced by the different groups, Kruskal-Wallis Test (H) showed these were not significantly different (H (2)= 1.22, p= 0.59), nor were there significant differences in the number of procedural errors made by the three groups (H (3)= 3.80, p= 0.31). Z-test results showed there were no significant differences between the three transfer tests nor within or between groups at each test (p> 0.05).
4.3.4.4 Responses to secondary task

Both experimental and comparative groups achieved high scores for the correct responses during the secondary task condition. The percentage of correct responses in the GO group was 90% (SD= 0.11) compared with 94% (SD= 0.06) for the IO group, 93% (SD= 0.07) for the OO group, and 95% (SD= 0.08) for the COM2 group. Chi-squared ($\chi^2$) test results showed no significant differences between groups, $\chi^2$ (63) = 66.60, N= 75, p= 0.35.

4.3.4.5 Stress levels

For the GO, IO, OO, and COM2 groups, the mean STAI scores (out of 24 points) during the three transfer tests ranged between 6 and 23 (M= 12.25, SD= 3.66), 6 and 19 (M= 12.68, SD= 2.37), 9 and 21 (M= 13.90, SD= 2.81), and 7 and 18 (M= 12.92, SD= 2.13), respectively (Figure 4.11). For the STAI survey, the value for the Cronbach $\alpha$
(standardised) ($\alpha$) was 0.851. This indicated a good internal reliability (Cohen and Williamson, 1988). The internal reliability for the STAI 1, 2, and 3 was Cronbach $\alpha= 0.732$, 0.783, and 0.802, respectively. These indicated a good internal reliability of the STAI (Gliem and Gliem). These values were similar to previous studies using this survey (Arora et al., 2010b). A group X transfer test (4 X 3) repeated measure ANOVA revealed no significant differences. STAI scores between the four groups showed no significant difference, $F (3, 71)= 1.23, p= 0.31$. STAI scores between each of the three transfer tests across the four groups were significantly different, $F (1, 71)= 137.98, p< 0.001$. A Bonferroni post-hoc test showed that there was a significant increase in STAI scores between transfer tests 1 and 2, and transfer tests 1 and 3 for GO, IO, OO, and COM2 groups (Table 4.6). This significant increase was also evident between transfer tests 2 and 3 for IO group, ($p= 0.03, d= -0.48$) (Figure 4.11).

Table 4.6. Comparisons of State Trait Anxiety Inventory (STAI) scores between transfer tests 1, 2, and 3 within each of the experimental and comparative groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Comparison Test</th>
<th>Reference Test</th>
<th>n</th>
<th>P value</th>
<th>Cohen’s d</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>GO</td>
<td>1</td>
<td>2</td>
<td>23</td>
<td>$&lt; 0.001$</td>
<td>0.75*</td>
<td></td>
</tr>
<tr>
<td>GO</td>
<td>1</td>
<td>3</td>
<td>23</td>
<td>$&lt; 0.001$</td>
<td>1.00*</td>
<td></td>
</tr>
<tr>
<td>IO</td>
<td>1</td>
<td>2</td>
<td>23</td>
<td>$&lt; 0.001$</td>
<td>1.05*</td>
<td></td>
</tr>
<tr>
<td>IO</td>
<td>1</td>
<td>3</td>
<td>23</td>
<td>$&lt; 0.001$</td>
<td>1.46*</td>
<td></td>
</tr>
<tr>
<td>OO</td>
<td>1</td>
<td>2</td>
<td>13</td>
<td>$&lt; 0.001$</td>
<td>0.82*</td>
<td></td>
</tr>
<tr>
<td>OO</td>
<td>1</td>
<td>3</td>
<td>13</td>
<td>$&lt; 0.001$</td>
<td>1.32*</td>
<td></td>
</tr>
<tr>
<td>COM2</td>
<td>1</td>
<td>2</td>
<td>16</td>
<td>$&lt; 0.001$</td>
<td>1.08*</td>
<td></td>
</tr>
<tr>
<td>COM2</td>
<td>1</td>
<td>3</td>
<td>16</td>
<td>$&lt; 0.001$</td>
<td>1.40*</td>
<td></td>
</tr>
</tbody>
</table>

$GO=\text{ guided-observation, IO= instructed-observation, OO= observation-only, COM2= comparative group}$

Study 2, transfer test 1= primary task, transfer test 2 = primary task and multi-tasking, and transfer test 3= primary task and under stressful condition. * $d> 0.5= \text{large effect size.}$

During the three transfer tests, for the GO, IO, OO, and COM2 groups, the mean PSS scores (out of 40 points) ranged between 3 and 29 ($M= 15.13, SD= 7.02$), 4 and 22 ($M= 15.00, SD= 4.05$), 6 and 28 ($M= 17.38, SD= 6.12$), and 5 and 28 ($M= 15.63, SD= 5.06$), respectively (Figure 4.11). A one-way ANOVA of the PSS survey scores across transfer
tests for GO, IO, OO, and COM2 groups showed no significant effect of group, \( F (3, 74)= 0.57, p= 0.64 \) (Figure 4.11).

![Stress Scales](image)

**Figure 4.11.** Mean STAI survey scores (out of 24 points) and PSS scores (out of 40 points) at transfer tests 1 (STAI1), 2 (STAI2), and 3 (STAI3) for GO, IO, OO, and COM2 groups. STAI= state trait anxiety inventory, PSS= perceived stress scale, GO= guided-observation, IO= instructed-observation, OO= observation-only, COM2= comparative, error bars= +1 standard error. Significant difference between survey scores within each group, * = (p< 0.05), ** = (p< 0.01), *** = (p< 0.001).

The mean Heart Rate (HR) during the three transfer tests ranged between 64 and 115 (M= 83.16 bpm, SD= 10.89) for the GO, 62 and 138 (M= 85.24 bpm, SD= 13.10) for the IO, 70 and 105 (M= 91.05 bpm, SD= 6.81) for the OO, and 67 and 102 (M= 83.27 bpm, SD= 7.48) for the COM2 group (Figure 4.12). A group X transfer test (4 X 3) repeated measure ANOVA revealed no significant differences in HR measures between the four groups, \( F (3, 71)= 1.93, p= 0.13 \). A significant difference in HR between each of the three transfer tests across the four groups was evident, \( F (1, 71)= 177.19, p< 0.001 \). A Bonferroni post-hoc test showed that there was a significant increase in HR between
transfer tests 1, 2, and 3 for GO, IO, and OO groups (Table 4.7). However, differences in HR between transfer tests 2 and 3 for COM2 group were not significant (Figure 4.12).

Table 4.7. Comparisons of mean heart rate (HR) between transfer tests 1, 2, and 3 within each experimental and comparative group

<table>
<thead>
<tr>
<th>Group</th>
<th>Comparison Test</th>
<th>Reference Test</th>
<th>n</th>
<th>P value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>GO</td>
<td>1</td>
<td>2</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>-0.38</td>
</tr>
<tr>
<td>GO</td>
<td>1</td>
<td>3</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>-0.84*</td>
</tr>
<tr>
<td>GO</td>
<td>2</td>
<td>3</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>-0.38</td>
</tr>
<tr>
<td>IO</td>
<td>1</td>
<td>2</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>-0.53*</td>
</tr>
<tr>
<td>IO</td>
<td>1</td>
<td>3</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>-0.95*</td>
</tr>
<tr>
<td>IO</td>
<td>2</td>
<td>3</td>
<td>23</td>
<td>&lt; 0.001</td>
<td>-0.33</td>
</tr>
<tr>
<td>OO</td>
<td>1</td>
<td>2</td>
<td>13</td>
<td>0.004</td>
<td>-0.63*</td>
</tr>
<tr>
<td>OO</td>
<td>1</td>
<td>3</td>
<td>13</td>
<td>&lt; 0.001</td>
<td>-1.25*</td>
</tr>
<tr>
<td>OO</td>
<td>2</td>
<td>3</td>
<td>13</td>
<td>0.002</td>
<td>-0.68*</td>
</tr>
<tr>
<td>COM2</td>
<td>1</td>
<td>2</td>
<td>16</td>
<td>0.10</td>
<td>-0.48</td>
</tr>
<tr>
<td>COM2</td>
<td>1</td>
<td>3</td>
<td>16</td>
<td>0.001</td>
<td>-0.64*</td>
</tr>
</tbody>
</table>

GO= guided-observation, IO= instructed-observation, OO= observation-only, COM2= comparative group

Study 2, transfer test 1= primary task, transfer test 2= primary task and multi-tasking, and transfer test 3= primary task and under stressful condition. * d> 0.5= large effect size.

There was no significant association between HR and STAI survey scores (p>0.05), nor between HR and PSS scores (p>0.05). However, when PSS was regressed against STAI
1 (95% CI [0.09 to 0.28], p= 0.0002), STAI 2 (95% CI [0.11 to 0.32], p= 0.0001), and STAI 3 (95% CI [0.10 to 0.33], p= 0.0002), significant associations were found. This indicates an increase in the STAI value when the PSS increases.

4.3.4.6  **Reported rules**

For the GO, IO, and OO groups, the average number of rules related to the balance force technique ranged between 0-9 rules (M= 5.91, SD= 2.52), 4-11 rules (M= 8.96, SD= 1.80), and 0-9 rules (M= 3.85, SD= 2.85), respectively (Figure 4.13). A one way ANOVA of the number of reported rules in the three experimental groups showed a significant effect of group (F (2, 58)= 21.52, p< 0.001). A Games-Howell post-hoc test showed a significantly higher number of reported rules by the IO group compared with the GO group (p< 0.001, d= 1.42), and by the IO compared with the OO group (p< 0.001, d= 2.36). However, differences between the GO and OO groups were not statistically significant (p= 0.10).

![Number of Reported Rules](image)

Figure 4.13. Mean number of rules related to the balanced force technique reported by GO, IO, and OO groups following the testing phase.

GO= guided-observation, IO= instructed-observation, OO= observation-only, error bars= +1 standard error. * significant difference between GO and OO groups (p< 0.05). *** significant difference between IO and OO; IO and GO groups (p< 0.001).
4.4 Discussion

This study evaluated the effect of learning by observation on the acquisition of fine motor skills used during hand instrumentation of root canals. It also aimed to investigate the effect of pressured and stressful conditions on performance. The pressured condition involved imposing a time constraint on participants to complete the task a minute faster than the best time they were told they had achieved in the previous tests. The stressful condition involved telling each student prior to undertaking the root canal preparation task that he/she would have three minutes to prepare a speech and two minutes to deliver the speech in front of a video camera. Participants were also informed that this presentation would be reviewed by an endodontic academic who teaches at another dental school in Australia, who would use this presentation to develop materials explaining aspects of endodontics to future students. As noted in Section 4.2.4.5, participants were informed that there was no need to prepare a talk or be videoed, nor would there be any review by an endodontic academic.

Observational learning utilised in the current study involved guided-observation (GO), instructed-observation (IO), or observation-only (OO). Observation (in the context of demonstration by an expert) is a common tool for supporting procedural knowledge development for simulated and clinical activities in dentistry (Fugill, 2005; 2012; Suksudaj et al., 2015). Visual demonstrations of simulated root canal procedures and techniques during teaching have been promoted by the Australian Society of Endodontology (Australian Society of Endodontology, 2007). Therefore, it was considered important to investigate how to promote motor skill learning using observational learning strategies.
During learning, accuracy of canal preparation and completion times in the three experimental groups (GO, IO, and OO) were similar over the course of the learning blocks. While the IO group made significantly fewer procedural errors in the blocks with a narrow/curved canal than the OO group, overall, all observation groups showed improvement during the learning trials. Based on the similar level of performance achieved between GI, IO, and OO groups by the end of this phase, it is suggested that participants working under each condition were equally competent in performance and that they had learnt key endodontic canal preparation skills during the learning trials. These findings are similar to those of Masters et al. (2008a) who evaluated the effect of similar observational learning strategies on a surgical task (i.e. suturing and knot tying), and found a significant improvement in performance (i.e. completion times and hand movements) for each group over the learning trials, with no differences between the groups.

Given the differences in complexity of the different blocks, there were significant differences in accuracy of canal preparation and completion times between the learning blocks within each experimental group. Specifically, preparations of the curved canals, both wide and narrow were less accurate than the narrow/straight canal, with the wide/curved canal being associated with the least accurate preparation. Completion times varied, with a decrease in time as participants learning trials progressed through the blocks.

These differences in accuracy and completion times between the blocks for all experimental groups confirm that the level of difficulty across the blocks varied. As mentioned previously, the sequence of the three learning blocks was based on pilot
testing (see Section 3.2.3.1). Completion times for the second (narrow/straight) and third (narrow/curved) canals were similar. However, fewer procedural errors were produced with narrow/curved canals compared with the wide/curved and narrow/straight canals. This might be related to a learning effect, resulting from practising on the previous blocks (i.e. wide/curved and narrow/straight canals).

The high number of participants displaying procedural errors when preparing the wide/curved canal may have also been associated with the larger size of hand instruments used with the wide canal compared with the narrow canals (see Section 3.4). Participants in all groups made errors in the wide/curved canal block, suggesting that this first block performance may have shifted to explicit conscious processes (i.e. hypothesis-testing). Accuracy of performance improved after this block, supported by the decrease in number of errors across all three groups. As noted previously, the balanced force technique is a complex technique, and this may have contributed to the number of procedural errors produced by participants. However, as this was the technique used in the endodontic programme in the University of Adelaide, this technique was used to enable comparisons with outcomes between groups.

During the testing phase, three transfer tests were used for the experimental and comparative groups. Transfer test 1 involved root canal preparation of the distal canal of a mandibular first molar plastic tooth (i.e. primary task). Transfer test 2 involved the same task as in test 1 but, in addition, participants were required to recall a ‘target’ word from a random series of words (i.e. multi-tasking). Transfer test 3 involved the same task as in test 1 but, in addition, participants were required to carry out the task under
pressured and stressful conditions (i.e. time constraints and the stress of having to speak publicly).

In summary, all experimental groups achieved a similar level of performance after the learning phase as the comparative group (i.e. in terms of preparation accuracy, completion times and procedural errors in transfer test 1). In the subsequent tests (i.e. multi-tasking (transfer test 2), and pressured (transfer test 3) performance related to accuracy of preparation was maintained across all groups and differences in procedural errors were not evident. However, completion times within each observational learning group and comparative group decreased significantly under multi-tasking and stressful conditions. The only significant differences between groups were longer completion times for the OO group than those for the comparative group under multi-tasking and stressful conditions. The IO group reported significantly more 'root canal instrumentation rules' than the GO and OO groups.

It was hypothesised that learning by observation combined with physical guidance (GO) would result in stable performance under multi-tasking and stressful conditions (Masters et al., 2008a). In contrast, observing videos with instructions (IO) or without instructions (OO) were expected to promote hypothesis testing using working memory resources, which would lead to performance breakdown under multi-tasking and stressful conditions (Poolton et al., 2011). However, the level of accuracy between the observational learning groups was similar. This suggests that the GO group did not achieve an implicit learning paradigm as expected. Furthermore, the results suggest that all three experimental groups learnt more explicitly. This conclusion is supported by a lower than expected accuracy of preparation across the three experimental groups.
These findings are not consistent with previous studies (Masters et al., 2008a). For example, Masters et al. (2008a) found that performance of an IO group showed deterioration in performance (i.e. more hand movements and slower completion times) under multi-tasking conditions. However, this inconsistency might be explained by the simple nature of the task (i.e. suturing and knot-tying) used in Masters et al. (2008a) study compared with the more complex root canal preparation task used in this study.

To explain these results, it is important to review how procedural information related to the root canal hand instrumentation task was presented to each experimental observation group and the impact of these presentations on working memory. The poor performance of the observational groups might be explained by the relatively high complexity of the components presented in the video (i.e. three segments with visual cues), which may have resulted in overloading working memory and subsequent performance breakdown (Poolton et al., 2011).

Physical guidance used in this study involved both visuospatial perception and attention, and somatosensory information (i.e. receptors in muscles, tendons and fingertips; see Section 2.3.1). It is possible that the GO group may have paid less attention to the sensory feedback related to the task, and focused on monitoring the video on the computer screen (van Tilborg et al., 2011). This increase in complexity may have led to loading working memory and compromising the learning effect, resulting in lower levels of performance.

Retention of performance of the IO group under multi-tasking and stressful conditions may be explained by the audio/visual presentation of the hand instrumentation technique. Mousavi et al. (1995) suggested that the partially independent nature of
visual and auditory working memory might be useful when multiple sources are required for understanding. Therefore, effective working memory can be increased by presenting material in a mixed format instead of a single format. For example, visual forms of presentation (e.g. a written text and a diagram) alone are more likely to overload the visual processor. However, if the written material is presented in spoken form, some of the cognitive load can be moved to the auditory processor.

The decrease in completion times within each group in transfer tests 2 and 3 might be related to learning or practice effects (Ericsson et al., 1993). Another explanation is that participants were asked to complete each task faster than the previous task and, when they reached the final task, they were told to finish one minute faster than the best time they had achieved for the previous two tasks. It is possible that in this situation participants positively perceived the stress associated with working faster. Results have shown that participants develop adaptive physiological and cognitive responses to stress (Jamieson et al., 2012), which can enable them to maintain their performance and therefore improve their completion times. This is supported by the results obtained from the Perceived Stress Scale (PSS) showing that 80% of participants scored less than 20 points out of the possible 40 points. This indicates that these participants did not perceive stress as affecting their life negatively. The higher performance in terms of faster completion times by the comparative group compared to the observation-only group under multi-tasking and stressful conditions may be related to their experience and a longer period of simulated practice.

The implementation of the secondary task (i.e. multi-tasking) was effective in this study. This is supported by the high percentage of correct words identified during multi-
tasking suggesting that participants in both the experimental and comparative groups were using their working memory resources. However, access to fewer rules by the GO and OO groups compared to the IO group indicates that their level of hypothesis-test during root canal preparation tasks was limited. This suggests that the GO and OO forms of learning encouraged some degree of implicit motor learning compared with learning with instructions. In assessing a surgical suturing task, Masters et al. (2008a) obtained similar results and noted that GO and OO groups reported fewer movement-related knowledge compared with an IO group.

Stress manipulation used in this study was also effective. This is supported by the increase in HR (an objective measure) and STAI scores (subjective measures) for all participants, indicating an increase in their stress levels as they focussed through the transfer tests. However, higher levels of stress during multi-tasking and stressful conditions was not associated with decreased accuracy of performance in the experimental and comparative groups. As mentioned earlier, this may be related to the development of an adaptive response to stress that enabled participants to maintain their performance under multi-tasking and stressful conditions. Poolton et al. (2011) evaluated the effect of different sources of stress on performance of laparoscopic skills following video demonstration of the task, and also found that high stress scores were not associated with deterioration of performance.

Despite the increased interest in the role of observational learning in motor skill acquisition and its use in dentistry (Fugill, 2005; 2012), there is limited research about possible strategies to optimise learning by modelling, or about the factors that influence its complexity and attentional demands (Magill and Anderson, 2013c). For example,
there is little information about the most appropriate timing and source of procedural
information (i.e. verbal, audio, or visual) to be provided during motor learning, or about
the frequency of demonstrations.

In a recent review of experts’ opinions on strategies that promote implicit and explicit
motor learning, there was no consensus by the experts regarding the classification of
observational learning strategies (Kleynen et al., 2014). This review was published after
the design of the current study was completed. It confirmed that this is an area where
there is no clear agreement and future research is warranted.

4.5 Study limitations

As for study 1 (see Section 3.5), this study did not include a delayed retention test due
to the limited time available for data collection and the timing of commencement and
completion of the simulation endodontic course during the third-year of the Adelaide
Bachelor of Dental Surgery program. Other limitations include the nature of the motor
task undertaken in this study and the participants involved. As discussed previously, root
canal hand instrumentation is a complex motor task that involves the development and
integration of both cognitive and fine motor skills. In contrast, previous studies
conducted in relation to observational learning have focused mainly on sporting activities
and basic surgical motor skills (Wulf et al., 1998; Masters et al., 2008a; Poolton et al.,
2011).

4.6 Implications for practice

Learning via observation (in the context of demonstration by an expert) is a
common choice for learning fine motor skills for simulated and clinical activities in
dentistry (Fugill, 2005; 2012; Suksudaj et al., 2015). Furthermore, visual demonstrations of simulated root canal procedures and techniques during learning have been promoted by the ASE guidelines for undergraduate education in endodontics (Australian Society of Endodontontology, 2007). However, it is proposed that, in future, educators should focus on the design of activities that aim to enable an implicit approach to learning, especially during the early stages of learning. It is recommended that educators should aim to simplify the presentation of the different components of a task to reduce the load on working memory (Poolton et al., 2011). It is also recommended to take advantage of the partially independent nature of visual and auditory working memory by presenting simplified video demonstrations with basic audio instructions (cues) about the motor skill task. Furthermore, emphasis should be placed on the importance of providing minimal instructions related to root canal procedures. These instructions should focus on the outcome of the movement rather than the movement itself (Wulf et al., 2010). As mentioned (Section 4.4), both the amount and the timing of instructions are likely to play important roles in the learning process.

4.7 Future research

Future studies need to test a range of observational methods that include different frequencies, timings and sources of procedural knowledge (e.g. a mixture of audio and video instructions) to achieve implicit learning. Further evaluation of the effect of stress on transfer of simulation skills to the clinical environment would also be desirable. Future research should also focus on conducting experiments to examine the effect of observational learning on delayed retention and transfer tests. Investigation of
alternative implicit motor learning paradigms (e.g. dual task learning, discovery learning and using analogy) is also recommended. Testing a range of root canal preparation techniques, including simpler approaches (e.g., watch-winding and filing techniques) are recommended as they may enable students to learn some basic instrument manipulation techniques before moving onto the more complex BFT. Investigation of the effect of observational learning on other fine motor tasks in dentistry, including access cavity preparation, crown preparation, cavity preparation in restorative dentistry, and other surgical procedures that involve fine motor skills is also needed. Further consideration of future possibilities for research in the field of motor skill development in dentistry is provided in the General Discussion (see Section 6.4).

4.8 Conclusions

Accuracy of canal preparation and completion times of the guided-observation, instructed-observation, and observation-only groups were similar during learning, suggesting that the experimental groups were equally competent in their performance at that time. Furthermore, the three observational groups who had 1.5-2h of practice achieved levels of performance that were comparable to those displayed by students in the Adelaide BDS undergraduate endodontic programme who had 15-20h of practice. When tested, accuracy of canal preparation did not differ significantly within each of the observation and comparative groups across the primary task (transfer test 1), multi-tasking (transfer test 2), or pressured (transfer test 3) conditions, nor between the groups at each transfer test. This suggests that learning through physical guidance did not achieve a completely implicit approach to motor learning.
Performance of skills learnt via concurrent physical guidance and watching a video may divide attention between visuospatial (visual feedback) and somatosensory receptors (tactile sensation), and thereby load the working memory and compromise the implicit learning effect. However, access to fewer rules by the guided-observation and observation-only groups compared to the instructed-observation group indicated that their level of hypothesis-test during root canal preparation tasks was limited, suggesting that both forms of learning encouraged some aspects of implicit motor learning compared with the instructed-observation learning. The retention of performance of the instructed-observation group under multi-tasking and stressful conditions can be related to the audio/visual presentation of the hand instrumentation technique. The partially independent nature of the visual and auditory working memories, resulting in less load on working memory, may have lead to maintenance of performance.

Completion times within each observational learning group decreased significantly when multi-tasking and under stressful conditions. It was also shown that high levels of stress were not associated with performance breakdown of root canal hand instrumentation skills. These results probably relate to the development of an adaptive response to stress that enabled participants to improve their completion times and maintain their performance under multi-tasking and stressful conditions.

The stable performance of the comparative group under multi-tasking conditions, in terms of accuracy, may be explained by a longer time spent practising hand instrumentation procedures as part of their conventional endodontic course. Specifically, this involved a deliberate practice (practice and time) effect and a longer simulated practice time (20 hours) compared with (1.5 hours) those for the experimental groups.
These findings do not support the original hypothesis and indicate that the method adopted for learning by observation with guidance was not consistent with implicit learning approaches. This conclusion is supported by the high number of errors during learning trials on plastic blocks and the apparent low level of accuracy of performance during transfer tests. The observational learning strategies used in this study seem to have overloaded working memory in terms of amount and complexity of procedural knowledge. This overload for novice participants is suggested to increase their attentional demands between the various components of the same task, thereby, leading to impairment of their performance. Observational learning is a commonly-used approach in medical and dental education but there is little research to back up its use. Further controlled studies of observational learning for dental students are needed, including testing alternative implicit learning paradigms when learning endodontic skills. These studies should lead to better outcomes, especially in stressful environments.
5 Study 3: Impact of reinvestment on performance

5.1 Introduction

Reinvestment involves conscious observation and control of movements involving working memory, with subsequent breakdown of performance (Masters and Maxwell, 2008). As discussed previously (see Section 2.5.4), reinvestment is proposed to be more disruptive of complex motor tasks involving many components that must be coordinated (Masters, 1992). This is applicable to learning root canal preparation, a complex procedure that requires cognitive access to both procedural knowledge and declarative knowledge. The propensity to reinvest and the impact of reinvestment varies depending on the amount of task-related declarative knowledge available and the ease of cognitive access to that knowledge by performers (Masters and Maxwell, 2008). For example, reinvestment can be more disruptive for experienced performers who rely more on automated behaviours related to procedural knowledge rather than novices who depend on task-associated knowledge to perform non-automated behaviours (Masters and Maxwell, 2008).

As discussed in Section 2.5.4, there are various approaches that can minimise the impact of reinvestment on performance. Studies have found that the value of implicit motor learning by novices exceeds the expected objective of acquiring motor skills. These studies have shown that learning implicitly provides robust performance (compared to explicit learners) under stressful conditions, fatigue and when high levels of cognitive effort are required (e.g. when performing a secondary task) (see Section 2.5.4) (Masters, 1992; e.g. Liao and Masters, 2001; Masters et al., 2008c). The main objective of implicit
learning is to provide learning protocols that minimise hypothesis testing and reduce the use of working memory for error detection and correction. As a result, it is difficult for the learner to provide verbal details about how a motor task is carried out (Masters et al., 2008a). Various implicit motor skill learning approaches have been tested (see Section 2.5.4.1). For example, learning using a procedure to reduce the production of errors (Maxwell et al., 2001; Lam et al., 2010b) and learning by observation combined with guidance (Masters et al., 2008a; Poolton et al., 2011; Kleynen et al., 2014).

In line with the evidence provided from previously mentioned studies on implicit motor learning (see Section 2.5.4.1), it is important to examine the impact of reinvestment on performance after learning endodontic skills. Specifically, this involved assessing individual propensity for reinvesting conscious control processes under demanding conditions (Jackson et al., 2013) using psychometric surveys designed to measure reinvestment in general (Reinvestment Scale (RS); Masters et al. (1993), movement-specific reinvestment (Movement-Specific Reinvestment Scale (MSRS); Masters et al. (2005) and decision making task focused reinvestment (Decision-Specific Reinvestment Scale (DSRS); Kinrade et al. (2010) (see Section 5.2).

Therefore, the main aim of this study was to investigate the impact of reinvestment on performance of the dental students who participated in Study 1 and Study 2. The three reinvestment surveys (i.e. RS, MSRS, and DSRS) designed to explore a propensity to reinvest were used. To inform the interpretation of the survey scores, validity and reliability analyses for each of the three reinvestment surveys were reported. The resultant surveys scores for dental students were also compared with other published studies.
Scores derived from the surveys were used to divide the samples from Study 1 and 2 into low and high reinvesters. It was hypothesised that individuals with a high propensity for conscious monitoring during root canal preparation would not perform as well as low reinvesters, as a consequence of allocating working memory resources to monitoring and controlling their movements.

5.2 Methods

All participants (i.e. experimental and comparative groups) in Studies 1 and 2 completed the three reinvestment surveys at least three weeks after completing the testing phase. The three reinvestment surveys (Masters et al., 1993; Masters et al., 2005; Kinrade et al., 2010) (see Section 2.5.4) related to their propensity to engage in conscious self-monitoring and controlled processing of their movements and decisions in general, that is they were not specific to dentistry or endodontics (Masters et al., 2005; Kinrade et al., 2010).

5.2.1 The Reinvestment Scale (RS)

The Reinvestment Scale (Masters et al., 1993) consists of 20 yes/no items related to self-focus of attention (see Appendix 9.11.1). These items are anticipated to predict propensity for reinvesting controlled processing, particularly under stressful and pressured conditions. The first seven items in the survey are related to Rehearsal (RH) (Roger and Nesshoever, 1987). Rehearsal refers to individuals with a tendency to rehearse or ruminate about emotional events in life. For example, “I often find myself thinking over and over about things that have made me angry”. These individuals are more prone to a high level of anxiety under pressured and demanding conditions. The
next 12 items in the survey refer to self-consciousness (Fenigstein et al., 1975). These items can be further divided into six items assessing Private Self-Consciousness (i.e. attention given to self-thought processes). For example, “I am aware of the way my mind works when I work through a problem”. The other six items are related to Public Self-Consciousness (i.e. attention to self as a social object influencing others). For example, “I am concerned about what other people think of me”. The final item in the survey is related to Cognitive Failure (CF) (Broadbent et al., 1982). For example, “Do you have trouble making up your mind?”. This item is intended to assess a predisposition to making mistakes in which actions mismatch self-intention. Item seven in the survey (i.e. “I worry less about the future than most people I know”) is reverse scored (i.e. No=Yes and Yes=No). The Reinvestment Scale has been reported to have good internal reliability (Cronbach alpha of 0.86) and test-retest reliability ($r$ of 0.74) over a period of four months (Masters et al., 1993). For each study, an overall score for each individual was calculated by assigning a value of 0 for “No” and 1 for “Yes”, and these scores were then summed. Therefore, scores could range from 0 to 20.

### 5.2.2 The Movement-Specific Reinvestment Scale (MSRS)

The Movement-Specific Reinvestment Scale (Masters et al., 2005) consists of 10 items that are rated on a six-point Likert scale from 0 (strongly disagree) to 5 (strongly agree) (see Appendix 9.11.2). These items are designed to assess the performer’s susceptibility to conscious monitoring and control of their movement. The MSRS comprises five items related to Movement Self-Consciousness, which indicate an individual’s concern about moving in public, reflecting their self-awareness about their style of movement and making a good impression when they move. The remaining five
items relate to conscious motor processing, which is characterised by thorough thinking about the process of movement, as reflected in previous, current, and future movements. High scores on these items indicate monitoring the mechanics of the movement. The MSRS has been reported to have an acceptable internal reliability for these two components (Cronbach α of 0.78 and 0.71) and high test-retest reliability ($r$ of 0.67 and 0.76) (Masters and Maxwell, 2008). An overall score for each individual in both studies was calculated by assigning a value of 0 for “strongly disagree”, 1 for “moderately disagree”, 2 for “weakly disagree”, 3 for “weakly agree”, 4 for “moderately agree” and 5 for “strongly agree”, and these scores were then summed. Therefore, scores could range from 0 to 50.

5.2.3 **The Decision-Specific Reinvestment Scale (DSRS)**

The Decision-Specific Reinvestment Scale (Kinrade et al., 2010) was adapted from the RS and MSRS and consists of 13 items to identify individuals with a greater predisposition to making poor decisions under pressure (see Appendix 9.11.3). Items are rated on a five-point Likert scale from 0 (extremely uncharacteristic) to 4 (extremely characteristic). The DSRS consists of two factors: six items focused on Decision Reinvestment, that is the role of conscious monitoring in decision-making processes. The remaining seven items are concerned with Decision Rumination, that is repetitive thoughts about past poor decisions. The DSRS has been reported to have a high internal reliability for each of these components (Cronbach α of 0.89 and 0.91) (Kinrade et al., 2010). For both studies, an overall score for each individual was calculated by assigning a

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1 Scoring of the MSRS can sometimes be from 1 to 6, with 1 = strongly disagree and 6 = strongly agree, giving a total of 30 for each of the MSC and CMP factors (Malhotra et al., 2015a).
value from 0 for “extremely uncharacteristic” to 4 for “extremely characteristic”, and these scores were then summed. Therefore, scores could range from 0 to 52.

5.2.4 Data analysis

5.2.4.1 Descriptive statistics

All data were coded, de-identified and randomly sequenced prior to data analysis. Tests of normality were performed where appropriate using normal probability plots (Wilk and Gnanadesikan, 1968) and equal variance tests (Shapiro and Wilk, 1965). Percentages of responses and the overall score for each individual for each of the three reinvestment surveys were calculated. Mean values and standard deviations for each survey were calculated according to the method described by Field (2009a). Pearson product-moment correlations were used to test the association between scores for each survey. For comparison, results from the current study were contrasted with the available data from previous studies (Masters et al., 1993; Masters et al., 2005; Kinrade et al., 2010) using an independent Student’s t-test. Effect sizes (Cohen’s d) were calculated using the method described in Section 3.2.7. Descriptive statistics and validity assessments were computed using SPSS (version 20.0; SPSS Inc, Chicago, IL).

5.2.4.2 Validity assessments

To inform interpretation of the scores for each survey, the fit of the data to the hypothesised models was tested using Confirmatory Factor Analysis (CFA) and internal consistency reliability was assessed by Cronbach alpha (α) (Cook and Beckman, 2006). Due to the limitations of sample size in each study, data from Study 1 and Study 2 were combined for these analyses.
Confirmatory factor analysis (CFA) of Reinvestment Surveys

CFA and measures of model fit were obtained to assess how well the combined data from the current studies fit the models reported from each of the surveys (Masters et al., 1993; Masters et al., 2005; Kinrade et al., 2010). The data were determined to display “good,” “acceptable,” or “poor” fit based on a comparison of the fit indices acquired from the CFAs with the recommended cut-off values according to the literature (see Appendix 9.12). Use of a variety of indices was important because different indices describe different aspects of the model fit (Crowley and Fan, 1997). The indices selected were reported to be the least affected by sample size, model misspecification and parameter estimates (Hooper et al., 2008).

If CFA model fit was poor, an Exploratory Factor Analysis (EFA) was performed by removing constraints from the original model (i.e. rotating items between factors using Varimax and orthogonal rotations) (Gerbing and Hamilton, 1996). The resultant EFA compared the composition of the original CFA factors and showed their fit indices. Pearson product-moment correlations were used to test the association between factors in each survey, and items within each subscale factor. The statistical software used for Confirmatory Factor Analysis (CFA) was SAS (version 9.3; SAS Institute Inc., Cary, NC, USA).

Internal consistency reliability

Internal consistency reliability for each factor of the three surveys was estimated using Cronbach alpha (α). This statistic examines the extent to which items within a given factor are inter-correlated with one another. Values of Cronbach’s alpha can range from

165
0 to 1. Internal consistency reliability is suggested to be acceptable when Cronbach’s $\alpha \geq 0.70$, good when $\geq 0.80$, and high for a value $\geq 0.90$ (Lance et al., 2006).

### 5.2.4.3 Impact of reinvestment on performance

Participants were assigned to low and high reinvestment groups using a post-hoc median split and based on the continuous data from the reinvestment survey scores (Maxwell et al., 2006; Malhotra et al., 2012). This was achieved by placing scores that were below the median into a “low” group and scores that were above the median into a “high” group. Values that were exactly at the median were placed into either group (i.e. allocated to provide most equivalent groups in size) (De Coster et al., 2011). This division facilitated the analysis of interaction effects related to the performance and stress measures (see Section 4.2.2.7) of groups in Study 1 and Study 2. However, due to limitations related to the use of the median split (MacCallum et al., 2002), additional analyses of interactions between reinvestment and performance of the groups were used in which the 25th and 75th percentiles were defined as “low” and “high” reinvesters in both studies. This was achieved by ordering the survey scores in an ascending order and identifying 25th percentile and 75th percentile scores of the total number of participants for each of the three reinvestment surveys.

Pearson product-moment correlations were calculated to test the association between the three reinvestment survey scores and variations in accuracy of preparation and completion time (\( \Delta = \text{transfer test 2} - \text{transfer test 1} \)) (Maxwell et al., 2001). Analyses of variance (ANOVA), followed by post-hoc analyses were performed to test for significant differences between the performance and stress measures for the low and high reinvesters. On the basis of the median split for each survey, mixed-design group (high
reinvesters, low reinvesters) X condition (transfer tests) analyses of variance (ANOVA) were calculated. Follow-up post-hoc were utilised to explain the interaction effects as described in Section 3.2.7.3.

5.3 Results

Data were obtained from the scores of the three reinvestment surveys (RS, MSRS, and DSRS) for participants in Study 1 and Study 2. Participants’ ages ranged from 19-34 years, with a mean age of 22.4 ± 2.6 years. Other demographic data related to characteristics of the participants are presented in Sections 3.3.1 and 4.3.1.

5.3.1 Descriptive statistics for Study 1

5.3.1.1 Responses to the three surveys

Reinvestment Scale (RS)

The percentage of “Yes” responses for the RS for Study 1 ranged from 19% to 86%, where the percentage of “No” responses ranged from 14% to 81% (Table 5.1). It was clear that for the majority of items (15 out of 20 items), a majority of participants responded positively to the items.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Study 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I remember things that upset me or make me angry for a long time</td>
<td>66</td>
</tr>
<tr>
<td>afterwards.</td>
<td>34</td>
</tr>
<tr>
<td>2) I get “worked up” just thinking about things that have upset me in the</td>
<td>58</td>
</tr>
<tr>
<td>past.</td>
<td>42</td>
</tr>
<tr>
<td>3) I often find myself thinking over and over about things that have made</td>
<td>46</td>
</tr>
<tr>
<td>me angry.</td>
<td>54</td>
</tr>
<tr>
<td>4) I think about ways of getting back at people who have made me angry</td>
<td>19</td>
</tr>
<tr>
<td>long after the event has happened.</td>
<td>81</td>
</tr>
<tr>
<td>5) I never forget people making me angry or upset, even about small things.</td>
<td>41</td>
</tr>
<tr>
<td>6) When I am reminded of my past failures, I feel as if they are happening</td>
<td>53</td>
</tr>
<tr>
<td>all over again</td>
<td>47</td>
</tr>
</tbody>
</table>
7) I worry less about the future than most people I know (r) 58 42
8) I'm always trying to figure myself out. 66 34
9) I reflect about myself a lot. 78 22
10) I'm constantly examining my motives. 54 46
11) I sometimes have the feeling that I’m off somewhere watching myself. 25 75
12) I’m alert to changes in my mood. 86 14
13) I’m aware of the way my mind works when I work through a problem. 68 32
14) I’m concerned about my style of doing things. 59 41
15) I’m concerned about the way I present myself. 76 24
16) I’m self-conscious about the way I look. 73 27
17) I usually worry about making a good impression. 86 14
18) One of the last things I do before leaving my house is look in the mirror. 66 34
19) I’m concerned about what other people think of me. 76 24
20) Do you have trouble making up your mind? 63 37

%Yes= Percentage of Yes response, %No= Percentage of No response, (r)= reversed item

**Movement-Specific Reinvestment Scale (MSRS)**

Participants’ responses to items within the MSRS for Study 1 ranged from 0% to 46% (Table 5.2). It was clear that the majority of participants responded with agree to 9 out of 10 items in this survey.

<table>
<thead>
<tr>
<th>Questions</th>
<th>%SD</th>
<th>%MD</th>
<th>%WD</th>
<th>%WA</th>
<th>%MA</th>
<th>%SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I rarely forget the times when my movements have failed me</td>
<td>7</td>
<td>19</td>
<td>10</td>
<td>25</td>
<td>34</td>
<td>5</td>
</tr>
<tr>
<td>2) I am always trying to figure out why my actions failed</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>17</td>
<td>44</td>
<td>19</td>
</tr>
<tr>
<td>3) I reflect about my movement a lot</td>
<td>2</td>
<td>10</td>
<td>8</td>
<td>32</td>
<td>37</td>
<td>10</td>
</tr>
<tr>
<td>4) I am always trying to think about my movements when I carry them out</td>
<td>3</td>
<td>10</td>
<td>8</td>
<td>36</td>
<td>32</td>
<td>10</td>
</tr>
<tr>
<td>5) I am self-conscious about the way I look when I am moving</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>29</td>
<td>37</td>
<td>14</td>
</tr>
<tr>
<td>6) I sometimes have the feeling that I am watching myself move</td>
<td>19</td>
<td>31</td>
<td>14</td>
<td>17</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>7) I am aware of the way my body works when I am carrying out a movement</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>29</td>
<td>46</td>
<td>10</td>
</tr>
<tr>
<td>8) I am concerned about my style of moving</td>
<td>5</td>
<td>19</td>
<td>17</td>
<td>17</td>
<td>34</td>
<td>8</td>
</tr>
<tr>
<td>9) If I see my reflection in a shop window, I will examine my movements</td>
<td>3</td>
<td>15</td>
<td>3</td>
<td>19</td>
<td>29</td>
<td>31</td>
</tr>
<tr>
<td>10) I am concerned about what people think about me when I am moving</td>
<td>5</td>
<td>14</td>
<td>3</td>
<td>36</td>
<td>34</td>
<td>8</td>
</tr>
</tbody>
</table>

%SD= Percentage of strongly disagree response, %MD= Percentage of moderately disagree response, %WD= Percentage of weakly disagree response, %WA= Percentage of weakly agree response, %MA= Percentage of moderately agree response, %SA= Percentage of strongly agree response.
**Decision-Specific Reinvestment Scale (DSRS)**

Participants’ responses to items within the DSRS for Study 1 ranged from 0% to 44% (Table 5.3). For just over half of the items in this survey, the majority of participants identified these items were characteristic of them in term of decision making.

Table 5.3. Percentages for responses to items for the Decision-Specific Reinvestment Scale in Study 1

<table>
<thead>
<tr>
<th>Questions</th>
<th>%EU</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>%EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I’m always trying to figure out how I make decisions.</td>
<td>5</td>
<td>17</td>
<td>27</td>
<td>41</td>
<td>10</td>
</tr>
<tr>
<td>2) I’m concerned about my style of decision-making.</td>
<td>5</td>
<td>31</td>
<td>24</td>
<td>31</td>
<td>10</td>
</tr>
<tr>
<td>3) I remember poor decisions I make for a long time afterwards.</td>
<td>0</td>
<td>12</td>
<td>12</td>
<td>34</td>
<td>42</td>
</tr>
<tr>
<td>4) I’m constantly examining the reasons for my decisions.</td>
<td>0</td>
<td>12</td>
<td>36</td>
<td>44</td>
<td>8</td>
</tr>
<tr>
<td>5) I get “worked up” just thinking about poor decisions I have made in the past.</td>
<td>8</td>
<td>17</td>
<td>15</td>
<td>34</td>
<td>25</td>
</tr>
<tr>
<td>6) I sometimes have the feeling that I’m observing my decision making process.</td>
<td>19</td>
<td>24</td>
<td>27</td>
<td>24</td>
<td>7</td>
</tr>
<tr>
<td>7) I often find myself thinking over and over about poor decisions that I have made in the past.</td>
<td>7</td>
<td>19</td>
<td>14</td>
<td>39</td>
<td>22</td>
</tr>
<tr>
<td>8) I think about better decisions I could have made long after the event has happened.</td>
<td>0</td>
<td>5</td>
<td>27</td>
<td>37</td>
<td>31</td>
</tr>
<tr>
<td>9) I am alert to changes in how much thought I give to my decisions.</td>
<td>5</td>
<td>22</td>
<td>27</td>
<td>39</td>
<td>7</td>
</tr>
<tr>
<td>10) I’m aware of the way my mind works when I make a decision.</td>
<td>2</td>
<td>14</td>
<td>34</td>
<td>34</td>
<td>17</td>
</tr>
<tr>
<td>11) I rarely forget the times when I have made a bad decision, even about the minor things.</td>
<td>2</td>
<td>32</td>
<td>20</td>
<td>29</td>
<td>17</td>
</tr>
<tr>
<td>12) When I am reminded about poor decisions I have made in the past, I feel as if they are happening all over again.</td>
<td>12</td>
<td>22</td>
<td>24</td>
<td>27</td>
<td>15</td>
</tr>
<tr>
<td>13) I’m concerned about what other people think of the decisions I make.</td>
<td>3</td>
<td>10</td>
<td>22</td>
<td>44</td>
<td>20</td>
</tr>
</tbody>
</table>

%EU= Percentage of extremely uncharacteristic response, %EC= Percentage of extremely characteristic response. Scale responses ranged from 0=EU to 4=EC.

5.3.1.2 Reinvestment survey scores

Descriptive statistics showed that participants’ reinvestment scores ranged from 5 to 18 (M= 12.17, SD= 3.62) for the RS, 8-45 (M= 30.53, SD= 7.76) for the MSRS, and 8-45 (M= 31.49, SD= 8.61) for the DSRS. While, the mean score of the E less participants was the highest across the three reinvestment surveys, one-way ANOVA analysis revealed no significant differences between E less, E ful and COM1 mean survey scores for RS (p=...
Correlation analysis showed significant correlations between total survey scores for the RS and the MSRS ($r (56)= 0.55$, $p< 0.001$), RS and the DSRS ($r (56)= 0.60$, $p< 0.001$), and MSRS and the DSRS ($r (56)= 0.51$, $p< 0.001$).

Figure 5.1. Scores from the errorless (E less), errorful (E ful), and comparative (COM1) groups for the three reinvestment surveys.  

**RS/20** = Reinvestment Scale (out of 20 points), **MSRS/50** = Movement-Specific Reinvestment Scale (out of 50 points), **DSRS/52** = Decision-Specific Reinvestment Scale (out of 52 points), error bars= +1 standard error mean.

### 5.3.2 Descriptive statistics for Study 2

#### 5.3.2.1 Percentage of responses to the three surveys

**Reinvestment Scale (RS)**

The percentage of “Yes” responses ranged from 13% to 89%, where the percentage of “No” responses ranged from 11% to 87% (Table 5.4). For Just over half of the items (11 out of 20 items) in this survey, the majority of participants responded positively to the items, which was similar to responses for the RS in Study 1.
Table 5.4. Percentages for responses to items for the Reinvestment Scale in Study 2

<table>
<thead>
<tr>
<th>Questions</th>
<th>Study 2</th>
<th>%Yes</th>
<th>%No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I remember things that upset me or make me angry for a long time</td>
<td></td>
<td>59</td>
<td>41</td>
</tr>
<tr>
<td>afterwards.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) I get “worked up” just thinking about things that have upset me in the past.</td>
<td></td>
<td>41</td>
<td>59</td>
</tr>
<tr>
<td>3) I often find myself thinking over and over about things that have made me angry.</td>
<td></td>
<td>36</td>
<td>64</td>
</tr>
<tr>
<td>4) I think about ways of getting back at people who have made me angry long after the event has happened.</td>
<td></td>
<td>13</td>
<td>87</td>
</tr>
<tr>
<td>5) I never forget people making me angry or upset, even about small things.</td>
<td></td>
<td>28</td>
<td>72</td>
</tr>
<tr>
<td>6) When I am reminded of my past failures, I feel as if they are happening all over again.</td>
<td></td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>7) I worry less about the future than most people I know (r)</td>
<td></td>
<td>73</td>
<td>27</td>
</tr>
<tr>
<td>8) I’m always trying to figure myself out.</td>
<td></td>
<td>67</td>
<td>33</td>
</tr>
<tr>
<td>9) I reflect about myself a lot.</td>
<td></td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>10) I’m constantly examining my motives.</td>
<td></td>
<td>52</td>
<td>48</td>
</tr>
<tr>
<td>11) I sometimes have the feeling that I’m off somewhere watching myself.</td>
<td></td>
<td>15</td>
<td>85</td>
</tr>
<tr>
<td>12) I’m alert to changes in my mood.</td>
<td></td>
<td>89</td>
<td>11</td>
</tr>
<tr>
<td>13) I’m aware of the way my mind works when I work through a problem.</td>
<td></td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>14) I’m concerned about my style of doing things.</td>
<td></td>
<td>49</td>
<td>51</td>
</tr>
<tr>
<td>15) I’m concerned about the way I present myself.</td>
<td></td>
<td>72</td>
<td>28</td>
</tr>
<tr>
<td>16) I’m self-conscious about the way I look.</td>
<td></td>
<td>65</td>
<td>35</td>
</tr>
<tr>
<td>17) I usually worry about making a good impression.</td>
<td></td>
<td>73</td>
<td>27</td>
</tr>
<tr>
<td>18) One of the last things I do before leaving my house is look in the mirror.</td>
<td></td>
<td>57</td>
<td>43</td>
</tr>
<tr>
<td>19) I’m concerned about what other people think of me.</td>
<td></td>
<td>68</td>
<td>32</td>
</tr>
<tr>
<td>20) Do you have trouble making up your mind?</td>
<td></td>
<td>47</td>
<td>53</td>
</tr>
</tbody>
</table>

%Yes= Percentage of Yes response, %No= Percentage of No response, (r)= reversed item

Movement-Specific Reinvestment Scale (MSRS)

Participants’ responses to items within the MSRS ranged from 0% to 51% (Table 5.5). Similar to study 1, the majority of participants responded with agree to 8 out of 10 items in this survey.

Table 5.5. Percentages for responses to items for the Movement-Specific Reinvestment Scale in Study 2

<table>
<thead>
<tr>
<th>Questions</th>
<th>%SD</th>
<th>%MD</th>
<th>%WD</th>
<th>%WA</th>
<th>%MA</th>
<th>%SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I rarely forget the times when my movements have failed me</td>
<td>1</td>
<td>16</td>
<td>15</td>
<td>25</td>
<td>36</td>
<td>7</td>
</tr>
<tr>
<td>2) I am always trying to figure out why my actions failed</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>23</td>
<td>51</td>
<td>15</td>
</tr>
<tr>
<td>3) I reflect about my movement a lot</td>
<td>1</td>
<td>11</td>
<td>9</td>
<td>27</td>
<td>44</td>
<td>8</td>
</tr>
<tr>
<td>4) I am always trying to think about my movements when I carry them out</td>
<td>0</td>
<td>12</td>
<td>7</td>
<td>32</td>
<td>44</td>
<td>5</td>
</tr>
<tr>
<td>5) I am self-conscious about the way I look when I am moving</td>
<td>4</td>
<td>15</td>
<td>16</td>
<td>31</td>
<td>33</td>
<td>1</td>
</tr>
<tr>
<td>6) I sometimes have the feeling that I am watching myself move</td>
<td>11</td>
<td>28</td>
<td>12</td>
<td>33</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>7) I am aware of the way my body works when I am carrying out a movement</td>
<td>3</td>
<td>11</td>
<td>15</td>
<td>39</td>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>8) I am concerned about my style of moving</td>
<td>5</td>
<td>27</td>
<td>24</td>
<td>23</td>
<td>21</td>
<td>0</td>
</tr>
</tbody>
</table>
9) If I see my reflection in a shop window, I will examine my movements
10) I am concerned about what people think about me when I am moving

%SD = Percentage of strongly disagree response, %MD = Percentage of moderately disagree response,
%WD = Percentage of weakly disagree response, %WA = Percentage of weakly agree response, %MA =
Percentage of moderately agree response, %SA = Percentage of strongly agree response.

**Decision-Specific Reinvestment Scale (DSRS)**

Participants’ responses to items within the DSRS ranged from 1% to 45%
(Table 5.6). Similar to Study 1, for just over half of the items in this survey, the majority of
participants identified these items were characteristic of them in term of decision making.

<table>
<thead>
<tr>
<th>Questions</th>
<th>EU 0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I’m always trying to figure out how I make decisions.</td>
<td>1</td>
<td>23</td>
<td>27</td>
<td>39</td>
<td>11</td>
</tr>
<tr>
<td>2) I’m concerned about my style of decision-making.</td>
<td>8</td>
<td>33</td>
<td>23</td>
<td>32</td>
<td>4</td>
</tr>
<tr>
<td>3) I remember poor decisions I make for a long time afterwards.</td>
<td>5</td>
<td>7</td>
<td>23</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>4) I’m constantly examining the reasons for my decisions.</td>
<td>1</td>
<td>15</td>
<td>24</td>
<td>43</td>
<td>17</td>
</tr>
<tr>
<td>5) I get “worked up” just thinking about poor decisions I have made in the past.</td>
<td>11</td>
<td>21</td>
<td>28</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>6) I sometimes have the feeling that I’m observing my decision making process.</td>
<td>7</td>
<td>32</td>
<td>31</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>7) I often find myself thinking over and over about poor decisions that I have made in the past.</td>
<td>11</td>
<td>28</td>
<td>20</td>
<td>35</td>
<td>7</td>
</tr>
<tr>
<td>8) I think about better decisions I could have made long after the event has happened.</td>
<td>4</td>
<td>11</td>
<td>29</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>9) I am alert to changes in how much thought I give to my decisions.</td>
<td>1</td>
<td>25</td>
<td>27</td>
<td>43</td>
<td>4</td>
</tr>
<tr>
<td>10) I’m aware of the way my mind works when I make a decision.</td>
<td>4</td>
<td>9</td>
<td>37</td>
<td>37</td>
<td>12</td>
</tr>
<tr>
<td>11) I rarely forget the times when I have made a bad decision, even about the minor things.</td>
<td>12</td>
<td>24</td>
<td>29</td>
<td>28</td>
<td>7</td>
</tr>
<tr>
<td>12) When I am reminded about poor decisions I have made in the past, I feel as if they are happening all over again.</td>
<td>12</td>
<td>36</td>
<td>21</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>13) I’m concerned about what other people think of the decisions I make.</td>
<td>3</td>
<td>23</td>
<td>28</td>
<td>36</td>
<td>11</td>
</tr>
</tbody>
</table>

%EU = Percentage of extremely uncharacteristic response, %EC = Percentage of extremely characteristic response. Scale responses ranged from 0=EU to 4=EC.
5.3.2.2 Reinvestment survey scores for Study 2

Descriptive statistics showed that participants’ reinvestment scores ranged from 3 to 19 (M= 10.99, SD= 3.41) for the RS, 11-45 (M= 28.97, SD= 6.97) for the MSRS, and 9-48 (M= 28.84, SD= 7.83) for the DSRS. A one-way ANOVA analysis revealed no significant differences between GO, IO, OO and COM2 mean survey scores for RS (p= 0.479), MSRS (p= 0.320) and DSRS (p= 0.189) (Figure 5.2). Correlation analysis showed a significant correlation between total survey scores for the RS and the MSRS (r (72)= 0.37, p= 0.001), RS and the DSRS (r (72)= 0.52, p< 0.001), and MSRS and the DSRS (r (72)= 0.42, p< 0.001).

![Mean Reinvestment Scores](Figure 5.2. Scores from the guided-observation (GO), instructed-observation (IO), observation-only (OO), and comparative (COM2) groups for the three reinvestment surveys. RS/20= Reinvestment Scale (out of 20 points), MSRS/50= Movement-Specific Reinvestment Scale (out of 50 points), DSRS/52= Decision-Specific Reinvestment Scale (out of 52 points), error bars= +1 standard error mean.)

5.3.3 Comparison of survey scores with previous studies

Comparison of the overall mean survey scores from Study 1 and 2 with data from the previous published studies related to the reinvestment surveys, showed higher scores for current study participants for both RS and DSRS (Table 5.7). For the RS, an unpaired t-test revealed that the mean survey score for the current sample was significantly higher
than the one reported by Masters et al. (1993) \((t(271) = 3.58, p < 0.001, d = 0.43)\).

Moreover, the mean survey score for the DSRS in the current sample was significantly higher than the one reported by Kinrade et al. (2010) \((t(237) = 2.38, p = 0.02, d = 0.31)\).

### Table 5.7. Comparison of the mean survey scores between the present study (Study 1 and 2 data combined) and previous published data for the three reinvestment surveys

<table>
<thead>
<tr>
<th>Survey</th>
<th>n</th>
<th>Mean Survey Score (SD)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS</td>
<td>134</td>
<td>11.51 (3.54)</td>
<td>present study</td>
</tr>
<tr>
<td></td>
<td>144</td>
<td>9.81 (4.37)</td>
<td>Masters et al. (1993)</td>
</tr>
<tr>
<td>MSRS</td>
<td>134</td>
<td>29.66 (7.34)</td>
<td>present study</td>
</tr>
<tr>
<td></td>
<td>369</td>
<td>data not provided</td>
<td>Masters et al. (2005)</td>
</tr>
<tr>
<td>DSRS</td>
<td>134</td>
<td>29.93 (8.26)</td>
<td>present study</td>
</tr>
<tr>
<td></td>
<td>111</td>
<td>27.46 (7.97)</td>
<td>Kinrade et al. (2010)</td>
</tr>
</tbody>
</table>

**RS** = Reinvestment Scale, **MSRS** = Movement-Specific Reinvestment Scale, **DSRS** = Decision-Specific Reinvestment Scale.

### 5.3.4 Factor analysis and internal consistency reliability

#### 5.3.4.1 Reinvestment Scale (RS)

An unconstrained CFA was used to confirm that the combined data from Study 1 and 2 provided a good fit to the original four-factor model (Masters et al., 1993). While the CFI and GFI were < 0.90, indicated a poor fit of the data, results from SRMR \((\leq 0.08)\) and RMSEA \((< 0.05)\) indicated a good model fit. Overall, it was considered that the data provided an acceptable fit to the model (see Table 5.8). Factor analysis data provided by Masters et al. (1993) related to the Reinvestment Scale were limited, which did not enable comparison with the current data (See Appendix 9.15).
Table 5.8. Goodness of fit tests of factors for confirmatory (CFA) and exploratory factor analysis (EFA) models for the Reinvestment Scale

<table>
<thead>
<tr>
<th></th>
<th>Cut-off Value</th>
<th>CFA</th>
<th>EFA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AIC</strong></td>
<td>lowest is optimal</td>
<td>304</td>
<td>293</td>
</tr>
<tr>
<td><strong>Chi-squared test</strong></td>
<td>p&gt; 0.05^</td>
<td>(X²=212, df 164)**</td>
<td>(X²=201, df 164)*</td>
</tr>
<tr>
<td><strong>CFI</strong></td>
<td>&gt; 0.95^, ≥0.90^</td>
<td>0.85</td>
<td>0.89</td>
</tr>
<tr>
<td><strong>GFI</strong></td>
<td>&gt; 0.95^, ≥0.90^</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td><strong>SRMR</strong></td>
<td>≤ 0.08^</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>RMSEA</strong></td>
<td>&lt; 0.05^, 0.05-0.08^</td>
<td>0.04</td>
<td>0.05</td>
</tr>
</tbody>
</table>

AIC= Akaike Information Criterion, CFI= Comparative Fit Index, GFI= Goodness-of-Fit Index, SRMR= Standardised Root Mean-squared Residual, RMSEA= Root Mean Square Error of Approximation, * p< 0.05, ** p< 0.01. ^ values indicate a good fit. ^ values indicate an acceptable fit.

For each of the factors in the CFA model, less than 10 percent of the variance was explained (The Rehearsal (RH) factor: 3.35%, the Private Self-Consciousness (PrSC) factor: 2.19%, the Public Self-Consciousness (PuSC) factor: 1.75%, and the Cognitive Failure (CF) factor: 1.51%) (see Appendix 9.12).

A CFA model with no correlation between factors was completed but the model fit remained poor. An alternative exploratory factor model using the Rotated Factor Pattern was tested, with changes to factor allocations for items 7, 12, 13, 14 and 20 (see Appendix 9.14). The four new reinvestment factors explained less than 10 percent of the variances (RH: 2.69%, PrSC: 2.43%, PuSC: 2.13%, and CF: 1.56%). Correlation coefficients showed that the factors were generally independent in both models. The change in item classification indicated by the EFA did not result in improvement of the overall fit of the Reinvestment Scale model (see Table 5.8). Items and loadings for the Exploratory Factor Analysis (EFA) of the Reinvestment Scale (RS) are presented in (Appendix 9.13).

Therefore, the CFA model was retained. Due to the low factor loadings and small percentage of variance explained by the RS factors, it was considered to use the total survey score for the RS (not the subscales scores) for subsequent analyses of the survey.
The RS failed to demonstrate acceptable internal consistency reliability. The subscale factors internal consistency reliability were below the acceptable value (≥ 0.70). Cronbach’s α for RH, PrSC, and PuSC were 0.69, 0.52, and 0.63, respectively. However, the overall internal consistency reliability for the RS was acceptable (Cronbach’s α of 0.70).

5.3.4.2 Movement-Specific Reinvestment Scale (MSRS)

An unconstrained CFA was used to confirm that the fit of the combined data from Study 1 and 2 provided a good fit to the two-factor model of the MSRS (Masters et al., 2005). The CFI and GFI were ≥ 0.90, indicating an acceptable model fit. Moreover, results showed a good fit for the SRMR (≤ 0.08) and an acceptable model fit for the RMSEA (0.05-0.08). Therefore, it was considered that the data provided an acceptable fit to the model (see Table 5.9). Factor analysis data reported by Masters et al. (2005) for the MSRS provided a better model fit compared with data in the present study (see Appendix 9.15).

Table 5.9. Goodness of fit tests of factors for confirmatory (CFA) and exploratory factor analysis (EFA) models for the Movement-Specific Reinvestment Scale

<table>
<thead>
<tr>
<th>Cut-off Value</th>
<th>CFA</th>
<th>EFA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AIC</strong></td>
<td>lowest is optimal</td>
<td>101</td>
</tr>
<tr>
<td><strong>Chi-squared test</strong></td>
<td>p &gt; 0.05^</td>
<td>(X²=59, df 34)**</td>
</tr>
<tr>
<td><strong>CFI</strong></td>
<td>&gt; 0.95^, ≥0.90*</td>
<td>0.93</td>
</tr>
<tr>
<td><strong>GFI</strong></td>
<td>&gt; 0.95^, ≥0.90*</td>
<td>0.92</td>
</tr>
<tr>
<td><strong>SRMR</strong></td>
<td>≤ 0.08^</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>RMSEA</strong></td>
<td>&lt; 0.05^, 0.05-0.08*</td>
<td>0.08</td>
</tr>
</tbody>
</table>

AIC= Akaike Information Criterion, CFI= Comparative Fit Index, GFI= Goodness-of-Fit Index SRMR= Standardised Root Mean-squared Residual, RMSEA= Root Mean Square Error of Approximation, *p< 0.05, ** p< 0.01. ^ values indicate a good fit. * values indicate an acceptable fit.

From the CFA model, the two factors explained just over 5 percent of the variance (Movement Self-Consciousness (MSC) factor: 3.56%, and the Conscious Motor Processing (CMP) factor: 1.78% of the variance (see Appendix 9.12). Therefore, a CFA model with no
correlation between factors was also tried but resulted in a poorer fit. Using the Rotated Factor Pattern, an alternative exploratory factor model was tested, with changes in item allocation to factors (see Appendix 9.14). Two factors were included using the reinvestment data, with rotation. However, the two reviewed reinvestment factors only explained a similar percent of the variance (MSC: 2.99, and CMP: 2.35). Correlation coefficients showed that the factors were generally independent in both models. The change in item classification indicated by the EFA model did not result in improvement of the overall fit of the MSRS model (see Table 5.9). Items and loadings for the Exploratory Factor Analysis (EFA) of the MSRS are presented in (Appendix 9.13). Therefore, the CFA model was retained. Due to the low factor loadings and small percentage of variance explained by the MSRS factors, the total survey score for the MSRS (not the subscales scores) was used for subsequent analyses of the survey.

The MSRS demonstrated acceptable internal consistency reliability. This was supported by good internal consistency reliability for the MSC subscale factor, which scored a Cronbach’s α of 0.80. While, Cronbach’s α score of CMP factor was 0.69. The overall internal consistency reliability for the MSRS was acceptable (Cronbach’s α of 0.78).

5.3.4.3 Decision-Specific Reinvestment Scale (DSRS)

An unconstrained CFA used to confirm that the combined data from both Study 1 and 2 provided a good fit to the two-factor model of the DSRS (Kinrade et al., 2010). The GFI was < 0.90 indicating a poor model fit. However, results showed a good fit for the SRMR (≤ 0.08) and a marginal model fit for the RMSEA (0.08-0.1). Overall, it was considered that the data provided an acceptable fit to the model (see Table 5.10). Factor
analysis data reported by Kinrade et al. (2010) related to DSRS provided a comparable model fit to data in the current study (see Appendix 9.15).

For each of the factors in the CFA model, nearly 7 percent of variance was explained (Decision Reinvestment (DRe) factor: 4.72%, and the Decision Rumination (DRu) factor: 1.99% (see Appendix 9.12).

A CFA model with no correlation between factors was tested but resulted in a poorer fit. Using the Rotated Factor Pattern, an alternative exploratory factor model was tested, with changes to item allocation to factors (see Appendix 9.14). Two factors were included using the reinvestment data, with rotation. Using EFA, an alternative model fit was tested by moving a number of items from one factor to another. The two reviewed reinvestment factors were only able to explain a similar percent of the variances (DRe: 4.00%, and DRu: 2.72%). Correlation coefficients showed that the factors were generally independent. The change in classification resulting from the EFA did not provide an improvement of the overall fit of the DSRS model (see Table 5.10). Items and loadings for

<table>
<thead>
<tr>
<th>Cut-off Value</th>
<th>CFA</th>
<th>EFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIC</td>
<td>lowest is optimal</td>
<td>180</td>
</tr>
<tr>
<td>Chi-squared test</td>
<td>p &gt; 0.05(^\wedge)</td>
<td>(X^2=126, df 64)***</td>
</tr>
<tr>
<td>CFI</td>
<td>&gt; 0.95(^\wedge), ≥0.90(^*)</td>
<td>0.90</td>
</tr>
<tr>
<td>GFI</td>
<td>&gt; 0.95(^\wedge), ≥0.90(^*)</td>
<td>0.88</td>
</tr>
<tr>
<td>SRMR</td>
<td>≤ 0.08(^\wedge)</td>
<td>0.08</td>
</tr>
<tr>
<td>RMSEA</td>
<td>&lt; 0.05(^\wedge), 0.05-0.08(^*)</td>
<td>0.09</td>
</tr>
</tbody>
</table>

AIC= Akaike Information Criterion, CFI= Comparative Fit Index, GFI= Goodness-of-Fit Index, SRMR= Standardised Root Mean-squared Residual, RMSEA= Root Mean Square Error of Approximation, *** p< 0.001. \(^\wedge\) values indicate a good fit. \(^*\) values indicate an acceptable fit.
the Exploratory Factor Analysis (EFA) of the Decision-Specific Reinvestment Scale (DSRS) are presented in (Appendix 9.12.13). Therefore, the CFA model was retained. Due to the low factor loadings and small percentage of variance explained by the DSRS factors, it was considered to use the total survey score for the DSRS (not the subscales scores) for subsequent analyses of the survey.

The DSRS demonstrated good internal consistency reliability. This was supported by acceptable and good internal consistency reliability for the DRe and the DRu subscale factors, respectively. The Cronbach’s α of the DRe factor was 0.74, and 0.86 for the DRu factor. The overall internal consistency reliability for the DSRS was also good (Cronbach’s α of 0.85).

5.3.5 Impact of reinvestment on performance

5.3.5.1 Performance of low and high reinvesters in Study 1

Using a post-hoc median split based on the scores from the three reinvestment surveys, participants the E less, E ful and COM1 groups were assigned to low and high reinvestment groups (see section 5.2.4.3). The median value for the Reinvestment Scale (RS) was 13. Therefore, a low reinvestment score was classified as < 13, while a high reinvestment score was ≥ 13. For the Movement-Specific Reinvestment Scale (MSRS) and the Decision-Specific Reinvestment Scale (DSRS) the median values were 32. Therefore, a low reinvestment score was classified as < 32, while a high reinvestment score was ≥ 32 (see Table 5.11).
Table 5.11. Numbers of low (L) and high (H) reinvesters in each group based on a median split of the three reinvestment surveys scores

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>RS</th>
<th>MSRS</th>
<th>DSRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td></td>
<td>13.00</td>
<td>32.00</td>
<td>32.00</td>
</tr>
<tr>
<td>E less</td>
<td>21</td>
<td>6</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>E ful</td>
<td>21</td>
<td>11</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>COM1</td>
<td>17</td>
<td>11</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

RS= Reinvestment Scale, MSRS= Movement-Specific Reinvestment Scale, DSRS= Decision-Specific Reinvestment Scale, L= number of low reinvesters, H= number of high reinvesters, E less= errorless group, E ful= errorful group, COM1= comparative group.

Analysis of the three reinvestment surveys (RS, MSRS, and DSRS) for canal preparation accuracy (Figure 5.3) and completion times (Figure 5.4) across transfer tests 1 and 2, showed no significant effect of reinvestment group (p>0.05), nor significant effect of the test condition (p>0.05).

Figure 5.3. Mean distance (millimetres) that the last instrument reached compared to the target distance (19.5 mm) in transfer tests 1 (primary task) and 2 (multi-tasking) for low and high reinvesters based on a median split, for the three reinvestment surveys. Reinvestment Scale (RS), Movement-Specific Reinvestment Scale (MSRS), and Decision-Specific Reinvestment Scale (DSRS). Decrease in length = reduced accuracy, error bars= +1 standard error.
Further analyses of the performance of reinvesters (using the 25th and 75th percentiles) for each of the three reinvestment surveys across the transfer tests showed neither a significant effect of reinvestment group \( (p>0.05) \), nor of the test condition on accuracy of preparation \( (p>0.05) \) (Figure 5.5). There were no significant differences in relation to completion times for both the RS and MSRS surveys \( (p>0.05) \) (Figure 5.6). However, for the DSRS, a main effect of the testing condition was found. Specifically, both ‘low’ reinvesters and ‘high’ reinvesters completed the canal preparation in a significantly shorter time when multi-tasking, \( F (1, 26)= 6.12, p= 0.020, d= 0.48 \) (Figure 5.6). Analyses of the associations between reinvestment survey scores and changes in accuracy of preparation and completion time showed no significant correlation, \( (p>0.05) \).
Figure 5.5. Mean distance (millimetres) that the last instrument reached compared to the target distance (19.5 mm) in transfer tests 1 (primary task) and 2 (multi-tasking) for low and high reinvesters (using 25th & 75th percentiles) for the three reinvestment surveys. 
Reinvestment Scale (RS), Movement-Specific Reinvestment Scale (MSRS), and Decision-Specific Reinvestment Scale (DSRS). Decrease in length = reduced accuracy, error bars= ±1 standard error.

Figure 5.6. Mean time (minutes) spent to complete the task during transfer tests 1 (primary task) and 2 (multi-tasking) for low and high reinvesters (using 25th & 75th percentiles) for the three reinvestment surveys. 
Reinvestment Scale (RS), Movement-Specific Reinvestment Scale (MSRS), and Decision-Specific Reinvestment Scale (DSRS). Error bars= ±1 standard error. * significant difference between transfer tests 1 & 2 within DSRS (p< 0.05).
5.3.5.2 Performance of low and high reinvesters in Study 2

Using a post-hoc median split based on the three reinvestment survey scores, participants in GO, IO, OO, and COM2 groups were assigned to low and high reinvestment groups (see section 5.2.4.3). The median value for the Reinvestment Scale (RS) was 11. Therefore, a low reinvestment score was classified as < 11, while a high reinvestment score was ≥ 11. For the Movement-Specific Reinvestment Scale (MSRS) and the Decision-Specific Reinvestment Scale (DSRS) the median values were 29. Therefore, a low reinvestment score was classified as < 29, while a high reinvestment score was ≥ 29 (see Table 5.12).

Table 5.12. Numbers of low (L) and high (H) reinvesters in each group based on a median split of the three reinvestment survey scores

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>RS</th>
<th></th>
<th>MSRS</th>
<th></th>
<th>DSRS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>Median</td>
<td></td>
<td>11.00</td>
<td></td>
<td>29.00</td>
<td></td>
<td>29.00</td>
<td></td>
</tr>
<tr>
<td>GO</td>
<td>23</td>
<td>10</td>
<td>13</td>
<td>10</td>
<td>13</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>IO</td>
<td>23</td>
<td>12</td>
<td>11</td>
<td>11</td>
<td>12</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>OO</td>
<td>13</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>4</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>COM2</td>
<td>16</td>
<td>6</td>
<td>10</td>
<td>6</td>
<td>10</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>

RS= Reinvestment Scale, MSRS= Movement-Specific Reinvestment Scale, DSRS= Decision-Specific Reinvestment Scale, L= number of low reinvesters, H= number of high reinvesters, GO= guided-observation, IO= instructed-observation, OO= observation-only, COM2= comparative group.

Analysis of the three reinvestment surveys (RS, MSRS, and DSRS) for the accuracy in canal preparation of low and high reinvesters across transfer tests 1, 2 and 3 showed no significant effect of group (p> 0.05), or of condition (p> 0.05) (refer to Figure 5.7).

However, results for completion times (Figure 5.8) across the three transfer tests showed a significant effect of the test condition within the RS, F (1, 73)= 322.73, p< 0.001, the MSRS, F (1, 63)= 280.07, p< 0.001, and the DSRS, F (1, 63)= 279.31, p< 0.001. Bonferroni post-hoc tests revealed significant differences in completion times between transfer tests
1, 2, and 3 for RS, MSRS and DSRS surveys, with (p’s< 0.001). Other results related to completion times showed no significant effect of the reinvestment group (p> 0.05).

Figure 5.7. Mean distance (millimetres) that the last instrument reached compared to the target distance (19.5 mm) in transfer tests 1 (primary task), 2 (multi-tasking), and 3 (under stress) for low and high reinvesters (based on a median split) for the three reinvestment surveys. Reinvestment Scale (RS), Movement-Specific Reinvestment Scale (MSRS), and Decision-Specific Reinvestment Scale (DSRS). Decrease in length = reduced accuracy, error bars= +1 standard error.

Figure 5.8. Mean time (minutes) spent to complete the task during transfer tests 1 (primary task), 2 (multi-tasking), and 3 (under stress) for low and high reinvesters (based on a median split) for the three reinvestment surveys. Reinvestment Scale (RS), Movement-Specific Reinvestment Scale (MSRS), and Decision-Specific Reinvestment Scale (DSRS), error bars= +1 standard error. *** significant difference between tests 1-3 within the RS, the MSRS, and the DSRS (p< 0.001).
Further analyses of the performance of the low and high reinvesters (based on the 25th and 75th percentiles) for each of the three reinvestment surveys across the three transfer tests showed a significant effect of the test condition on accuracy of preparation within the RS, $F (1, 36) = 10.36$, $p = 0.003$, and the DSRS, $F (1, 36) = 5.37$, $p = 0.026$ (Figure 5.9). Bonferroni post-hoc tests revealed significant deterioration in accuracy of preparation under stressful conditions compared with the primary task for the low reinvesters within the RS ($p = 0.006$, $d = 1.00$), and a significant decrease in accuracy of preparation when multi-tasking compared with the primary task condition for the high reinvesters within the DSRS ($p = 0.009$, $d = 1.12$). Other results related to accuracy of preparation showed no significant effect of the reinvestment group ($p > 0.05$).

Completion times of the low and high reinvesters across the three transfer tests showed a significant effect of the test condition within the RS, $F (1, 36) = 10.36$, $p = 0.003$, the MSRS, $F (1, 36) = 10.36$, $p = 0.003$, and the DSRS, $F (1, 36) = 161.74$, $p < 0.001$ (Figure 5.10). Bonferroni post-hoc tests revealed a significant decrease in completion times under multi-tasking and stressful conditions compared with the primary task, and a significant decrease under stressful condition compared with the multi-tasking completion times for RS, MSRS and DSRS surveys with $p$ values $< 0.001$. Other results related to completion time showed no significant effect of the reinvestment group ($p > 0.05$).
Figure 5.9. Mean distance (millimetres) that the last instrument reached compared to the target distance (19.5 mm) in transfer tests 1 (primary task) and 2 (multi-tasking) for low and high reinvesters (using 25th & 75th percentiles) for the three reinvestment surveys.

Reinvestment Scale (RS), Movement-Specific Reinvestment Scale (MSRS), and Decision-Specific Reinvestment Scale (DSRS). Decrease in length = reduced accuracy, error bars= +1 standard error. ** significant difference between tests 1 and 3 within the RS; and tests 1 and 2 within the DSRS (p< 0.01).

Figure 5.10. Mean distance (millimetres) that the last instrument reached compared to the target distance (19.5 mm) in transfer tests 1 (primary task) and 2 (multi-tasking) for low and high reinvesters (using 25th & 75th percentiles) for the three reinvestment surveys.

Reinvestment Scale (RS), Movement-Specific Reinvestment Scale (MSRS), and Decision-Specific Reinvestment Scale (DSRS). Decrease in length = reduced accuracy, error bars= +1 standard error. ***significant difference between tests 1-3 within the RS, the MSRS, and the DSRS (p< 0.001).
Analysis of the three reinvestment surveys (RS, MSRS, and DSRS) using median split data for heart rates of the low and high reinvesters across transfer tests 1, 2 and 3 showed no significant effect of group (p> 0.05), but did reveal a significant effect of condition (p< 0.05) (refer to Figure 5.11). A one-way ANOVA analysis revealed significant increases in participants’ heart rates under multi-tasking and stressful conditions for RS, MSRS and DSRS surveys (p’s< 0.001). Analyses of the association between reinvestment survey scores and changes in heart rates showed no significant correlation, (p> 0.05).

![Study 2: Stress Measure (HR)](image)

Figure 5.11. Mean heart rate (HR) measures in transfer tests 1 (primary task), 2 (multi-tasking), and 3 (under stress) for low and high reinvesters (based on a median split) for the three reinvestment surveys. Reinvestment Scale (RS), Movement-Specific Reinvestment Scale (MSRS), and Decision-Specific Reinvestment Scale (DSRS). Decrease in length = reduced accuracy, error bars= +1 standard error.*** significant difference between transfer tests 1, 2, and 3 for each reinvestment survey, p< 0.001.

Analysis of the three reinvestment surveys (RS, MSRS, and DSRS) using median split data for the STAI survey scores of low and high reinvesters across transfer tests 1, 2 and 3 showed a significant effect of group at RS scores, F (1, 73)= 7.65, p= 0.007. Bonferroni post-hoc tests revealed high reinvesters had significantly higher STAI scores than low reinvesters at transfer tests 2 (p= 0.001, d= 0.78), and 3 (p= 0.004, d= 0.67) for
Results also showed a significant effect of the condition in the three reinvestment survey scores, $F(1, 73)= 458.13, p< 0.001$ (refer to Figure 5.12). A one-way ANOVA analysis revealed significant differences between transfer tests 1, 2, and 3 STAI mean survey scores for the three reinvestment surveys, with ($p < 0.001$). A one way ANOVA of the for low and high reinvesters (based on a median split) for three reinvestment surveys showed a significant difference in the PSS survey scores across transfer tests. Results showed a significant increase in the perceived stress scores for the high reinvesters compared with the low reinvesters at RS ($p= 0.012, d= 0.60$) and DSRS ($p= 0.010, d= 0.62$) (Figure 5.13).

**Figure 5.12.** Mean state trait anxiety inventory (STAI) survey scores (out of 24 points) in transfer tests 1 (primary task), 2 (multi-tasking), and 3 (under stress) for low and high reinvesters (based on a median split) for the three reinvestment surveys. Reinvestment Scale (RS), Movement-Specific Reinvestment Scale (MSRS), and Decision-Specific Reinvestment Scale (DSRS). Decrease in length = reduced accuracy, error bars= +1 standard error. ** significant difference between low and high reinvesters during multi-tasking and stress conditions for the RS, $p< 0.01$. *** significant difference between transfer tests 1, 2, and 3 for each reinvestment survey, $p< 0.001$. 
Figure 5.13. Mean perceived stress scale (PSS) scores (out of 40 points) in transfer tests 1 (primary task), 2 (multi-tasking), and 3 (under stress) for low and high reinvesters (based on a median split), for the three reinvestment surveys. Reinvestment Scale (RS), Movement-Specific Reinvestment Scale (MSRS), and Decision-Specific Reinvestment Scale (DSRS). Decrease in length = reduced accuracy, error bars = $\pm 1$ standard error. * significant difference between low and high reinvesters for RS and DSRS, $p<0.05$.

Analyses of the associations between RS and DSRS survey scores and changes in STAI survey and PSS scores showed significant correlations, $p<0.05$. The RS scores were significantly associated with STAI scores at transfer tests 2 ($r(75)=0.37$, $p=0.001$) and transfer test 3 ($r(75)=0.39$, $p=0.001$). RS scores were also significantly associated with PSS scores $r(75)=0.47$, $p<0.001$. The DSRS scores were significantly associated with STAI scores at transfer tests 2 ($r(75)=0.24$, $p=0.035$) and 3 ($r(75)=0.28$, $p=0.016$). DSRS scores were also significantly associated with PSS scores $r(75)=0.44$, $p<0.001$. 
5.4 Discussion

The calculated mean survey scores and medians were comparable for the three reinvestment surveys, indicating that the data were approximately normally distributed. Responses related to the three reinvestment surveys suggested a high tendency for self-consciousness and control. This is supported by the higher percentages of positive responses related to self-consciousness items in the RS and the moderately high positive responses related to movement control and decision-making. Comparison of the overall survey scores from Study 1 and 2 with data from the previous published studies (Masters et al., 1993; Masters et al., 2005; Kinrade et al., 2010) related to the reinvestment surveys, showed significantly higher scores for current study participants for both RS and DSRS.

Results from the confirmatory factor analysis for the three reinvestment surveys showed acceptable fit of data to the previously reported models. Examination of the underlying structure of the three surveys showed that items within the original factors for each survey could not explain the variance in the models. Therefore, the total survey scores for the three reinvestment surveys were considered for subsequent analyses rather than the subscales scores. The internal consistency reliability of factors within the three surveys were acceptable to good (Lance et al., 2006).

For the three reinvestment surveys, no significant differences in scores were found between the groups in both studies. Furthermore, no significant differences in performance were found between low and high reinvesters, based on a median split, for either the primary task (transfer test 1) or multi-tasking conditions (transfer test 2) in Study 1, or under stressful conditions (transfer test 3) in Study 2. Relatively, no significant
associations were found between the reinvestment survey scores and differences in accuracy of preparation and completion times in both Study 1 and 2. However, for the Decision-Specific Reinvestment Scale in Study 1, both low and high reinvesters based on percentiles took a significantly shorter time to complete the task under a multi-tasking condition. Results related to low and high reinvesters in Study 2, showed a significant deterioration in performance accuracy of the low reinvesters under stressful conditions within the RS, and a significant decrease in accuracy of preparation when multi-tasking for the high reinvesters within the DSRS. Results related to completion times and stress measures (i.e. heart rate, STAI and PSS) in Study 2 for low and high reinvesters for the three reinvestment surveys showed comparable results with data related to performance of the experimental and comparative groups in Study 2. These results showed a significant decrease in completion times under multi-tasking and stressful conditions, they also showed a significant increases in participants’ heart rates and STAI scores under multi-tasking and stressful conditions for the three reinvestment surveys. Moreover, results showed a significant increase in the perceived stress scores for the high reinvesters compared with the low reinvesters within the RS and DSRS.

It was initially hypothesised that the performance of high reinvesters would deteriorate when carrying out root canal hand instrumentation under multi-tasking conditions. It was posited that a reduction in performance would result from high reinvesters allocating working memory resources to monitoring and controlling their movements. However, results from Study 1 and Study 2 did not support this hypothesis. The apparent limited impact of reinvestment on performance of the participants may be explained by the small numbers of low and high reinvesters in the study, as well as the low level of complexity of instructions provided in Study 1 and the variable level of
complexity of video demonstrations and instructions provided in Study 2. Specifically, the instructions provided to participants in the experimental groups in Study 1 were simple and task-related. Furthermore, the observational learning groups in Study 2 seemed to be mentally overloaded with the volume and complexity of information provided in the video demonstration (i.e. different segments and visual cues on progress and direction of movements). This overload for the novice participants is suggested to have increased their attentional demands between the various components of the same task, thereby, leading to impairment of their performance (Poolton et al., 2011).

Results from the confirmatory factor analysis for the reinvestment surveys showed that the current data provided an acceptable fit to the original models. However, factor structure was not consistent with findings from the original Reinvestment and Movement-Specific surveys (Masters et al., 1993; Masters et al., 2005) where good model fit was reported for the data with higher loadings for the factors and more variance explained. An acceptable model fit reported in the current study might relate to some items measuring multiple factors. Moreover, it is suggested that some items loaded on different factors from the original scale. It might also be that some items within a factor were not related to each other (Hurley et al., 1997). Another explanation might be related to the relatively small sample sizes. Williams et al. (2010) suggested that sample sizes should be 200 or greater in order to successfully conduct factor analysis. Therefore, caution is needed when interpreting findings related to score validity of each of the three surveys in predicting performance breakdown under pressured conditions.

Another explanation could be related to factors influencing propensity to reinvest and the disposition for reinvestment. Studies in sports and surgery suggest that the
propensity to reinvest and the impact of reinvestment can vary depending on the amount of task-related declarative knowledge and the ease of cognitive access to that knowledge by performers (Masters and Maxwell, 2008). For example, the effect of reinvestment might be more disruptive for skilled performers who depend more on automated behaviours associated with procedural knowledge than for novices who rely on task-related knowledge to perform non-automated behaviours (Masters and Maxwell, 2008).

Propensity to reinvest has been suggested to be associated with performance context and task attentional demands (Jackson et al., 2006; Jackson et al., 2013; Malhotra et al., 2015b). For example, Jackson et al. (2006) examined skilled hockey and soccer players performing dribbling tasks under different demanding conditions and found the negative impact of reinvestment on performance of soccer dribbling (less complex) was reduced compared to hockey dribbling (more complex). This finding suggests that propensity to reinvest is dependent on complexity of the motor task. However, this seems to depend on the performer’s perception of the learning process being motivational or demanding. For example, Malhotra et al. (2015b) investigated the two dimensions of personality in the Movement-Specific Reinvestment Scale and found that the impact of self-consciousness on performance can be influenced positively or negatively depending on whether the performer perceives the learning process to be either motivational or demanding. Medical participants, for instance, may place higher priority on simulating surgeons when performing a laparoscopic task, and therefore perform more slowly as they perceive the task to be demanding rather than motivational (Malhotra et al., 2014). On the other hand, novice science students performing a golf putting task may perceive the motor learning task to be motivational rather than demanding. This could then have a positive impact on their performance (Malhotra et al., 2015a). The negative effect of
the complex nature of the root canal preparation tasks in the current study seemed to be weakened by the positive motivational nature of dental students based on their perception of stressful events in life. This might be related to different dimensions of personality relevant to dental students. These differences in dental students are supported by the statistically significant higher Reinvestment and Decision mean survey scores compared with the reported scores from the original surveys (see Table 5.7).

5.5 Study limitations

The present study was limited in terms of the relatively small sample sizes, which compromised statistical power required for conducting factor analyses, and for comparing performances of low and high reinvesters. Williams et al. (2010) suggested that sample sizes should be 200 or greater in order to successfully conduct factor analysis. Therefore, caution is needed when interpreting findings related to score validity of each of the three surveys in predicting performance breakdown under pressured conditions. It is important to indicate that a power study was conducted to explore the required sample sizes (see Sections 3.2.4.3 and 4.2.3.3). However, there are no other studies that have used implicit and explicit approaches in dental education or endodontics to provide relevant data for sample size calculations. Subsequent studies could draw on data for reinvestment scores to confirm sample sizes calculations.

Another limitation that should be considered is that the three reinvestment surveys are self-reported measures that rely on individual reporting on self-behaviours and feelings. The scores of these surveys may have been affected by some individuals over- or under-estimating their capabilities, bias from socially desirable responding, and some
repeating the same answer regardless of the question being asked (Orrell et al., 2009). Furthermore, these surveys were provided to participants together through an email with no control over the order of picking and filling the surveys. Since some items are similar in the three surveys, the order of filling these surveys might have also been biased by individual perception of the similarity of the items, thereby affecting their motivation to carefully read the items before providing the response (Dillman et al., 2014).

Participants included in this study were dental students rather than novice sport science undergraduate students. Although there are published data available for reinvestment amongst sports persons, there are no such data available for dental students. This suggests a need for a Dentistry-Specific Reinvestment Scale that relates specifically to the fine motor task context and attentional demands required in dentistry.

5.6 Future research

Future research is needed involving further validation data for the three reinvestment surveys in dental students using a larger sample size that fits with the minimum sample sizes required for confirmatory factor analysis. Furthermore, future studies may consider the unique nature of dental students and their perceptions of stress, and the complex and demanding working environment. This suggests the need to explore the possibility to develop and construct a new psychometric instrument (Dentistry-Specific Reinvestment Scale) devised to identify dental students who are more susceptible to movement breakdown and disrupted decision-making under multi-tasking and stressful conditions.
5.7 Conclusions

The overall survey scores for the three reinvestment surveys showed no significant differences in scores between the groups in both Study 1 and 2. Comparison of the overall survey scores from both studies with data from the previous published studies showed significantly higher scores for current study participants. Findings from the confirmatory factor analysis for the Reinvestment Scale, the Movement-Specific Reinvestment Scale, and the Decision-Specific Reinvestment Scale show that the data provided an acceptable fit to the three models.

The apparently low impact of reinvestment on performance of participants in this study may be explained by the small number of low and high participants in Study 1 and 2, and the variable level complexity in the instructions provided. Propensity to reinvest is suggested to be dependent on performance context and task attentional demands. The fine motor learning context in endodontics and the complexity of dental tasks are likely to be different to those encountered in sports or in surgery, which might explain the variable impact of reinvestment on performance. Factors such as timing and sources of procedural information to be provided during motor learning, and frequency of demonstrations, are likely to influence task complexity and attentional demands. Further investigation of these aspects of learning in dental students is needed, including testing different implicit learning paradigms and investigating the role that the reinvestment might play when learning endodontic skills.

The fine motor learning context in dentistry and the variable complexity of dental tasks are likely to be different to those encountered in sports or in surgery, which might have affected the dispositional to reinvestment. Further investigation of these aspects
including identifying susceptibility to movement breakdown and disrupted decision-making of dental students under multi-tasking and stressful conditions is needed. Future investigation is warranted about the role that the reinvestment might play when learning endodontic skills and further validation of data related to the three reinvestment surveys in dental students would be valuable using larger sample sizes.
6 General discussion

6.1 Introduction

This research project on fine motor skills in endodontics was chosen based on the candidate’s personal interest in the field of endodontics and his experience of teaching in pre-clinical and clinical endodontic courses that had highlighted various issues relevant to students’ learning of endodontics. Students have consistently reported facing difficulties and being confused about the different procedures and steps involved in learning root canal preparation techniques and procedures. This feedback from students raised questions about the availability of evidence and theoretical models on the development of psychomotor skills for performing the precise surgical procedures required in dentistry.

As mentioned previously (see Section 2.5.4.1), there is a growing body of evidence suggesting that motor learning using strategies consistent with implicit learning may result in improved performance that is maintained under multi-tasking and stressful conditions. Many implicit learning strategies have been reported (Kleynen et al., 2015). These include learning motor skills under secondary task conditions (e.g. golf putting: Masters, 1992); learning without errors (e.g. golf putting: Maxwell et al., 2001; Poolton et al., 2005; Lam et al., 2010b); learning with physical guidance (skiing: Wulf et al., 1998; e.g. suturing and knot tying: Masters et al., 2008b); learning by analogy (e.g. table tennis: Liao and Masters, 2001); or observational learning (e.g. suture and knot tying: Masters et al., 2008a). Two of these learning strategies were investigated in the current research project, specifically, errorless learning (Study 1) and observational learning (Study 2). The selection of these two strategies was based mainly on their relevance and frequent use in
dental education generally and in endodontics specifically. Both Study 1 and Study 2 involved root canal preparation tasks during both learning and testing phases.

Therefore, the aim of this research project was to compare the outcomes of learning using errorless and guided-observation methods (i.e. implicit) and using errorful, instructed-observation, and observation-only methods (i.e. explicit) on the acquisition of fine motor skills associated with root canal hand instrumentation (Studies 1 and 2). It also aimed to investigate the impact of a combination of sources of stress (time pressure and evaluation stressors) (Study 2) and assess the impact of reinvestment (Study 3) on the performance of pre-clinical dental students who had learnt using these different approaches. It was hypothesised that errorless and guided-observation learners would maintain their performance under multi-tasking and stressful conditions. In contrast, it was expected that errorful, instructed-observation, and observation-only learners would demonstrate a reduction in performance under multi-tasking or stressful conditions. It was hypothesised that the performance of high reinvesters would deteriorate when carrying out root canal hand instrumentation under multi-tasking or stressful conditions.

During learning, accuracy of preparation and completion times in all experimental groups (for both Study 1 and 2) were similar over the course of the different learning blocks. Overall, all experimental groups showed improvement during the learning trials and, based on their similar level of performance by the end of this phase, it is suggested that participants working under each condition were equally competent in performance and that they had learnt key endodontic canal preparation skills during the learning trials. This is supported by the similar levels of performance by the experimental and comparative groups in both Study 1 and 2. As mentioned previously, given differences in
complexity of the different blocks in Study 1 and 2, there were significant differences in
accuracy of canal preparation and completion times between the learning blocks within
each experimental group. Specifically, preparation of the wide/ curved canal was
associated with a relatively high number of participants making procedural errors. These
results indicated that participants’ performance may have shifted when instrumenting
the wide/ curved canal block to explicit conscious processes (i.e. hypothesis-testing).
However, subsequent performance of the errorless learning group was not affected by
this shift as they started training on the simplest wide/ straight canal block then
progressed to the wide/ curved block (see Section 3.4).

During the testing phase, performance of the errorless and errorful groups was
consistent with the hypothesis, with the errorless group maintaining their performance
when multi-tasking. Reducing the number of errors (errorless) during motor skill learning
is suggested to minimise the need for hypothesis testing to correct unsuccessful
attempts, thereby reducing involvement of working memory when performing motor
tasks and encouraging implicit motor learning (Kleynen et al., 2014). In contrast, the level
of accuracy between the three observational learning groups was similar, failing to
support the original hypothesis. This indicates that the methods adopted for learning by
observation with guidance were probably not consistent with implicit learning
approaches. In fact, the results suggest that all three observational groups learnt more
explicitly. Comparison of performance between the experimental and comparative
groups in Study 1 and 2, during the primary task and multi-tasking conditions, showed
comparable completion times. However, the level of preparation accuracy of the
observational and comparative groups in Study 2 was lower than that of the errorless,
errorful and comparative groups in Study 1. This conclusion is supported by the high
number of errors during the learning trials on plastic blocks and the apparently low level
of accuracy of performance during the transfer tests. The observational learning
strategies used in this study seem to have overloaded working memory with a high
volume and complexity of procedural knowledge presented in the video demonstrations.
This overload for novice participants may have increased their attentional demands
between the various components of the same task, leading to impairment of their
performance. Moreover, the lower levels of accuracy of performance of the experimental
and comparative groups in Study 2 might be related to cohort effects. These cohort
differences may be related to variations in the demonstrations of the endodontic
procedures provided by the part-time tutors who supervise the simulation sessions (see
Section 3.2.1, p 56).

In terms of the expected performance of low and high reinvesters, the results from
Study 3 did not support the hypothesis. The apparent limited impact of reinvestment on
performance of the participants may be explained by the small numbers of low and high
reinvesters in both studies, as well as the variable level of complexity of instructions
(Study 1) and demonstrations (Study 2) provided. As mentioned previously, the
propensity to reinvest and the impact of reinvestment have been suggested to be
associated with the performance context, task attentional demands (i.e. complexity of the
task), and whether the performer perceives the learning process to be either motivational
or demanding. The fine motor learning context in endodontics and the complexity of
dental tasks are likely to be different to those encountered in sports or in surgery, which
might explain the variable impact of reinvestment on performance.
Dental training is considered to be complex, demanding and stressful by undergraduate dental students (Divaris et al., 2008). Likewise, endodontic training is perceived to be difficult and stressful (Martins et al., 2012). Furthermore, dental students appear to experience higher levels of stress during their training compared to medical students (Birks et al., 2009). This stress is related to the demanding nature of their training, including managing the requirements and complexity of simulated laboratory activities during the early years of their program, and patient care and management during the later years of their degree. These stressors have been found to impact negatively on their performance, physiological health and quality of life (Elani et al., 2014). The demanding dental environment also means that multi-tasking is a standard feature of working during simulation and clinical activities. In both settings, dental students are required to learn a set of clinical technical skills, as well as to apply information relevant to patient care and respond to the dental assistant while working. Findings from Study 1 showed that learning endodontic skills under conditions that limit errors resulted in stable performance when multi-tasking.

Learning from errors (i.e. errorful learning or trial-and-error) is a common method of learning motor skills in dentistry (Hendricson, 2012). However, errors are not acceptable when treating live dental patients. Therefore, dental students need to demonstrate a certain level of competency during their learning in a simulated clinical environment prior to performing clinical work on patients. However, the learning of procedural knowledge related to simulated learning activities has been associated with high costs in terms of staffing and facilities (Tedesco, 1995; McNally et al., 2002; Glickman et al., 2005). In addition, the increasing complexity of modern dental procedures (e.g. manipulation of dental materials, instruments and equipment) requires ever-increasing
levels of accuracy in performance, leaving little room for errors. There are mixed opinions about the role of errors during motor skill learning (Lee et al., 2015). One view is that errors (i.e. errorful learning) can be beneficial to motor learning. This view is generated from the Schema theory (Schmidt, 1975) which suggests that errors contribute to refining and strengthening characteristics of the movement in a motor program (see Section 2.5.1). Furthermore, Schmidt (1975) described motor learning as a process of problem-solving and noted that feedback (i.e. knowledge of results) is required for novices in the early stages of learning to detect errors and facilitate error self-detection in subsequent stages of learning. However, the Schema theory is limited in explaining the theoretical role of augmented feedback, when retention and transfer tests are conducted (Schmidt and Lee, 2005c).

Another view considers errors to be detrimental to the motor learning process. This view is supported by the theory of Reinvestment (Masters et al., 1993; Masters and Maxwell, 2008). This theory suggests that the conscious attempts to control and monitor movements may result in disruption of the automated execution of a motor task, resulting in performance breakdown (see Section 2.5.4). However, Masters and colleagues argues that the reinvestment process does not take place if a motor skill has been learned implicitly (i.e. in absence of conscious processing) rather than explicitly, especially in the early stages of learning. Therefore, learning by limiting errors (i.e. errorless) is predicted to reduce the need to correct errors (involving conscious processing) through hypothesis testing.

A third view suggests that a mixture of errorful and errorless approaches to learning (i.e. a hybrid view) can help to optimise the motor learning process (Lee et al., 2015). Lee
et al. (2015) evaluated the role of errors in motor learning of a sequential keypress motor task and found that errorful learning (i.e. providing participants with more choices in pressing the keypad) can in some instances be beneficial to the learning process. For example, they proposed providing learners with moderate levels of choice (i.e. two to three out of a possible four). However, this study did not involve any demanding conditions (e.g. multi-tasking or stressful conditions) to test the retention of performance under these conditions. Moreover, it did not assess whether the learning that occurred was implicit or explicit. Results from the current study show that reducing errors in the early stages of learning a complex task resulted in sustained performance under multi-tasking conditions. It is proposed this resulted from participants having fewer chances for error correction through hypothesis testing, thereby reducing reliance on working memory resources to perform hand instrumentation tasks. This is the first time such a finding has been reported in dentistry.

The findings from Study 1 and Study 2 are in line with expert opinion in the field of sports and psychology in relation to implicit and explicit learning. For example, in a study using the Delphi technique to explore opinions by experts about implicit and explicit learning methods, it was suggested that learning via limiting errors (errorless) encourages more implicit learning in general. However, no consensus was reached regarding observational learning (Kleynen et al., 2014). Furthermore, there is no agreement among experts currently regarding the application of explicit and implicit motor skill learning (Kleynen et al., 2015). However, distinctions could be drawn by establishing whether a method can promote either implicit or explicit motor learning by addressing the type of knowledge acquired during the learning process, and the amount of attention and self-consciousness needed to learn (Kleynen et al., 2014). In designing motor learning tasks, it
is also important to consider influential factors, such as instructions, limitations in the environment, type and stage of motor task, and personal abilities (see Section 2.4). Implicit motor learning can be promoted by restricting the use of instructions and feedback, whereas explicit motor learning can be achieved by providing instructions and various types of feedback. When providing instructions during implicit learning, an external focus of attention should be considered. In addition, the design of practice activity should involve practising the entire motor skill, not segments of the whole task. For example, when practising root canal preparation tasks, instructions should be simplified and focus on the result of the motor task, for example, progressing the instrument inside the canal and reshaping the root canal walls (i.e. external focus of attention). Moreover, the practice session should involve all steps (blocked practice) of the crown down technique, including progressing the hand instruments inside the canal, using the balanced force technique and cleaning and washing of the root canal.

6.2 Study limitations

Study 1, 2, and 3 were limited in terms of the lack of a delayed retention test. A delayed retention test is an important tool to evaluate permanent changes in motor skill performance (learning effect) (Schmidt and Lee, 2005b; Sanli and Lee, 2014). However, as noted, this was not possible due to the limited time available for data collection and the timing of commencement and completion of the simulation endodontic course during the third-year of the Adelaide Bachelor of Dental Surgery program. Another limitation (in Study 2) that should be noted is that the stress manipulation used in this study was conducted in a controlled laboratory setting rather than in a real clinical situation.
Furthermore, the manipulations used to induce stress (i.e. a time constraint and presentation/evaluation condition) represent only two of the many contributory factors that can place pressure on a dental student in clinical situations.

The relatively small sample sizes in the experimental and comparative groups in both studies made it difficult to compare performances of low and high reinvesters. This compromised statistical power, specifically when forming sub-groups of low and high reinvesters. Therefore, caution is needed when interpreting findings related to performance of low and high reinvesters. It is important to indicate that power studies were conducted to examine the required sample sizes for the experimental and comparative groups. Unfortunately, there are presently no other studies that have used implicit and explicit learning approaches in dental education or endodontics that could be used for comparison.

Other limitations that should be considered are the nature of the motor task undertaken in Study 1 and 2, and the participants involved. As discussed previously, root canal hand instrumentation is a complex motor task that involves the development and integration of both cognitive and fine motor skills. In contrast, previous studies conducted in relation to implicit motor learning have focused mainly on sporting activities and basic surgical motor skills (Wulf et al., 1998; Maxwell et al., 2001; Poolton et al., 2005; Masters et al., 2008a; Masters et al., 2008c; Poolton et al., 2011). Furthermore, participants included in both studies were dental students rather than athletes or medical trainees. Although there are published data available for reinvestment amongst athletes, there are no such data available for dental students. As noted previously, the
development of a dentistry-specific reinvestment scale that reflects on fine motor task context and attentional demands related to dental students is indicated.

6.3 Implications for practice

ASE guidelines for undergraduate education in endodontology (Australian Society of Endodontology, 2007) recommend the use of simulated plastic blocks/teeth prior to the use of extracted natural teeth, particularly during the early stages of learning root canal preparation. When using extracted human teeth (even an anterior single-rooted tooth), variable external and internal anatomy, as well as the condition of the root, make the task of root canal preparation challenging and sometimes discouraging. The use of simulated root canals, on the other hand, permits standardisation of root canal hardness, length, width (diameter), location and degree of canal curvature. However, it is recognised that the high cost of these simulated plastic blocks/teeth may preclude their routine use in many dental schools. Furthermore, the ASE also recommends the use of visual demonstrations of simulated root canal procedures and techniques during learning.

Results from the current studies provide useful qualifications and extensions for these ASE recommendations. For example, additional recommendations should focus on designing activities that promote implicit (e.g. errorless) learning approaches, especially during the early stages of learning. Learning from simple to complex (step-by-step) might seem to be a logical choice for learning motor skills but selecting a simple enough task to begin with is not always easy. For example, in root canal preparation tasks, starting with an anterior tooth (single canal) and moving to a premolar or molar (multiple canals) might seem appropriate. However, design of the task should focus on standardising the
curvature and size of the selected root canal and minimising the anatomical variation in the root canal system. Based on results from the Study 1, it is recommended to start with a wide/straight canal, followed by narrow/straight, wide/curved, and then finish with a narrow/curved canal. Furthermore, these recommendations should emphasise the importance of providing simplified instructions/presentations related to the different components of a task to reduce the load on working memory (Poolton et al., 2011). These instructions should focus on the outcome of the movement rather than the movement itself (Wulf et al., 2010). It is also recommended to take advantage of the partially independent nature of the visual and auditory working memories by presenting simplified video demonstrations with basic audio instructions (cues) on the motor skill task. As mentioned, the amount, timing and frequency of the instructions play an important role in the learning process. These implicit activities are critical to improve learning, especially in the initial stages of learning a novel motor task.

6.4 Future research

Further evaluation of the robustness (whether the skill is retained) of errorless motor skill learning under pressured and stressful conditions to confirm the implicit nature of this approach are needed. Future studies could also address testing an alternate order of blocks that may align better with an errorless learning approach (i.e. wide/straight, narrow/straight, wide/curved, and narrow/curved canals). A range of observational models could also be tested, including different frequencies, timings and sources of procedural knowledge presentation (e.g. a mixture of audio and video instructions) to achieve implicit learning. Investigation of alternative implicit motor learning paradigms
(e.g. dual task learning, discovery learning and using analogy) is also recommended. Future research should also focus on conducting experiments to examine the effect of errorless and observational learning on delayed retention and transfer tests.

Further evaluation of the effect of stress on transfer of simulation skills to the clinical environment would also be desirable. Investigation of the effect of observational learning and alternative approaches to learning other fine motor tasks in dentistry, including access cavity preparation, crown preparation, cavity preparation in restorative dentistry, and other surgical procedures that involve fine motor skills, is also needed.
7 Conclusions

Accuracy of preparation and completion times of the experimental groups in both Study 1 and 2 were similar during learning, suggesting that the experimental groups were equally competent in their performance at that time. Furthermore, the experimental groups who had 1.5-2h of practice achieved levels of performance that were comparable to those displayed by students in the Adelaide BDS undergraduate endodontic programme who had 15-20h of practice.

When tested, accuracy of preparation in the errorless group was maintained when multi-tasking, whereas accuracy deteriorated significantly in the errorful group. However, accuracy of canal preparation did not differ significantly within each of the observation and comparative groups across primary task (transfer test 1), multi-tasking (transfer test 2), or pressured (transfer test 3) conditions, nor between the groups at each transfer test. This suggests that learning through physical guidance did not support an implicit approach to motor learning. Performance of skills learned via an errorless approach may place fewer demands on working memory than performance of skills learned via an errorful approach. However, performance of skills learnt via concurrent physical guidance and video monitoring may divide attention between visuospatial (visual feedback) and somatosensory receptors (tactile sensation), and thereby load the working memory and compromise the implicit learning effect.

The deterioration of performance in the errorful group might be explained by an overload on working memory resources, whereas the retention of performance of the instructed-observation group under multi-tasking and stressful conditions can be related
to the partially independent nature of the visual and auditory working memories, resulting in less load on working memory.

The present findings provide the first evidence that learning endodontic skills under conditions that limit errors results in more stable performance in terms of accuracy of preparation when multi-tasking. Furthermore, the observational learning strategies adopted for learning by observation with guidance were not consistent with implicit learning approaches. This conclusion is supported by the high number of errors during learning trials on plastic blocks and the apparent low level of accuracy of performance during transfer tests.

Completion times within each observational learning group decreased significantly when multi-tasking and under stressful conditions. It was also shown that high levels of stress were not associated with performance breakdown of root canal hand instrumentation skills. These results may relate to the development of an adaptive response to stress that enabled participants to improve their completion times and maintain their performance under multi-tasking and stressful conditions.

The stable performance of the comparative groups under multi-tasking (Study 1 and 2) and stressful (Study 2) conditions in terms of accuracy may be explained by a longer time spent practising hand instrumentation procedures as part of their conventional endodontic course. Specifically, this involved a deliberate practice effect (practice and time) and a longer simulated practice time (20 hours) compared with (1.5 hours) those for the experimental groups. The lower levels of accuracy of performance of the experimental and comparative groups in Study 2 compared with Study 1 might be related to cohort effects. These cohort differences may be related to variations in the
demonstrations of the endodontic procedures provided by the part-time tutors who supervise the simulation sessions.

The apparently low impact of reinvestment on performance of participants presented in Study 3 may be explained by the small number of low and high participants in the study and the variable level of complexity in the instructions provided. Propensity to reinvestment is suggested to be dependent on performance context and task attentional demands. The fine motor learning context in endodontics and the complexity of dental tasks are likely to be different to those encountered in sports or in surgery, which might explain the variable impact of reinvestment on performance. Factors such as timing and sources of procedural information to be provided during motor learning, and frequency of demonstrations, are likely to influence task complexity and attentional demands. Further investigation of these aspects of learning in dental students is needed, including testing different implicit learning paradigms and investigating the role that the reinvestment might play when learning endodontic skills. These studies should inform design of learning activities to achieve better outcomes, especially during multi-tasking and under stressful environments.
8 References


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9 Appendices

9.1 List of achievements and professional development activities of Mohamed El-Kishawi during PhD candidature 2012-2015

Research grants


M. El-Kishawi, G. Townsend, P. Cathro, R. Masters, T. Winning (2014) Australian Dental Research Foundation (ADRF) grant. Improving students’ learning and performance in pre-clinical endodontics ($4,500)

M. El-Kishawi, G. Townsend, P. Cathro, R. Masters, T. Winning (2014) International Association of Dental Research (IADR), Education Research Group (ERG) grant. Improving students’ learning and performance in pre-clinical endodontics ($US 1,000)

Published abstracts for conference presentations during candidature


M. El-Kishawi, G. Townsend, P. Cathro, R. Masters, T. Winning. Learning motor skills in dentistry: comparing different approaches. Abstract submitted, poster and oral presentation at the 55th Annual Scientific Meeting of the IADR Australia & New Zealand Division, Dunedin, New Zealand, 24-26 August 2015.


M. El-Kishawi, G. Townsend, P. Cathro, R. Masters, T. Winning. Effect of implicit learning on the acquisition of fine motor skills in pre-clinical endodontics. Abstract submitted and oral presentation performed at the Australian & New Zealand Association for Health Professional Educators Conference 2014, Griffith University, Gold Coast, Queensland, Australia, July 2014.


**Other professional development activities**

Visited Faculty of Education, University of Waikato, New Zealand (26-27th August 2015), and gave a presentation on PhD research project and had discussions about results.
9.2 Steps for root canal instrumentation using hand instruments

Steps of Root Canal Instrumentation using Hand-files

**Stage 1** (Crown-down)
Coronal Preparation

**Stage 2**
Apical Gauge
Middle Preparation

**Stage 3** (Step-back)

Objectives of instrumentation (Mechanical):
- Preparation to a sound apical stop at 0.5 mm short of the apical foramen.
- Preparing canal to taper apically, with the narrowest cross-section diameter at apex.
- Develop continuously tapered funnel-shaped preparation with maintenance of this canal curvature.
- Confine cleaning/shaping procedures to root canal system.
- Removal of all residual debris in root canal system.

RP = Reference Point (indicated by a rubber stopper)
GG = Gates-Glidden Bur
WL = Working Length (0.5-1 mm short of radiographic apex)
MAF = Master Apical File (2-3 sizes larger than the 1st file which binds apically AFTER crown down preparation)

The balanced force movement of files (Roane et al., 1995)
- A straight file is placed into the root canal until it binds against the wall.
- The file is then rotated clockwise through 60-90° so that it binds, threads within the dentine and advances apically.
- The file is moved anterograde through 120-130° with apical pressure, crushing and breaking off the dentine threads and enlarging the root canal.
- A final clockwise rotation without apical advancement allows flutes to be loaded with debris and removed from the canal.
9.3 Ethical approval notice for Study 1

23 August 2012

Associate Professor T Winning
School of Dentistry

Dear Associate Professor Winning

PROJECT NO: H-2012-117

Improving students' learning and performance in pre-clinical endodontics

I write to advise you that on behalf of the Human Research Ethics Committee I have approved the above project. Please refer to the enclosed endorsement sheet for further details and conditions that may be applicable to this approval. Ethics approval is granted for a period of three years subject to satisfactory annual progress reporting. Ethics approval may be extended subject to submission of a satisfactory ethics renewal report prior to expiry.

The ethics expiry date for this project is: 31 August 2015

Where possible, participants taking part in the study should be given a copy of the Information Sheet and the signed Consent Form to retain.

Please note that any changes to the project which might affect its continued ethical acceptability will invalidate the project's approval. In such cases an amended protocol must be submitted to the Committee for further approval. It is a condition of approval that you immediately report anything which might warrant review of ethical approval including (a) serious or unexpected adverse effects on participants (b) proposed changes in the protocol; and (c) unforeseen events that might affect continued ethical acceptability of the project. It is also a condition of approval that you inform the Committee, giving reasons, if the project is discontinued before the expected date of completion.

A reporting form for the annual progress report, project completion and ethics renewal report is available from the website at http://www.adelaide.edu.au/ethics/human/guidelines/reporting/

Yours sincerely,

Dr John Semmler
Acting Convenor
Human Research Ethics Committee
Applicant: Associate Professor T Winning

School: School of Dentistry

Project Title: Improving students’ learning and performance in pre-clinical endodontics

THE UNIVERSITY OF ADELAIDE HUMAN RESEARCH ETHICS COMMITTEE

Project No: H-2012-117

RM No: 0000013963

APPROVED for the period until: 31 August 2015

It is noted that this study will be conducted by Dr Mohamed El-Kishawi, Masters student.

Refer also to the accompanying letter setting out requirements applying to approval.

Dr John Semmler
Acting Convenor
Human Research Ethics Committee

Date: 22 AUG 2012
9.4 Pilot test (Study 1)

9.4.1 Study 1 pilot blocks and teeth

http://www.nissin-dental.net/products/DentalTrainingProducts/Parts/S1/index.html

![S1 Series blocks](image1)

- Maxillary Central Incisor / S1-U1
- Mandibular First Molar / S1-L6

http://www.nissin-dental.net/products/DentalTrainingProducts/Parts/S8/index.html

![Curvature straight](image2)

- S8-BS2-Unstained
- S8-BC2-Unstained


![S4 Series](image3)

- 10° curvature / S4-U1-10°
- 20° curvature / S4-U1-20°
- 30° curvature / S4-U1-30°
https://www.dentsply.co.uk/Products/Endodontics/Accessories/Training-Blocks.aspx

ENDO TRAINING BLOCKS  Ref: A017700000200
0.15 - 0.35 taper .02
Contains 8 units

http://www.nissin-dental.net/products/DentalTrainingProducts/Parts/B22X_Series/index.html

Anatomical Pulp Cavity & Root Model [B22X Series] Lower 6
### 9.4.2 Study 1: pilot test results for order of learning blocks according to difficulty

<table>
<thead>
<tr>
<th>Blocks</th>
<th>Participant1</th>
<th>Participant2</th>
<th>Participant3</th>
<th>Participant4</th>
<th>Participant5</th>
<th>Participant6</th>
<th>Participant7</th>
<th>Participant8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Time:2.28</td>
<td>Time:1.00</td>
<td>Time:1.31</td>
<td>Time:1.32</td>
<td>Time:3.11</td>
<td>Time:0.37</td>
<td>Time:2.43</td>
<td>Time:1.21</td>
</tr>
<tr>
<td></td>
<td>Order: B Rank:3</td>
<td>Order: A Rank:3</td>
<td>Order: H Rank:4</td>
<td>Order: G Rank:1</td>
<td>Order: F Rank:1</td>
<td>Order: E Rank:3</td>
<td>Order: D Rank:1</td>
<td>Order: C Rank:1</td>
</tr>
<tr>
<td>2</td>
<td>Time:3.2</td>
<td>Time:2.12</td>
<td>Time:5.06</td>
<td>Time:0.48</td>
<td>Time:1.29</td>
<td>Time:1.20</td>
<td>Time:1.13</td>
<td>Time:1.13</td>
</tr>
<tr>
<td></td>
<td>Order: C Rank:1</td>
<td>Order: B Rank:2</td>
<td>Order: A Rank:2</td>
<td>Order: H Rank:3</td>
<td>Order: G Rank:3</td>
<td>Order: F Rank:5</td>
<td>Order: E Rank:4</td>
<td>Order: D Rank:3</td>
</tr>
<tr>
<td>3</td>
<td>Time:3.3</td>
<td>Time:7.43</td>
<td>Time:3.13</td>
<td>Time:4.37</td>
<td>Time:2.45</td>
<td>Time:1.29</td>
<td>Time:1.43</td>
<td>Time:2.43</td>
</tr>
<tr>
<td></td>
<td>Bent #1</td>
<td>1mm short</td>
<td>2mm short</td>
<td>1mm short</td>
<td>1mm short</td>
<td>1mm short</td>
<td>1mm short</td>
<td>1mm short</td>
</tr>
<tr>
<td></td>
<td>Time:3.30</td>
<td>Time:5.49</td>
<td>Time:8.00</td>
<td>Time:5.30</td>
<td>Time:9.30</td>
<td>Time:1.41</td>
<td>Time:1.26</td>
<td>Time:1.48</td>
</tr>
<tr>
<td></td>
<td>1mm short</td>
<td>2mm short</td>
<td>2mm short</td>
<td>3mm short</td>
<td>2mm short</td>
<td>2mm short</td>
<td>2mm short</td>
<td>2mm short</td>
</tr>
<tr>
<td></td>
<td>Blocked</td>
<td>Blocked</td>
<td>Blocked</td>
<td>Blocked</td>
<td>Blocked</td>
<td>Blocked</td>
<td>Blocked</td>
<td>Blocked</td>
</tr>
<tr>
<td></td>
<td>#2 &amp; #3 broken</td>
<td>#2 &amp; #3 broken</td>
<td>#2 &amp; #3 broken</td>
<td>#2 &amp; #3 broken</td>
<td>#2 &amp; #3 broken</td>
<td>#2 &amp; #3 broken</td>
<td>#2 &amp; #3 broken</td>
<td>#2 &amp; #3 broken</td>
</tr>
</tbody>
</table>

W=Wide, N=Narrow, L6=Lower first molar mesial canals
9.4.3 Study 1: pilot test completion times results for learning blocks

<table>
<thead>
<tr>
<th>Block type</th>
<th>Completion time (min) (mean ± SD)</th>
<th>Order according to difficulty</th>
</tr>
</thead>
<tbody>
<tr>
<td>W0</td>
<td>1.48 ± 0.96</td>
<td>1</td>
</tr>
<tr>
<td>W10</td>
<td>2.10 ± 1.47</td>
<td>2</td>
</tr>
<tr>
<td>W20</td>
<td>3.23 ± 1.84</td>
<td>3</td>
</tr>
<tr>
<td>WL6</td>
<td>3.87 ± 2.19</td>
<td>6</td>
</tr>
<tr>
<td>N0</td>
<td>5.42 ± 3.59</td>
<td>5</td>
</tr>
<tr>
<td>N20</td>
<td>3.83 ± 3.04</td>
<td>4</td>
</tr>
<tr>
<td>N30</td>
<td>8.34 ± 3.59</td>
<td>8</td>
</tr>
<tr>
<td>N40</td>
<td>5.02 ± 1.22</td>
<td>7</td>
</tr>
</tbody>
</table>

W0°=wide straight canal block, W10°=wide 10° curved canal, W20°=wide 20° curved canal, WL6= lower molar wide mesial curved canals, N0°=narrow straight canal, and N20°=narrow 20° curved canal, N30°= narrow 30° curved canal, N40°= narrow 40° curved canal.

9.4.4 Study 1: pilot for number of trials to show improvement

Improvement test (block W20°)

<table>
<thead>
<tr>
<th>Trial</th>
<th>Completion time (min) (mean ± SD)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.14 ± 4.38</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>5.44 ± 1.92</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>4.56 ± 3.05</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>4.75 ± 1.79</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>4.58 ± 1.27</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>3.65 ± 2.11</td>
<td>6</td>
</tr>
</tbody>
</table>

Blocked canals were excluded

Improvement test (block N20°)

<table>
<thead>
<tr>
<th>Trial</th>
<th>Completion time (min) (mean ± SD)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.28 ± 2.85</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>5.40 ± 2.24</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>6.82 ± 1.53</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5.25 ± 1.18</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>3.59 ± 0.85</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>3.71 ± 2.92</td>
<td>5</td>
</tr>
</tbody>
</table>

Blocked canals were excluded
Improvement test
(Block W20)

Improvement test
(Block N20)

Completion time (min)

Trials

Mean

Completion time (min)

Trials

Mean
9.5 Run sheets Study 1 and 2

9.5.1 Learning phase

<table>
<thead>
<tr>
<th>Block</th>
<th>Trial 1</th>
<th>Comments</th>
<th>Trial 2</th>
<th>Comments</th>
<th>Trial 3</th>
<th>Comments</th>
<th>Trial 4</th>
<th>Comments</th>
</tr>
</thead>
</table>

Check list:
- Keep the block on the tray all the time
- Try to use the technique as was demonstrated in the video
- You should not have any soreness in your fingers (prevent)
- Push the syringe needle all the way down
- Do not use purple instrument and wash after you are done
- After reaching instrument 3 and you think you need to go back to a previous instrument, you can.
- Rubber stopper is fixed with glue; let me know if it is loose
- If you need rest at any point, just let me know.
## 9.5.2 Transfer test

### Transfer tests on tooth #36

<table>
<thead>
<tr>
<th>Canal</th>
<th>Test</th>
<th>CB Tooth Location</th>
<th>Completion Time</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Transfer 1</td>
<td>A ☐ B ☐ NiTi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1st use</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Transfer 2</td>
<td>A ☐ B ☐ NiTi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2nd use</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Transfer 3</td>
<td>A ☐ B ☐ NiTi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3rd use</td>
<td></td>
</tr>
</tbody>
</table>

D=Distal canal, NiTi=Nickel Titanium file, A=Mesially positioned tooth, B=Distally positioned tooth

---

**Date/Time:**

Was radiograph useful? How?

**Name:**

**Height:** | **Weight:**

Loupes: Y, N, since: Freq: Mag:

**Age:**

**Gender:** M F

**Hand:** Right Left

**Sight:** Normal Corrected: Glasses, Contacts Not corrected

**Other fine motor skills experience:**

Skills:

Sports:

Video games:

**Participant's Comments:**

Any difference with audio, timer, evaluation? Did it affect your work?
Can you rank them from most stressful?

---

Any finger soreness? When? Did it affect your work?
### Audio response recording sheet

<table>
<thead>
<tr>
<th>Time</th>
<th>Suction</th>
<th>Correct response</th>
<th>Participant Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Minute</td>
<td>1</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>suction</td>
<td></td>
</tr>
<tr>
<td>2 Minute</td>
<td>4</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>open</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td>3 Minute</td>
<td>7</td>
<td>open</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>suction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>suction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>suction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>open</td>
<td></td>
</tr>
<tr>
<td>4 Minute</td>
<td>15</td>
<td>mirror</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>irrigation</td>
<td></td>
</tr>
<tr>
<td>5 Minute</td>
<td>17</td>
<td>open</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td>6 Minute</td>
<td>19</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>mirror</td>
<td></td>
</tr>
<tr>
<td>7 Minute</td>
<td>22</td>
<td>mirror</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>suction</td>
<td></td>
</tr>
<tr>
<td>8 Minute</td>
<td>25</td>
<td>open</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>wider</td>
<td></td>
</tr>
<tr>
<td>9 Minute</td>
<td>27</td>
<td>mirror</td>
<td></td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>wider</td>
<td></td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td>10 Minute</td>
<td>30</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>open</td>
<td></td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>wider</td>
<td></td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>suction</td>
<td></td>
</tr>
<tr>
<td>11 Minute</td>
<td>37</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>irrigation</td>
<td></td>
</tr>
<tr>
<td>12 Minute</td>
<td>39</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>mirror</td>
<td></td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>irrigation</td>
<td></td>
</tr>
</tbody>
</table>

Can you remember any of the words that you called out when you heard the word suction?

How many times was suction mentioned?
9.6 Ethical approval notice for Study 2

17 December 2013

Associate Professor T Winning
School of Dentistry

Dear Associate Professor Winning

PROJECT NO: H-2012-117
Improving students’ learning and performance in pre-clinical endodontics

Thank you for the ethics application dated 3.12.13 requesting an additional study to the above project. I write to advise you that on behalf of the Human Research Ethics Committee I have approved the request to conduct the second stage of the above project as detailed in the submitted documents.

The ethical endorsement for the project applies for the period until: 31 August 2015

Participants taking part in the study should be given a copy of the Information Sheet and the signed Consent Form to retain.

Please note that any changes to the project which might affect its continued ethical acceptability will invalidate the project’s approval. In such cases an amended protocol must be submitted to the Committee for further approval. It is a condition of approval that you immediately report anything which might warrant review of ethical approval including (a) serious or unexpected adverse effects on participants (b) proposed changes in the protocol; and (c) unforeseen events that might affect continued ethical acceptability of the project. It is also a condition of approval that you inform the Committee, giving reasons, if the project is discontinued before the expected date of completion.

A reporting form is available from the Committee’s website. This may be used to renew ethical approval or report on project status including completion.

Yours sincerely

Dr John Semmler
Convenor
Human Research Ethics Committee
9.7 Study 2 video link:

https://youtu.be/-wsYJHTmt80

9.8 Study 2 video script:

Verbal audio instructions provided in the instructed-observation group video:

Section 1 of the video: basic technique for using hand instrument (times in minutes on left correspond to each step)

00:00- step 1: Pick up the instrument by the plastic handle, and insert it into the channel, when you feel resistance use gentle pressure to engage the sides of the channel and turn it a ¼ turn to the right.

00:07- Step 2: While maintaining pressure on the instrument make a ¾ turn to the left.

00:14- Step 3: Then without using any pressure turn the instrument a ¼ turn to the right.

00:17- Step 4: Finally, disengage the instrument from the channel and remove it.

Repeat these 4 steps so you can see the rubber stopper is about 1mm closer to the upper surface of the block. This means you might repeat these steps 3-4 times.

Section 2 of the video: basic technique (step by step) with diagrams

00:48- step 1: Hold the instrument from the plastic end, and insert the instrument in the channel with gentle pressure and when you feel resistance turn the instrument ¼ (CW) turn to the right (as illustrated in the diagram) and engage the sides of channel.

01:00- Step 2: While maintaining pressure on the instrument, make a ¾ (CCW) turn to the left as illustrated in the diagram.
01:11- Step 3: Then release the pressure and turn the instrument a ¼ (CW) turn to the right as illustrated in the diagram.

01:20- Step 4: Finally, disengage the instrument and remove it from the channel as illustrated in the diagram.

01:28- between each of your instruments clean the channel by inserting the small purple handled instrument and move it in and out frequently. Make sure that the instrument goes all the way down until the rubber stopper touches the top of the block as illustrated in the diagram.

01:40- then wash out the channel using the syringe by inserting the needle into the channel as far as possible and use copious amount of water as illustrated in the diagram.

Section 3 of the video: full procedure

02:00- Pick up hand instrument number 1 from the plastic end and place it in the channel. Then perform the steps as instructed in the previous section of the video. Repeat these steps 3-4 times with each instrument until you notice a progress of the instrument about 1mm in the channel (ie. the rubber stopper is about 1mm closer to the upper surface of the block).

02:51- Pick up the small (purple) instrument and clean the channel as instructed.

03:08- Use the water syringe to wash the channel as instructed.

03:30- Pick up hand instrument number 2 and place it in the channel. Then perform the steps as instructed in the previous section of the video. Repeat the steps 3-4 times until you notice a progress of about 1mm in the channel.
04:24- Pick up the small (purple) instrument and clean the channel as instructed.

04:41- Use the water syringe to wash the channel as instructed.

04:53- Pick up hand instrument number 3 and place it in the channel. Then perform the steps as instructed in the previous section of the video. Repeat the steps 3-4 times until you notice that the instrument’s rubber stopper touches the top surface of the block, and it feels free in the channel.

05:55- Pick up the small (purple) instrument and clean the channel as instructed.

06:05- Use the water syringe to wash the channel as instructed.

Repeat these 4 steps for each instrument from 1-3 and on the last instrument the rubber stopper should level with top of block.
## 9.9 Stress scales

### 9.9.1 State-Trait Anxiety Inventory (STAI)

Name ___________________________________ Date __________ Age __________

**Directions:**
A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel right now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Some-what</th>
<th>Moderately so</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>I feel calm</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I feel tense</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I feel upset</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I am relaxed</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I am content</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I am worried</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
9.9.2 Perceived Stress Scale (PSS)

Name ___________________________________ Date __________ Age __________

Directions:
The questions in this scale ask you about your feelings and thoughts during THE LAST MONTH. In each case, please indicate your response by placing an “X” over the circle representing HOW OFTEN you felt or thought a certain way.

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>Almost Never</th>
<th>Sometimes</th>
<th>Fairly Often</th>
<th>Very Often</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. In the last month, how often have you been upset because of something that happened unexpectedly?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2. In the last month, how often have you felt that you were unable to control the important things in your life?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3. In the last month, how often have you felt nervous and “stressed”?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4. In the last month, how often have you felt confident about your ability to handle your personal problems?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5. In the last month, how often have you felt that things were going your way?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>6. In the last month, how often have you found that you could not cope with all the things that you had to do?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>7. In the last month, how often have you been able to control irritations in your life?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>8. In the last month, how often have you felt that you were on top of things?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>9. In the last month, how often have you been angered because of things that were outside your control?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>10. In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
9.10 Sample of Heart Rate data during learning and testing phases
9.11 Reinvestment surveys:

9.11.1 The Reinvestment Scale
© Masters, Polman & Hammond (1993)

Name _______________________ Date __________ Age ___________

Directions: A number of statements which people have used to describe themselves are listed below. Read each statement and then circle the appropriate answer to indicate whether this statement generally describes you. There are no right or wrong answers. Do not spend too much time on any one statement, but give the answer which seems best to describe you.

1. I remember things that upset me or make me angry for a long time afterwards.
   - Yes
   - No

2. I get “worked up” just thinking about things that have upset me in the past.
   - Yes
   - No

3. I often find myself thinking over and over about things that have made me angry.
   - Yes
   - No

4. I think about ways of getting back at people who have made me angry long after the event has happened.
   - Yes
   - No

5. I never forget people making me angry or upset, even about small things.
   - Yes
   - No

6. When I am reminded of my past failures, I feel as if they are happening all over again
   - Yes
   - No

7. I worry less about the future than most people I know.
   - Yes
   - No

8. I’m always trying to figure myself out.
   - Yes
   - No

9. I reflect about myself a lot.
   - Yes
   - No
10. I’m constantly examining my motives.
   - Yes
   - No

11. I sometimes have the feeling that I’m off somewhere watching myself.
   - Yes
   - No

12. I’m alert to changes in my mood.
   - Yes
   - No

13. I’m aware of the way my mind works when I work through a problem.
   - Yes
   - No

   - Yes
   - No

15. I’m concerned about the way I present myself.
   - Yes
   - No

16. I’m self-conscious about the way I look.
   - Yes
   - No

17. I usually worry about making a good impression.
   - Yes
   - No

18. One of the last things I do before leaving my house is look in the mirror.
   - Yes
   - No

19. I’m concerned about what other people think of me.
   - Yes
   - No

20. Do you have trouble making up your mind?
   - Yes
   - No
9.11.2 Movement-Specific Reinvestment Scale  
© Masters, Eves & Maxwell (2005)

Name __________________________ Date _______________ Age ______ Hand  ○ Left  ○ Right

Directions: Below are a number of statements about your movements. The possible answers go from 'strongly disagree' to 'strongly agree'. There are no right and wrong answers so circle the answer that best describes how you feel for each question.

1. I rarely forget the times when my movements have failed me
   ○ Strongly disagree
   ○ Moderately disagree
   ○ Weakly disagree
   ○ Weakly agree
   ○ Moderately agree
   ○ Strongly agree

2. I am always trying to figure out why my actions failed
   ○ Strongly disagree
   ○ Moderately disagree
   ○ Weakly disagree
   ○ Weakly agree
   ○ Moderately agree
   ○ Strongly agree

3. I reflect about my movement a lot
   ○ Strongly disagree
   ○ Moderately disagree
   ○ Weakly disagree
   ○ Weakly agree
   ○ Moderately agree
   ○ Strongly agree

4. I am always trying to think about my movements when I carry them out
   ○ Strongly disagree
   ○ Moderately disagree
   ○ Weakly disagree
   ○ Weakly agree
   ○ Moderately agree
   ○ Strongly agree

5. I am self conscious about the way I look when I am moving
   ○ Strongly disagree
   ○ Moderately disagree
   ○ Weakly disagree
   ○ Weakly agree
   ○ Moderately agree
   ○ Strongly agree
6. I sometimes have the feeling that I am watching myself move
   ○ Strongly disagree
   ○ Moderately disagree
   ○ Weakly disagree
   ○ Weakly agree
   ○ Moderately agree
   ○ Strongly agree

7. I am aware of the way my body works when I am carrying out a movement
   ○ Strongly disagree
   ○ Moderately disagree
   ○ Weakly disagree
   ○ Weakly agree
   ○ Moderately agree
   ○ Strongly agree

8. I am concerned about my style of moving
   ○ Strongly disagree
   ○ Moderately disagree
   ○ Weakly disagree
   ○ Weakly agree
   ○ Moderately agree
   ○ Strongly agree

9. If I see my reflection in a shop window, I will examine my movements
   ○ Strongly disagree
   ○ Moderately disagree
   ○ Weakly disagree
   ○ Weakly agree
   ○ Moderately agree
   ○ Strongly agree

10. I am concerned about what people think about me when I am moving
    ○ Strongly disagree
    ○ Moderately disagree
    ○ Weakly disagree
    ○ Weakly agree
    ○ Moderately agree
    ○ Strongly agree
9.11.3 Decision-Specific Reinvestment Scale
© KINRADE, JACKSON, ASHFORD, & BISHOP (2010)

Name ___________________________ Date __________ Age _______ Hand Left ○ Right ○

**Directions:** Below are a number of statements about your decision making. The possible answers go from ‘extremely uncharacteristic’ to ‘extremely characteristic’. There are no right or wrong answers so circle the answer that best describes how you feel for each question.

1. I’m always trying to figure out how I make decisions.
   - 0 1 2 3 4
   - extremely uncharacteristic          extremely characteristic

2. I’m concerned about my style of decision-making.
   - 0 1 2 3 4
   - extremely uncharacteristic          extremely characteristic

3. I remember poor decisions I make for a long time afterwards.
   - 0 1 2 3 4
   - extremely uncharacteristic          extremely characteristic

4. I’m constantly examining the reasons for my decisions.
   - 0 1 2 3 4
   - extremely uncharacteristic          extremely characteristic

5. I get “worked up” just thinking about poor decisions I have made in the past.
   - 0 1 2 3 4
   - extremely uncharacteristic          extremely characteristic

6. I sometimes have the feeling that I’m observing my decision making process.
   - 0 1 2 3 4
   - extremely uncharacteristic          extremely characteristic

7. I often find myself thinking over and over about poor decisions that I have made in the past.
   - 0 1 2 3 4
   - extremely uncharacteristic          extremely characteristic
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

8. I think about better decisions I could have made long after the event has happened.

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

9. I am alert to changes in how much thought I give to my decisions.

<p>| | | | | |</p>
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<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

10. I’m aware of the way my mind works when I make a decision.

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

11. I rarely forget the times when I have made a bad decision, even about the minor things.

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

12. When I am reminded about poor decisions I have made in the past, I feel as if they are happening all over again.

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

13. I’m concerned about what other people think of the decisions I make.

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
9.12 Confirmatory Factor Analysis (CFA) data

Table 9.1. Model fit indices used, their cut-off values, and description

<table>
<thead>
<tr>
<th>Model fit index</th>
<th>Cut-off Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIC</td>
<td>----</td>
<td>lowest is optimal</td>
<td>Akaike (1987)</td>
</tr>
<tr>
<td>Chi-squared test</td>
<td>&gt; 0.05*</td>
<td>good fit</td>
<td>Bentler and Bonett (1980)</td>
</tr>
<tr>
<td>GFI &amp; CFI</td>
<td>&gt; 0.95</td>
<td>good fit</td>
<td>Bentler and Bonett (1980)</td>
</tr>
<tr>
<td></td>
<td>≥ 0.90</td>
<td>acceptable fit</td>
<td>Bentler (1990)</td>
</tr>
<tr>
<td></td>
<td>&lt; 0.90</td>
<td>poor fit</td>
<td></td>
</tr>
<tr>
<td>SRMR</td>
<td>≤ 0.08</td>
<td>good fit</td>
<td>Hooper et al. (2008)</td>
</tr>
<tr>
<td>RMSEA</td>
<td>&lt; 0.05</td>
<td>good fit</td>
<td>Browne and Cudeck (1992)</td>
</tr>
<tr>
<td></td>
<td>0.05-0.08</td>
<td>acceptable fit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.08-0.1</td>
<td>marginal fit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 0.1</td>
<td>poor fit</td>
<td></td>
</tr>
</tbody>
</table>

AIC= Akaike Information Criterion, GFI= Goodness-of-Fit Index, CFI= Comparative Fit Index, SRMR= Standardised Root Mean-squared Residual, RMSEA= Root Mean Square Error of Approximation

* P value

Table 9.2. Items and loadings for the Confirmatory Factor Analysis (CFA) of the Reinvestment Scale (RS)

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RH</td>
</tr>
<tr>
<td>1) I remember things that upset me or make me angry for a long time afterwards.</td>
<td>0.28</td>
</tr>
<tr>
<td>2) I get “worked up” just thinking about things that have upset me in the past.</td>
<td>0.36</td>
</tr>
<tr>
<td>3) I often find myself thinking over and over about things that have made me angry.</td>
<td>0.32</td>
</tr>
<tr>
<td>4) I think about ways of getting back at people who have made me angry long after the event has happened.</td>
<td>0.20</td>
</tr>
<tr>
<td>5) I never forget people making me angry or upset, even about small things.</td>
<td>0.16</td>
</tr>
<tr>
<td>6) When I am reminded of my past failures, I feel as if they are happening all over again.</td>
<td>0.28</td>
</tr>
<tr>
<td>7) I worry less about the future than most people I know.</td>
<td>0.08</td>
</tr>
<tr>
<td>8) I’m always trying to figure myself out.</td>
<td>0.30</td>
</tr>
<tr>
<td>9) I reflect about myself a lot.</td>
<td>0.25</td>
</tr>
<tr>
<td>10) I’m constantly examining my motives.</td>
<td>0.30</td>
</tr>
<tr>
<td>11) I sometimes have the feeling that I’m off somewhere watching myself.</td>
<td>0.11</td>
</tr>
<tr>
<td>12) I’m alert to changes in my mood.</td>
<td>0.01</td>
</tr>
<tr>
<td>13) I’m aware of the way my mind works when I work through a problem.</td>
<td>0.05</td>
</tr>
<tr>
<td>14) I’m concerned about my style of doing things.</td>
<td>0.15</td>
</tr>
<tr>
<td>15) I’m concerned about the way I present myself.</td>
<td>0.18</td>
</tr>
<tr>
<td>16) I’m self-conscious about the way I look.</td>
<td>0.28</td>
</tr>
</tbody>
</table>
17) I usually worry about making a good impression.  
18) One of the last things I do before leaving my house is look in the mirror.  
19) I'm concerned about what other people think of me.  
20) Do you have trouble making up your mind?  

RH = Rehearsal, PrSC = Private Self-Consciousness, PuSC = Public Self-Consciousness, and CF = Cognitive Failure

Table 9.3. Items and loadings for the Confirmatory Factor Analysis (CFA) of the Movement-Specific Reinvestment Scale (MSRS)

<table>
<thead>
<tr>
<th>Item</th>
<th>MSC</th>
<th>CMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I rarely forget the times when my movements have failed me</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>2) I am always trying to figure out why my actions failed</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>3) I reflect about my movement a lot</td>
<td>1.08</td>
<td></td>
</tr>
<tr>
<td>4) I am always trying to think about my movements when I carry them out</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>5) I am self conscious about the way I look when I am moving</td>
<td>0.84</td>
<td></td>
</tr>
<tr>
<td>6) I sometimes have the feeling that I am watching myself move</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>7) I am aware of the way my body works when I am carrying out a movement</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>8) I am concerned about my style of moving</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>9) If I see my reflection in a shop window, I will examine my movements</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>10) I am concerned about what people think about me when I am moving</td>
<td>1.03</td>
<td></td>
</tr>
</tbody>
</table>

MSC = Movement Self-Consciousness, and CMP = Conscious Motor Processing

Table 9.4. Items and loadings for the Confirmatory Factor Analysis (CFA) of the Decision-Specific Reinvestment Scale (DSRS)

<table>
<thead>
<tr>
<th>Item</th>
<th>DRe</th>
<th>DRu</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I'm always trying to figure out how I make decisions.</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>2) I'm concerned about my style of decision-making.</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>3) I remember poor decisions I make for a long time afterwards.</td>
<td></td>
<td>0.73</td>
</tr>
<tr>
<td>4) I'm constantly examining the reasons for my decisions.</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>5) I get “worked up” just thinking about poor decisions I have made in the past</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>6) I sometimes have the feeling that I’m observing my decision making process</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>7) I often find myself thinking over and over about poor decisions that I have made in the past</td>
<td></td>
<td>0.98</td>
</tr>
<tr>
<td>8) I think about better decisions I could have made long after the event has happened</td>
<td></td>
<td>0.69</td>
</tr>
<tr>
<td>9) I am alert to changes in how much thought I give to my decisions.</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>10) I’m aware of the way my mind works when I make a decision.</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>11) I rarely forget the times when I have made a bad decision, even about the minor things</td>
<td></td>
<td>0.87</td>
</tr>
<tr>
<td>12) When I am reminded about poor decisions I have made in the past, I feel as if they are happening all over again</td>
<td></td>
<td>0.77</td>
</tr>
<tr>
<td>13) I’m concerned about what other people think of the decisions I make</td>
<td></td>
<td>0.41</td>
</tr>
</tbody>
</table>

DRe = Decision Reinvestment, and DRu = Decision Rumination
9.13 Exploratory Factor Analysis (EFA) data

Table 9.5. Items and loadings for the Exploratory Factor Analysis (EFA) of the Reinvestment Scale (RS)

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I remember things that upset me or make me angry for a long time afterwards.</td>
<td>0.28</td>
</tr>
<tr>
<td>2) I get “worked up” just thinking about things that have upset me in the past.</td>
<td>0.36</td>
</tr>
<tr>
<td>3) I often find myself thinking over and over about things that have made me angry.</td>
<td>0.32</td>
</tr>
<tr>
<td>4) I think about ways of getting back at people who have made me angry long after the event has happened.</td>
<td>0.19</td>
</tr>
<tr>
<td>5) I never forget people making me angry or upset, even about small things.</td>
<td>0.16</td>
</tr>
<tr>
<td>6) When I am reminded of my past failures, I feel as if they are happening all over again</td>
<td>0.27</td>
</tr>
<tr>
<td>7) I worry less about the future than most people I know.</td>
<td>0.12</td>
</tr>
<tr>
<td>8) I’m always trying to figure myself out.</td>
<td>0.30</td>
</tr>
<tr>
<td>9) I reflect about myself a lot.</td>
<td>0.23</td>
</tr>
<tr>
<td>10) I’m constantly examining my motives.</td>
<td>0.31</td>
</tr>
<tr>
<td>11) I sometimes have the feeling that I’m off somewhere watching myself.</td>
<td>0.11</td>
</tr>
<tr>
<td>12) I’m alert to changes in my mood.</td>
<td>1.60</td>
</tr>
<tr>
<td>13) I’m aware of the way my mind works when I work through a problem.</td>
<td>0.01</td>
</tr>
<tr>
<td>14) I’m concerned about my style of doing things.</td>
<td>0.21</td>
</tr>
<tr>
<td>15) I’m concerned about the way I present myself.</td>
<td>0.16</td>
</tr>
<tr>
<td>16) I’m self-conscious about the way I look.</td>
<td>0.28</td>
</tr>
<tr>
<td>17) I usually worry about making a good impression.</td>
<td>0.23</td>
</tr>
<tr>
<td>18) One of the last things I do before leaving my house is look in the mirror.</td>
<td>0.24</td>
</tr>
<tr>
<td>19) I’m concerned about what other people think of me.</td>
<td>0.24</td>
</tr>
<tr>
<td>20) Do you have trouble making up your mind?</td>
<td>0.21</td>
</tr>
</tbody>
</table>

RH = Rehearsal, PrSC = Private Self-Consciousness, PuSC = Public Self-Consciousness, and CF = Cognitive Failure
### Table 9.6. Items and loadings for the Exploratory Factor Analysis (EFA) of the Movement-Specific Reinvestment Scale (MSRS)

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MSC</td>
</tr>
<tr>
<td>1) I rarely forget the times when my movements have failed me</td>
<td>0.49</td>
</tr>
<tr>
<td>2) I am always trying to figure out why my actions failed</td>
<td>0.81</td>
</tr>
<tr>
<td>3) I reflect about my movement a lot</td>
<td>1.09</td>
</tr>
<tr>
<td>4) I am always trying to think about my movements when I carry them out</td>
<td>0.69</td>
</tr>
<tr>
<td>5) I am self conscious about the way I look when I am moving</td>
<td>0.85</td>
</tr>
<tr>
<td>6) I sometimes have the feeling that I am watching myself move</td>
<td>0.88</td>
</tr>
<tr>
<td>7) I am aware of the way my body works when I am carrying out a movement</td>
<td>0.29</td>
</tr>
<tr>
<td>8) I am concerned about my style of moving</td>
<td>1.00</td>
</tr>
<tr>
<td>9) If I see my reflection in a shop window, I will examine my movements</td>
<td>0.72</td>
</tr>
<tr>
<td>10) I am concerned about what people think about me when I am moving</td>
<td>1.01</td>
</tr>
</tbody>
</table>

**MSC=** Movement Self-Consciousness, and **CMP=** Conscious Motor Processing

### Table 9.7. Items and loadings for the Exploratory Factor Analysis (EFA) of the Decision-Specific Reinvestment Scale (DSRS)

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DRe</td>
</tr>
<tr>
<td>1) I’m always trying to figure out how I make decisions.</td>
<td>0.69</td>
</tr>
<tr>
<td>2) I’m concerned about my style of decision-making.</td>
<td></td>
</tr>
<tr>
<td>3) I remember poor decisions I make for a long time afterwards.</td>
<td>0.70</td>
</tr>
<tr>
<td>4) I’m constantly examining the reasons for my decisions.</td>
<td></td>
</tr>
<tr>
<td>5) I get “worked up” just thinking about poor decisions I have made in the past.</td>
<td>0.80</td>
</tr>
<tr>
<td>6) I sometimes have the feeling that I’m observing my decision making process.</td>
<td>0.53</td>
</tr>
<tr>
<td>7) I often find myself thinking over and over about poor decisions that I have made in the past.</td>
<td>0.81</td>
</tr>
<tr>
<td>8) I think about better decisions I could have made long after the event has happened.</td>
<td>0.71</td>
</tr>
<tr>
<td>9) I am alert to changes in how much thought I give to my decisions.</td>
<td></td>
</tr>
<tr>
<td>10) I’m aware of the way my mind works when I make a decision.</td>
<td>0.43</td>
</tr>
<tr>
<td>11) I rarely forget the times when I have made a bad decision, even about the minor things.</td>
<td></td>
</tr>
<tr>
<td>12) When I am reminded about poor decisions I have made in the past, I feel as if they are happening all over again.</td>
<td>0.65</td>
</tr>
<tr>
<td>13) I’m concerned about what other people think of the decisions I make.</td>
<td></td>
</tr>
</tbody>
</table>

**DRe=** Decision Reinvestment, and **DRu=** Decision Rumination
9.14 Composition of factors for confirmatory and exploratory factor analysis models

Table 9.8. The Reinvestment Scale composition of factors for confirmatory (CFA) and exploratory factor analysis (EFA) models

<table>
<thead>
<tr>
<th>Factor analysis</th>
<th>Items in RH</th>
<th>Items in PrSC</th>
<th>Items in PuSC</th>
<th>Items in CF</th>
<th>Correlations between factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFA</td>
<td>R1-R6, R7(reversed)</td>
<td>R8-R13</td>
<td>R14-R19</td>
<td>R20</td>
<td>0.21-0.63</td>
</tr>
<tr>
<td>EFA</td>
<td>R8-R11, R14</td>
<td>R7(reversed), R15-R20</td>
<td>R1-R6</td>
<td>R12, R13</td>
<td>-0.02-0.33</td>
</tr>
</tbody>
</table>

RH= Rehearsal, PrSC= Private Self-Consciousness, PuSC= Public Self-Consciousness, and CF= Cognitive Failure

Table 9.9. The Movement-Specific Reinvestment Scale composition of factors for confirmatory (CFA) and exploratory factor analysis (EFA) models

<table>
<thead>
<tr>
<th>Factor analysis</th>
<th>Items in MSC</th>
<th>Items in CMP</th>
<th>Correlations between factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFA</td>
<td>M1-M4,M7</td>
<td>M5,M6,M8-M10</td>
<td>0.49</td>
</tr>
<tr>
<td>EFA</td>
<td>M1,M2</td>
<td>M3-M10</td>
<td>0.49</td>
</tr>
</tbody>
</table>

MSC= Movement Self-Consciousness, and CMP= Conscious Motor Processing

Table 9.10. The Decision-Specific Reinvestment Scale composition of factors for confirmatory (CFA) and exploratory factor analysis (EFA) models

<table>
<thead>
<tr>
<th>Factor analysis</th>
<th>Items in DRe</th>
<th>Items in DRu</th>
<th>Correlations between factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFA</td>
<td>D1,D2,D4, D6, D9,D10</td>
<td>D3,D5,D7,D8,D11, -D13</td>
<td>0.48</td>
</tr>
<tr>
<td>EFA</td>
<td>D1, D6,D10</td>
<td>D3,D5,D7,D8,D12</td>
<td>0.48</td>
</tr>
</tbody>
</table>

DRe= Decision Reinvestment, and DRu= Decision Rumination
9.15 Comparison of factor analysis with previous studies

Table 9.11. Comparison of the comparative fit indices between the current study and the original surveys data for the three reinvestment surveys.

<table>
<thead>
<tr>
<th>Scale</th>
<th>$\chi^2$ (df)</th>
<th>CFI</th>
<th>GFI</th>
<th>SRMR</th>
<th>RMSEA</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS</td>
<td>212 (164)**</td>
<td>0.85</td>
<td>0.87</td>
<td>0.08</td>
<td>0.04</td>
<td>Current study</td>
</tr>
<tr>
<td></td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Masters et al. (1993)</td>
</tr>
<tr>
<td>MSRS</td>
<td>59 (34)**</td>
<td>0.93</td>
<td>0.92</td>
<td>0.08</td>
<td>0.08</td>
<td>Current study</td>
</tr>
<tr>
<td></td>
<td>13 (5)</td>
<td>0.97</td>
<td>0.98</td>
<td>0.04</td>
<td>0.06</td>
<td>asters et al. (2005)</td>
</tr>
<tr>
<td>DSRS</td>
<td>126 (64)**</td>
<td>0.90</td>
<td>0.88</td>
<td>0.08</td>
<td>0.09</td>
<td>Current study</td>
</tr>
<tr>
<td></td>
<td>130 (64)*****</td>
<td>0.95</td>
<td>0.87</td>
<td>0.04</td>
<td>0.09</td>
<td>Kinrade et al. (2010)</td>
</tr>
</tbody>
</table>

RS= Reinvestment Scale, MSRS= Movement-Specific Reinvestment Scale, DSRS= Decision-Specific Reinvestment Scale; $\chi^2$= Chi-squared test, df= degree of freedom, CFI= Comparative Fit Index, GFI= Goodness-of-Fit Index, SRMR= Standardised Root Mean-squared Residual, RMSEA= Root Mean Square Error of Approximation, *, ** p< 0.05, ** p< 0.01, *** p< 0.001, ---= data not reported.

Table 9.12. Comparison of subscale Cronbach alpha (\(\alpha\)) values between the current data and data from the Movement- and Decision-Specific Reinvestment Surveys.

<table>
<thead>
<tr>
<th>Reference</th>
<th>RS Overall ((\alpha))</th>
<th>MSRS MSC</th>
<th>CMP</th>
<th>Overall ((\alpha))</th>
<th>DRe</th>
<th>DRu</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current study</td>
<td>0.70</td>
<td>0.80</td>
<td>0.69</td>
<td>0.78</td>
<td>0.74</td>
<td>0.86</td>
<td>0.85</td>
</tr>
<tr>
<td>Masters et al. (1993)</td>
<td>0.86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ling et al. (2015)</td>
<td></td>
<td>0.78</td>
<td>0.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinrade et al. (2010)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

RS= Reinvestment Scale, MSRS= Movement-Specific Reinvestment Scale, MSC= Movement Self-Consciousness, and CMP= Conscious Motor Processing; DSRS= Decision-Specific Reinvestment Scale, DRe= Decision Reinvestment, and DRu= Decision Rumination; \(\alpha\)= Cronbach alpha.
تم بحمد الله
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