

**Changes in the elderly in speed of processing, internal
noise and cognitive functioning**

**Lynn Ward
B.A. (Hons), Adelaide**

**Thesis submitted in fulfilment of the requirements
for the Degree of Doctor of Philosophy**

**Department of Psychology
The University of Adelaide
November, 1994**

Awarded 1995

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ABSTRACT

Decline in rate of information processing is one of the most robust findings in the experimental ageing literature. It has been suggested that certain age-related deficits in perceptual and cognitive functioning may be the result of this decline. One suggestion for decline in processing speed is that it results from an increase in noise in the central nervous system. This thesis was concerned with the causes and consequences of age-related slowing.

Inspection Time (IT) is an index of processing efficiency derived using a backward masking procedure in an attempt to avoid interpretive difficulties associated with reaction time (RT) data. In addition, the original rationale for estimating IT provided a means of operationalising internal noise. These indices, IT and noise, have been examined in relation to cognitive ageing effects in this thesis. The empirical work presented has addressed five main concerns: (i) comparing speed of processing in young and elderly adults using the IT task; (ii) examining whether increasing noise accounts for decline in speed of processing in elderly adults - specifically, whether the former can be measured independently of the latter using a backward masking procedure; (iii) examining the relationship between cognitive performance and noise and speed measures; (iv) considering the role of attentional variables in IT performance, particularly among the elderly; and (v) examining the utility of the visual search paradigm in providing convergent support for the noise hypothesis. These concerns have been addressed in six studies.

In Experiment 1 no decline with age was found for estimates of IT, defined as the exposure duration required to reach 97.5% accuracy on a forced choice between two discrimination lines of different length. Consistent with expectations, elderly adults ($n=18$, mean age=68 years) completed fewer substitutions on the Digit Symbol Substitution (DSS) test of the WAIS-R than the young ($n=18$, mean age=20.6). Noise was measured using the lines discrimination task where discriminial difference between line lengths varied and exposure duration was held constant, either at 100 ms or the estimate of IT for each individual. Contrary to expectations, estimates of noise derived from the standard deviation of the psychometric function relating response accuracy to

discriminal difference on this task were higher in the younger group. This finding was most plausibly attributed to procedural shortcomings.

Experiments 2 and 3 examined visual search performance. Experiment 2 examined age-related changes in parameters of visual search performance in an attempt to examine convergent support for the noise hypothesis and to test the generalised slowing hypothesis. Subjects had to identify a target letter presented in an array of distracter letters with RT compared across three age groups (17-27 years, mean age=22.1, n=14; 63-74 years; mean age=68.1, n=16; 75-90, mean age=81.3, n=16). Target-distracter combinations were manipulated to encourage parallel or serial processing of information and on certain trials, target onset position was precued. Examination of RT data revealed no age-related decline in parallel processing but an age-related decline was found in speed of serial scanning. Interpretation of these data, however, was constrained by the existence of differential speed-accuracy trade-offs across groups of young and elderly subjects. Consistent with the noise hypothesis, age-related decline in target identification processes was found. A decline in selective attentional processes was most likely the result of a cognitive rather than a perceptual deficit. The finding that age-related interactions remained after data were subjected to natural logarithm transformations was not consistent with the strong version of the generalised slowing hypothesis. Experiment 3 considered whether the point at which search switches from parallel to serial could be isolated for individuals using RT data during a visual search task. Data was examined for a group of young adults (n=18, mean age=20.6). Locating this point could not be unequivocally determined by examination of RT data.

In Experiment 4, a further attempt was made to compare estimates of IT and noise in young (n=20, mean age=22.4 years) and elderly adults (n=36, mean age=67.5) using modified procedures from Experiment 1. Elderly adults displayed longer ITs which were not accounted for by differential use of task strategies. Interpretation of a significant increase in noise with age was constrained by a confounding of IT and noise estimates. A standard multiple regression conducted with age, DSS, IT and noise entered as independent variables indicated that only DSS contributed significantly to the prediction of abstract reasoning ability (Raven's Progressive Matrices).

In Experiments 4 and 5 an expanded judgement task (Frequency Accrual Speed Test, FAST) was used to provide an alternative estimate of speed of processing. The finding that FAST

was not sensitive to age in Experiment 4 was likely the result of a ceiling effect. Poorer FAST performance was found among elderly adults ($n=16$, mean age=74.6) in Experiment 5 in which task parameters were manipulated to increase difficulty level (Young group: $n=16$, mean age=20.8). An attempt to derive reliable estimates of IT from the FAST task was unsuccessful.

Experiment 6 examined further the relationship between ageing, abstract reasoning ability and speed of processing in young ($n=20$, mean age=18.9) and elderly ($n=32$, mean age=70.2 years) adults. Noise was not measured directly; rather performance variability was derived from a task that also provided a means for validating estimates of IT. Estimates of IT were derived according to standard procedures and also from two tasks in which attentional variables were manipulated. Elderly adults were not differentially affected when IT was measured using a variable intertrial interval, suggesting that there is no age-related decline in ability to maintain preparation. However, performance under dual task conditions (concurrent IT and a random number generation task) was consistent with the notion that ageing is associated with a reduction in processing resources. Consistent with predictions, multiple regression analysis indicated that age, DSS, IT estimated with both constant and variable intertrial intervals, and the IT validation task made unique contributions to the prediction of cognitive performance (Raven's PM). Interpretation was constrained by the finding that the unique contribution made by the backward masking variables which were assumed to reflect aspects of concentration was only evident when IT acted as a suppressor variable, partialling out variance unrelated to Raven's PM.

Overall, results suggested that speed of processing can be measured reliably in elderly adults using the IT task. Independent estimates for IT and noise, however, could not be derived using the backward masking procedure, suggesting that these two indices are confounded. Consistent with the processing rate theory of cognitive ageing, support was found for the suggestion that speed accounts, in part, for cognitive decline with age. Despite procedural difficulties, indices derived using backward masking procedures made a unique contribution to the prediction of cognitive ability. The finding that speed is not a unidimensional construct was consistent with the weak version of the generalised slowing hypothesis. Findings were consistent with a model in which both speed and attentional constructs were seen as determinants of cognitive performance.

STATEMENT

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Signed _____

Date 2/12/94

ACKNOWLEDGMENTS

I am deeply grateful for the support and assistance of a number of people without whom this thesis would not have been completed.

First and foremost, I would like to thank my supervisor Dr Ted Nettelbeck for his support and encouragement. Ted has always been keen to discuss my work and, in addition to having a very fast return rate for items submitted to him, has provided very thoughtful comments on drafts of the thesis. I value highly the support he has given me, both personally and professionally, over the years.

Thanks are also due to Dr Jane Mathias for providing moral support and helping me to keep my sense of humour, particularly during the writing-up phase. Jane provided me with a wonderful role model, a sympathetic ear and a "shopping-therapy" partner.

Carmen Rayner produced all of the Figures in the thesis. I am very grateful to her for the professional job that she has done and, most especially, for her patience and good humour.

My thanks to Bob Willson for his advice on statistical and computing matters and to Mark Brown who wrote the computer programs required to run the various tasks. Technical support was also provided by Geoff Matthews and Alan Boldock who cheerfully fixed the things I broke and Iris Liu and Janet Hamilton who gave advice on the myriad of word-processing problems that I had.

I am most grateful to the people who gave so generously of their time and cheerfully participated in the experiments. This thesis would not have been completed without the cooperation of the participants from the University of Adelaide and the University of South Australia, and the various senior citizen groups and Australian Retired Persons Association clubs that I visited.

Thanks are also due to my family for their encouragement and to Dick Ward, who proof-read the thesis and tried to help "de-jargonise" it.

Finally, and most importantly, I would like to thank my husband, Duncan, for having faith in me and for his love and support during this strange interlude in my life. I will be eternally grateful to him for his efforts in formatting the appendices and for saving various drafts of the thesis from that computer-netherworld to which I accidentally consigned them during various late night word-processing sessions.

CHAPTER ONE

INTRODUCTION



1.1 A reductionist approach to cognitive ageing

A great deal of work in the area of human ageing has been concerned with changes in the speed of information processing. This concern reflects the interest of researchers in the field of ageing in deriving time-based indices of performance, consistent with the currently dominant position in mainstream psychology of the cognitive paradigm generally, and the information processing perspective, more specifically. Researchers have approached changes to the rate of processing from two perspectives. Firstly, they have been concerned to demonstrate slowing with age as indicative of a reduction in cognitive resources that are sensitive to or influenced by temporal constraints. Secondly, they have utilised differences in speed to attempt to isolate changes in cognitive or information processing mechanisms *per se*. As a result, a very extensive literature exists on the link between speed, as expressed in a variety of situations, and ageing beyond about 60 years. Indeed, the slowing of processing with age has been referred to as one of the most robust findings in the experimental literature (Salthouse, 1985a).

Adoption of the second perspective mentioned above has led to a large number of studies utilising cross-sectional analyses of response latencies of young and elderly adults on a wide variety of tasks. The result of this enterprise has been to implicate virtually every stage of information processing in declines in performance with age (Salthouse & Somberg 1982a). Indeed, the processing mechanisms purportedly responsible for age differences are as varied as the tasks administered to isolate them. Salthouse (1985b), who has contributed to and critically evaluated this literature, has suggested that the field is suffering from the lack of a theoretical framework. What is needed, he suggested, is a coherent theory that can integrate experimental findings and provide direction for future

research so that workers in the area avoid the trap of simply continuing to provide descriptive lists of age-related changes in sundry aspects of performance.

Salthouse (1985a) has suggested that the generalised slowing hypothesis provides a parsimonious account of age-related changes in cognitive abilities. This hypothesis suggests that the fundamental deficit accompanying ageing is a general decline in the speed of processing which affects all of the components underlying information processing performance. Tasks then differ primarily with respect to the demands they make on temporal resources, and Salthouse has suggested that recourse to differences in the *amount* rather than the *type* of information processing required is sufficient to account for the myriad of specific deficits postulated in the field.

Evidence for slowing with age has been found using a variety of procedures including simple and choice reaction time tasks (Gottsdanker, 1982; Welford, 1977), tachistoscopic perception (Salthouse, 1976), masking studies (Till & Franklin, 1981; Walsh, 1976) and more complex mental rotation tasks (Cerella, Poon & Fozard, 1981). Further support is found in studies employing paper and pencil tests of speed such as the Digit Symbol Substitution subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981). There are additionally a number of reviews of the area available (Birren, Woods & Williams, 1980; Salthouse, 1985a; Welford, 1977). The main findings from such work are that (i) although speed of processing declines with age, the absolute magnitude of the difference depends on the task administered; (ii) the decline is thought to be due to central processing as opposed to peripheral or sensory factors; and, (iii) variability in speed both between individuals and within individuals increases with age.

Concern with the age-speed link opens up two potentially fruitful lines of inquiry. Firstly, one can seek explanations for the decline; and, secondly, one can examine what the consequences of the decline may be for general cognitive functioning in the ageing individual. This reductionist approach then provides a three-tiered analysis, locating changes in speed on the central tier in an explanatory framework. Higher level functioning is examined in terms of the limitations in temporal resources to which the information processing system is subjected. Speed, in turn, is explained in terms of lower level changes

such as deterioration in the central nervous system (CNS) of the ageing individual. Although there tends to be consensus regarding the existence of age-related slowing, theorists differ with respect to their interpretations of both the causes and consequences of the decline.

Of the various explanations for the decline in speed, one hypothesis that has been linked to broader behavioural changes concerns a decrease with age in the signal-to-noise ratio of the central nervous system (Crossman & Szafran, 1956; Gregory, 1957; Welford, 1960, 1981). Although detailed consideration will be given to this notion in Chapter 2, the main aspects of the theory will be also considered here. There are a number of different conceptualisations within the literature on ageing in which some form of noise is proposed to explain decline found in various forms of cognitive performance. Layton (1975) identified three ways in which the term has been used. The first is based on signal detection theory and suggests that the older nervous system is characterised by a lower signal-to-noise ratio. The second is the stimulus persistence model of Axelrod (1963), where the neural activity produced by stimulus events is assumed to take longer to subside with age and thus interferes with the processing of subsequent information. The third is Layton's own conceptualisation - perceptual noise - where ageing is characterised by a decrement in the ability to ignore or suppress information which is available for processing from the environment.

The three approaches are concerned with linking the behavioural changes associated with ageing to the impact of increasing variability in the information processing system. In the first two this may directly reflect the structural degeneration of the central nervous system. In the third, it is the result of a deficit (presumably structural, but unspecified), whereby there is increasing failure to ignore information which is external to the individual; that is, a problem in selecting information from the environment for processing. The third conceptualisation is linked to broader notions of selective attention and is considered further in section 1.3 where the procedures utilised in the empirical work presented in this thesis are outlined.

The neural noise hypothesis views noise as a biological limitation of the nervous system. It is based on the assumption that a fluctuating level of noise (or noninformation) is always present in the processing system and that, to be perceived, a given signal intensity must be greater than that of background noise. Briefly, a decline in the signal-to-noise ratio may be due to either a decrease in signal strength, an increase in random background disturbance, or some combination of both (Welford, 1980). This idea can be found in other areas of inquiry, for instance, communications and engineering technology, where the sensitivity of all detectors is assumed to be affected by random noise. This limits the discriminability of signals and thus the rate of information transmission within the system.

In the human information processing system, a decrease in signal-to-noise ratio will result in weaker, more variable stimulus representations in the CNS. Functionally, this increase in the likelihood of error which is occurring throughout the information processing system is manifest in a slowing of performance (Lindholm & Parkinson, 1983). A decline in signal-to-noise ratio may lead to increases in both between group and within individual variability in performance. The decline in speed of processing can, in principle, be accounted for by recourse to the existence of this limiting factor in the information processing system. Additionally, increasing variability between individuals with age may reflect differential noise levels resulting from the fact that CNS ageing occurs at different rates in different individuals. However, although age changes in noise level were first postulated in the 1950s and interest in the notion has been revived more recently (Cremer & Zeef, 1987; Salthouse & Lichty, 1985), the construct still lacks empirical validation.

The consequences of the decline in speed of processing, on the other hand, are well articulated by the generalised slowing hypothesis: all stages of processing are affected and a decline in cognitive functioning is the result (Birren, 1974). Cognitive changes with age are well-documented (see Denney, 1982 for review) and the relevant literature will be outlined in Chapter 2. Briefly, declines have been found with both cross-sectional analyses (Horn & Cattell, 1967) and longitudinal studies of intellectual functioning (Horn & Donaldson, 1976, 1977, 1980). The main difference between the two approaches has

concerned the magnitude and time of onset of the decline. Longitudinal studies typically report less marked declines and later onset.

Typically, verbal abilities, general information, and tasks that reflect knowledge and strategies built up over time show little decline with age, whereas reasoning, perceptual-motor, spatial abilities and tasks that involve the integration of new information decline (Horn, 1982, 1986; Horn & Cattell, 1967; Rabbitt, 1986; Salthouse, 1982). These findings reflect differences between what are referred to as crystallised and fluid abilities, respectively (Horn, 1982). Salthouse's (1985b) processing rate theory was put forward in an attempt to account for such cognitive changes with age. A number of researchers have recently begun to test empirically the relationship between speed of processing and intelligence in the elderly. There appears to be some qualified support for the link in the finding that correlations between age and many areas of cognitive performance are attenuated by controlling statistically for speed of processing (Hertzog, 1989; Nettelbeck & Rabbitt, 1992; Schaie, 1989).

1.2 The role of attention

The underlying assumption of the work outlined above is that the human brain operates as an information processing system, the capacity for cognitive processing of which is constrained by a limitation in resources - variations in speed are thought to reflect this limitation. The notion that the processing system is subject to structural limitations (Broadbent, 1958; Deutsch & Deutsch, 1963) or to limits of capacity (Kahnemann, 1973; Norman & Bobrow, 1975) has a long history in experimental psychology. The former idea is concerned with the structural or static demands of mental operations. The typical model is based on a channel or a number of channels of limited capacity. Structural limitations are investigated by varying task demands and observing resultant effects on performance. Capacity limitations, however, are concerned with the notion of energy or the potential for activation of particular structures within the system. That is, attention is conceptualised in terms of a limited source of energy which is required to activate processing systems (Kahnemann, 1973).

Certainly, not all structures require the allocation of attention for their activation and theorists agree that certain aspects of information processing appear to operate independently of capacity (Kahnemann, 1973; Schneider & Schiffrin, 1977). This distinction between what are known as automatic and controlled processes is important for identifying those aspects that will show an age decline and those that will not. Evidence suggests that the former remain intact with age, whereas the latter decline (Hasher & Zacks, 1979; Plude & Hoyer, 1981).

Kinsbourne (1980) has suggested that the cerebral integrity which is necessary for efficient cognitive functioning in terms of selectivity, directing attention, flexibility of focus and maintenance of concentration, may be compromised in the elderly. Certainly, there is evidence available on such performance changes with age, with many researchers inferring a structural or capacity limitation as a result (eg. Craik, 1977). Salthouse (1985b), however, is critical of explanations founded on the notion of attention. His conceptualisation of resources concerns three aspects of processing: (i) space - for example, size of short-term memory; (ii) time - the temporal requirements of processing operations; and (iii) energy - attention or arousal aspects. As has been indicated earlier, he has concentrated his theoretical efforts on the second of these and proposed his processing rate theory as a more parsimonious account of age changes than are those explanations currently available that are based on the third aspect; that is, attention.

Other workers, however, have not accepted the idea that notions of attention can be replaced by the general slowing hypothesis (eg Cornelius, Nesselroade, Willis & Baltes, 1983; Fisk, Fisher & Rogers, 1992; Stankov, 1983, 1988). Certainly, the idea that attentional resources might reflect some selective mechanism or control process which monitors various input channels continues to have intuitive appeal for explaining why some areas of cognitive processing decline with age whereas others remain intact or even improve. It could be argued that where redundancy of information or processing structures is involved, more noise can be tolerated in the system and thus less deterioration with age is found. Crystallised abilities then may reflect automatic processes and fluid abilities, controlled or resource-intensive processes. A similar argument has been put forward by

Rabbitt (1990), who suggests that individuals possessing high levels of processing resources may be able to compensate for certain losses in neural systems, particularly where effects are localised.

It has been argued that the notion of attentional resources is akin to Spearman's 'g' (Hunt, 1980), and that a capacity limitation may underlie individual differences on measured intelligence (Stankov, 1983). There is some evidence for a convergence of attentional variables with psychometric intelligence in the elderly (Cornelius, Willis, Nesselroade & Baltes, 1983). Indeed, Stankov's (1988) study, which examined 19 psychometric tests and 17 measures of attentional processes, suggested that three attentional factors - search, concentration, and flexibility - were responsible for age declines in fluid abilities.

1.3 Current Research

Despite Salthouse's assertion that the generalised slowing hypothesis provides a more parsimonious account of age changes, the explanatory power of attention as a mediating variable remains equivocal and worthy of examination. The clear distinction outlined above between internal noise, speed of processing and attentional resources may not remain, however, after closer scrutiny. Both attentional capacity explanations and the generalised slowing hypothesis for instance, are concerned with some *limitation in the resources available for processing* - in the former this is reflected in the capacity for activation of processing channels, whereas in the latter it is reflected in the rate of transfer of information within the channels. Similarly, although noise and speed have been presented as different levels of an explanatory framework, both are concerned with the *fidelity of the information processing system*. Distinguishing empirically between the two may be problematical.

The present research is concerned with the causes and consequences of age-related slowing in processing. The working hypothesis is that ageing is associated with changes in the central nervous system which lead to a noisier information processing system. Consequently, processing becomes slower and more variable and, functionally, this is

manifest in age-related changes in cognitive functioning. The impact of attention as a mediating variable in this relationship will be considered. An attempt will be made to examine how the various levels of explanation presented are related to one another and how limitations in the resources and the fidelity of the processing system can best be conceptualised.

Work in the two traditions (that is, speed and attention) can be brought together by considering the simple two-stage model of visual processing given in Figure 1.1. The first stage is concerned with the input of information to the system. The second reflects central processing. Superficially, the model resembles the distinction made between input handling and control processes by researchers concerned with modelling cognitive systems (Broadbent, 1977). Undoubtedly, such a model is an over-simplification of what occurs during processing, but it does provide a framework within which to examine the effects of noise and to operationalise notions of attention. One aim of the empirical work to be presented then is to consider the impact of noise on both input and central processes.



Figure 1.1 A two-stage model of visual processing.

As was indicated in section 1.2, the link between ageing and speed of processing is well documented. However, the finding that individuals can increase response accuracy by sacrificing speed (the so-called speed-accuracy trade-off) has led to interpretive difficulties when reaction time has been adopted as a dependent variable in age comparisons of the rate of information processing. The backward masking procedure, however, may allow one to examine both noise and rate of information processing in a manner which is independent of response speed. Briefly, the amount of time that a stimulus is available for processing is controlled by the experimenter rather than by the subject. Rate of information processing is then inferred from response accuracy at particular exposure durations. The index of

processing efficiency known as Inspection Time (IT) was derived within this procedure (Vickers, Nettelbeck & Willson, 1972). The IT index is operationally defined as the stimulus exposure duration necessary for a predetermined level of accuracy on a simple, forced two-choice discrimination task. IT is thought to reflect the general efficiency of the information processing system and the index has been examined in a large number of studies and with a number of different populations (see Nettelbeck, 1987 for a review).

A means of operationalising internal noise was also suggested during development of the IT index (Vickers et al., 1972). This development will be considered in Chapter 3; briefly, noise is derived from a task similar to IT, but the experimenter manipulates the discriminial difference within the two-choice task, rather than the exposure duration. Exposure duration remains constant and the difficulty of the discrimination is systematically manipulated. Following the classical theory of psychophysics, an index of noise is derived from the standard deviation of the cumulative normal ogive found when response accuracy is plotted against objective stimulus difference (Vickers et al., 1972). IT and noise, as operationally defined, are assumed to provide independent indices of performance. The backward masking procedure thus appears to provide a means of operationalising both noise and speed of processing, given certain assumptions. In addition, the attentional requirements of an IT task can be readily manipulated in order to examine the explanatory utility of the notion of attentional resources in accounting for age differences. The procedure was thus adopted in the empirical work to be presented in this thesis.

As was indicated in section 1.2, one view of the relationship between noise and ageing has been concerned with selective attention and the ability of individuals to select relevant information from background noise for processing (Layton, 1975). This conceptualisation will be examined in the empirical work to be presented in this thesis in an attempt to derive convergent support for the neural noise hypothesis. The visual search paradigm can be used to link selective attention and the level of noise in the processing system to the input processes stage of the model presented in Figure 1.1. Although detailed

consideration will be given to the paradigm in Chapter 4, a brief overview is also presented here.

A visual search task involves detecting or identifying a target (or targets) against an array of background stimuli or distracters. Typically, the task is used to provide information concerning the mode of information processing (serial or parallel). Parallel processing is thought to result from an even distribution of attention across a visual display (Eriksen & Spencer 1969; Schiffrin & Gardner, 1972), whereas serial search indicates a concentration of processing resources (Eriksen & Yeh, 1985; Prinzmetal & Banks, 1983). The size of the display which can be scanned in parallel is determined by discriminability. If the target contains a unique feature or is highly discriminable then attention is broadly spread, search is parallel and the target is said to "pop out" from the background. If the difference between target and distracters becomes unreliable relative to the level of noise in the system, search becomes serial (Treisman & Gormican, 1988).

Discriminability then influences performance on the visual search task and affects the manner in which information enters the information processing system. With increased noise in the processing system, the discriminability of a given target against background distracters would be reduced and attention would be expected to narrow in a compensatory manner. Thus, visual selective attention - operationally defined within the visual search procedure - provides a means of obtaining convergent support for the noise hypothesis.

Essentially then, this thesis presents a reductionist analysis of the effects of ageing. The psychometric paradigm is used to examine cognitive changes and the information processing perspective is adopted to provide operational definitions of noise, speed and attention. Relevant literature concerning the propositions outlined earlier will be presented in subsequent chapters. Specifically, age changes in speed and attentional resources and the notion of noise as an explanatory construct will be reviewed in Chapter 2. Cognitive changes associated with ageing and attempts to account for these using measures of attention and timed performance will also be reviewed in that chapter. Chapter 3 will be concerned with operationalising the constructs noise and speed of processing - methodological and conceptual issues arising from such attempts will also be considered.

The empirical work to be presented has addressed five main concerns:

- (i) Comparing speed of processing in young and elderly adults using a procedure that seeks to avoid interpretive difficulties associated with reaction time data.

- (ii) Examining the view that increasing noise leads to decline in speed with age - specifically, determining whether the former can be measured independently of the latter within the backward masking procedure.

- (iii) Examining the relationship between the cognitive performance of elderly persons and the noise and speed indices derived.

- (iv) Considering the role of attentional variables as mediators in the noise-speed-cognition chain.

- (v) Examining the ability of the visual search procedure to provide convergent support for the neural noise hypothesis and to link notions of noise and selective attention.

CHAPTER TWO

AGE CHANGES IN NOISE, SPEED, AND COGNITIVE PROCESSING: THEORETICAL CONSIDERATIONS AND EMPIRICAL FINDINGS

2.1 Introduction

The aim of this chapter is to present empirical support for the theoretical position and propositions outlined in Chapter 1. The relationship between the cognitive performance of ageing individuals and levels of internal noise, speed of processing and attentional resources will be considered. The intention is not to provide an exhaustive survey of the literature, but rather to consider the main findings of immediately relevant empirical work and their implications. The notion of noise as a limiting factor in the information processing system will be considered, followed by an overview of decline in speed of processing that occurs with age and a consideration of attentional resources. Finally, cognitive changes associated with ageing will be described and the explanatory power of speed and attentional constructs in accounting for such changes with age will be examined.

2.2 Noise as a factor limiting perceptual ability.

2.2.1 Historical context.

It has long been recognised that the ability to detect, discriminate and selectively respond to environmental information is fundamental for adaptive functioning. Empirical work in this field has been concerned with measuring the limits of our capacity firstly, to be receptive to stimulation and, secondly, to respond to stimulus differences (see Corso, 1967 for a review). The former is concerned with the measurement of absolute thresholds and the latter with differential thresholds of discriminative capacity. There is abundant experimental evidence to suggest that people are not perfect discriminators. The notion of

random disturbance or "noise" in the central nervous system has been suggested to account for this fact.

In 1834, Weber reported that, for an observer to report reliably a difference between two stimuli, a change in magnitude directly proportional to the initial stimulus intensity is required. This relationship, referred to as Weber's Law, has been found to break down at low stimulus intensity levels (see Boring, 1942 for a review). Fechner (1860) attributed such departures from Weber's Law to the existence of noise in the visual system. He suggested that neural activity occurring in the absence of external stimulation acts as a limiting factor in the experience of sensation. Fechner suggested that incoming stimuli must be sensed and interpreted by a brain which is already at some level of excitation due to spontaneous neural activity. Excitation produced by a given stimulus must be greater than that of this background level for perception to occur. Noise in the nervous system was thus held to be the basis of the absolute threshold. He referred to this neural activity in the visual modality as the "Augenschwarz", literally, "eye's blackness" but more commonly translated as the "intrinsic light of the eye".

Whereas Fechner assumed that the threshold represented a discrete barrier that must be passed for experience to occur, Jastrow (1888) argued that sensation and stimulation form a continuum and that the threshold varies according to the normal law of error. Consistent with this reasoning, Pierce and Jastrow (1885) found that, in a two-choice discrimination task, the function relating the probability of a correct response to objective stimulus difference is a continuous sigmoid curve. A number of conceptualisations have subsequently attributed the characteristic shape of this so-called psychometric function to the combined effect of noise from various sources in the information processing system (Vickers, 1979).

Such noise may be either external or internal in origin. External noise is that derived from the stimulus itself. In their physical quantum theory, Hecht, Schaer and Pirenne (1942) suggested that variations occur in the amount of physical energy which is absorbed from a stimulus. A stimulus of nominally constant intensity will thus produce a variable distribution of sensory effect due to differential energy absorption (Treisman,

1964). Other workers have concentrated on internal factors, derived from spontaneous neural firing (following Fechner), or central variability. As expressed by Jastrow a century ago, variability is due to "...lapses of attention, slight fatigues, and all the other numerous psychological fluctuations" (Jastrow, 1888, p284). Similarly, Cattell (1893) suggested that changes in neural conductivity, interest and inhibition are crucial. Welford (1968) emphasised that changes in cerebral activity provide a source of variability. He speculated that these may include (i) the after-effects of prior processing which, though not random, might reduce the strength of incoming signals; (ii) a reduction in cerebral blood flow and diffuse cell loss which may reduce signal strength; and (iii) an increase in background neural activity, possibly as a result of increased levels of arousal. The notion of internal noise has continued to have intuitive appeal, despite the fact that its physiological basis is crude (Welford, 1981).

Work in the 1950s built onto the notion of the visual threshold as a problem of discriminating signal from noise (Barlow, 1956; Bulmer & Howarth, 1957; Gregory & Cane, 1955). Indeed, Fechner's "Augenschwarz" may be seen as the precursor to the idea of retinal noise suggested by Barlow (1956). Such random activity in the CNS is thought to provide a fundamental limitation to discriminative capacity (Barlow, 1956, 1957a,b). Gregory and his co-workers (Cane and Gregory, 1957; Gregory, 1957) distinguished between retinal noise which is due to the spontaneous breakdown of photochemical molecules and the effect of quantum fluctuations in light, and neural noise which reflects variations in nerve impulse rate due to random factors. A number of techniques for estimating level of background-noise were derived from such work. Cane and Gregory (1957) suggested that retinal noise could be measured by extrapolating the linear portion of the function relating intensity to the change in intensity required for two stimuli to be just-noticeably-different, to the abscissa intercept. They suggested that neural noise is reflected in the slope of the line; with a steeper slope being associated with higher noise levels. Barlow (1956) suggested that an index of noise is provided by the intercepting ordinate of the regression line which relates the log transformed values of intensity to the change in intensity required to produce a just-noticeable-difference.

Treisman (1964) postulated a neurological model of discriminative capacity which included parameters derived from the noise sources discussed above. The first was the spontaneous firing or background activity level of the nervous system, following Fechner (1860) and Barlow (1956). The second was a reflection of the irreducible physical variability of the stimulus following Hecht et al. (1942). The third, referred to as neural noise, arose from variations in the responsiveness of neural pathways to sensory inputs. Treisman was able to account for the tendency of Weber functions to reflect a square root relationship at low stimulus intensities and a continuous transition to the linear law at high intensities by assuming that the sensory effect of stimulation can be represented as a normal distribution in the CNS.

Historically then, noise has been defined in terms of a number of independent sources: central variability, spontaneous neural activity and fluctuations in physical stimulus energy. On a functional level, noise has been conceptualised as a fundamental limitation to discriminative capacity, because it is assumed that all neural representations of stimuli are superimposed onto and interpreted against it. The suggestion that combining extrinsic and intrinsic sources of noise will produce neural activity that approximates a normal distribution is now generally accepted (Tanner & Swets, 1954; Vickers, 1979). Under such conditions, signal and noise will be represented in the information processing system by overlapping distributions of sensory effect. Functionally, increasing noise levels result in internal representations of stimuli being weaker and more variable. The need for an increase in signal strength for a stimulus to be perceived against background-noise will result in higher sensory thresholds. Similarly, a noisy system would be associated with lower tolerance thresholds for either noise added to a stimulus display or signal degradation (Salthouse & Lichty, 1985; Cremer & Zeef, 1987). Lindholm and Parkinson (1983) have suggested that, in such a conceptualisation, noise is synonymous with error in the processing system.

The notion of declining signal-to-noise ratio has been utilised by Welford to account for changes with age in a variety of phenomena, including sensory thresholds (1958), memory task performance (1969, 1981) and reaction time data (1960, 1981). More

recently, noise, defined as a loss of processing resolution, has been utilised to account for age differences found in certain memory and perceptual tasks by Allen and his co-workers (Allen, 1990; Allen, Madden & Crozier, 1991; Allen, Madden, Groth & Crozier, 1992; Krueger & Allen, 1987). Allen suggested that the processing resolution of the elderly is reduced by the presence of internal noise and that this leads to selective attentional deficits. In visual search tasks, elderly adults are more susceptible to nontarget interference, because noise leads to increasing similarity between target and nontarget letters, resulting in an increased need for rechecking. This work is concerned primarily with the visual search procedure and so will be outlined in more depth in Chapter 4.

The relationship between noise and decline in speed of processing is based on statistical sampling principles. It is assumed that an individual can compensate for a reduced signal to noise ratio by examining a stimulus for longer - in effect by taking additional samples of the data on which a decision is to be based. This analogy assumes that the human information processing system operates by taking discrete samples of stimulus information as a basis for decision making, with sampling error being reduced by increasing sample size. The need to extract more information from stimulus displays in order to reach a particular criterion for responding is reflected in a slowing in the speed with which a response is produced. Thus, noise is conceptualised in terms of CNS changes which reduce the fidelity of the information processing system. Vickers et al. (1972) have argued that noise in the processing system can be measured independently of speed using backward masking procedures, so that although an increase in noise will, in principle, lead to a slowing of response speed, *both* constructs are assumed to represent limitations to performance. This argument, considered in more depth in Chapter 3, suggests that although there may be a causal relationship between noise and speed of response, the two constructs are not necessarily synonymous.

2.2.2 Empirical support for age changes in noise.

The work of Cane and Gregory (1957) was concerned with delineating retinal and neural sources of internal noise. The extrapolation techniques outlined in section 2.2.1

were used to compare the threshold discrimination performance of young and elderly adults in auditory and visual modalities. They found a difference in the slope but not the abscissa intercept of the linear function relating intensity to the change in intensity required to produce a just-noticeable-difference, suggesting that ageing is associated with an increase in neural but not retinal noise.

Crossman and Szafran (1956) compared young and elderly subjects on a card sorting task and found that reaction times increased with discriminational difficulty for both age groups. The effect of difficult discriminations, however, was less marked for the older participants. They interpreted this finding as evidence for an increase with age in internal noise by suggesting that discriminations resemble statistical decisions which are made between two competing hypotheses on the basis of evidence being sampled. The difficulty of a decision is reflected in the ratio of the evidence gathered for the alternative responses. The effect of increasing the randomness associated with signals (that is, increasing noise) has less impact where the associated ratio is near unity (that is, for difficult discriminations).

Salthouse (1980) administered a same-different tachistoscopic judgement task to young and elderly adults under two conditions. In the first, stimuli were presented for a constant period of time but at varying discriminability levels. In the second, exposure duration varied while discriminability remained constant. The conditions were an attempt to manipulate signal-to-noise ratio - directly in the former and indirectly in the latter. Similar patterns of results were obtained when accuracy levels were plotted against both duration and discriminability, supporting the notion that a decline in signal-to-noise ratio was responsible for age differences in accuracy.

Vickers, Nettelbeck and Willson (1972) derived estimates of internal noise for young and elderly adults by reanalysing data from Botwinick, Brinley and Robbin (1958). The latter workers had measured discrimination accuracy in young and elderly adults during a lines discrimination task where stimulus exposure duration was held constant at either 2000 ms or 150 ms and discriminational difference was varied between 1 and 20%. The analysis of Vickers et al. (1972) was based on an assumption derived from the classical

theory of psychophysics, that the standard deviation of the function relating response accuracy to discriminial difference reflects the level of variability in the processing system. No group differences were found between estimates of noise derived when exposure duration was set at 2000 ms (0.10 degrees of visual angle in both groups). At 150 ms, however, levels of internal noise equal to 0.14 and 0.21 degrees of visual angle for young and elderly subjects, respectively, were found. This suggests that, with long exposure durations where the stimulus remains available for processing, elderly adults are able to continue to accumulate stimulus information, thus reducing the effect of noise on performance accuracy. When data accumulation is restricted, however, elderly adults are unable to compensate for higher noise levels and evidence obtained from the stimulus display is of lower quality than that of the young.

Interpretation of the noise estimates derived from the Vickers et al. (1972) analysis, however, is constrained by the fact that the stimulus exposure duration was held constant across subjects in the study. It is possible that the group differences in the estimates of noise were confounded by age differences in rate of perceptual sampling. This issue is addressed in the empirical work to be presented in this thesis and is considered further in Chapter 3.

Rather than attempting to measure noise directly, recent work has attempted to provide convergent support for the neural noise hypothesis by testing predictions derived from it. Salthouse and Lichty (1985) suggested that decline with age in identifying both embedded and incomplete figures is consistent with the notion that, as a result of higher noise levels, elderly adults are more susceptible than the young to externally added noise and stimulus degradation. However, these workers found support for only one of three predictions derived from the noise hypothesis, tested using a letter-recognition task. They suggested that a lower signal-to-noise ratio would result in weaker, more variable stimulus representations in the CNS and predicted that, as a result, elderly subjects would have longer reaction times and lower tolerance thresholds both for noise added to the letter display and for stimulus distortions. The latter two predictions were not supported. It is likely, however, that the nonsignificant results of Salthouse and Lichty (1985) were the

result of the simplicity of the stimuli employed and the fact that these did not contain overlapping stimulus elements; (stimuli were the symbols + and x).

Cremer and Zeef (1987) addressed this issue by using an incomplete picture identification task incorporating 8 complex stimulus patterns. They distinguished between two ways in which the nervous system may be thought to be noisy. The first, termed random noise (RN) is consistent with the signal detection conceptualisation that the older nervous system has a higher level of background-noise or a lower signal input level and thus, lower capacity for discrimination. Signal strength may be reduced by neuronal loss with age while noise level may rise as a result of an increase in spontaneous neural activity. The second, termed proximal noise (PN), is concerned with the propagation of information within neuronal networks. Cremer and Zeef suggested that the older nervous system may be characterised by "...less distinct and more diffuse associations between previously connected neuronal units..." (Cremer & Zeef, 1987, p515). Hence, they suggested the older CNS will have lower resolution for stimulus configurations. A stimulus representation will thus be weaker under conditions of high RN whereas under high PN it will appear to be distorted. Results obtained from the incomplete picture identification task compared the accuracy-completion functions of elderly adults with those of the young undergoing manipulations to simulate RN and PN. Data were consistent with the notion that ageing is characterised by an increase in RN but not PN.

Thus, although the noise hypothesis has been utilised to explain a number of different phenomena, empirical support for the notion that noise increases with age remains somewhat equivocal. Certainly, there have been no recent attempts either to measure noise in older adults or to relate individual differences on this index to other aspects of functioning. There is, however, a large body of evidence concerning a decline with age in the speed of information processing that Salthouse (1985a) has suggested can be parsimoniously accounted for by the existence of higher levels of internal noise. This evidence will be reviewed in the following section.

2.3 Empirical support for age-related decline in speed of information processing

2.3.1 Reaction time studies

The measurement of reaction time (RT) is one of the commonest paradigms used to isolate speed of information processing. Pachella (1974) defines RT as the time between the onset of a particular stimulus and initiation of the appropriate response to it.

Traditionally, RT tasks have been dichotomised as either simple (that is, a single stimulus associated with a particular response) or complex (that is, involving choice between competing stimuli and response alternatives). A large number of studies have been conducted comparing young and elderly adults on such tasks. Early work in the area was not as methodologically sophisticated as more recent work and employed relatively gross performance measures like card sorting time (Botwinick, Robbin & Brinley, 1960; Crossman & Szafran, 1956), time to lift a stylus in response to light onset (Griew, 1959) and time to respond to a light by jumping in the air (Onishi, 1966).

A number of reviews of the literature on ageing and RT are available (Birren, Woods & Williams, 1980; Salthouse, 1985a; Welford, 1977). The most consistent finding is that slowing with age occurs in both simple (SRT) and choice reaction time (CRT) tasks (Botwinick, Robbin & Brinley, 1960; Deupree & Simon, 1963; Era, Jokela & Heikkinen, 1986; Lindholm & Parkinson, 1983; Vrtunski, Patterson & Hill, 1984; Waugh, Fozard, Talland & Erwin, 1973; Wilkinson & Allison, 1989). Age differences have been found in both movement and decision time components of RT tasks that supposedly uncouple these components (Baylor & Spirduso, 1988; Clarkson, 1978; Era, Jokela & Heikkinen, 1986; Spirduso, 1975). Both inter- and intra-individual differences in speed of processing are found to increase with age (Birren, 1974). The absolute magnitude of the age difference varies as a function of task demands; and group differences increase with task difficulty or complexity (Birren, 1965; Birren & Botwinick, 1955a; Cerella, 1985; Era, Jokela & Heikkinen, 1986; Lindholm & Parkinson, 1983).

Welford (1977) reviewed 21 studies that compared young and elderly adults on SRT tasks and reported a median percentage increase of 26% in SRT from the third to the seventh decade. Salthouse (1985a) reviewed 50 studies using RT as a dependent variable

and suggested that the age difference on RT varies between 20% and 60%, reflecting an increase of between 5% and 15% per decade between the ages of 20 and 60 years. He reported correlations with age from SRT studies which range from $r=.19$ (Surwillo, 1963) to $r=.47$ (Potvin et al., 1973) with a median correlation of $r=.28$. For CRT studies the range of correlations is from $r=.22$ (Borkan & Norris, 1980) to $r=.64$ (Thomas et al., 1977) with a median correlation of $r=.43$.

Early work suggested that SRT differences with age are greater than reflex times (Magladery et al., 1958) and are not due simply to the activation time of muscles (Botwinick & Thompson, 1966; Weiss, 1965). Birren and Botwinick's (1955b) comparison of auditory RTs for foot, finger and jaw responses showed that, although the elderly were slower in all three modalities, this was not associated with the length of the peripheral pathways. Differences in the rate of transmission of information along peripheral nerves appear to make only a very minor contribution, suggesting that the age change is central rather than peripheral in origin (LaFratta & Canestrari, 1966; Welford, 1977; Weiss, 1965).

Both young and elderly adults have been found to shorten their RTs in response to both motivational imperatives (Botwinick, Brinley & Robbin, 1958; Perone & Baron, 1983) and opportunities for practice (Baron & Menich, 1985; Salthouse & Somberg, 1982b). Although group differences tend to remain after such manipulations, Falduto and Baron (1986) did find that practice attenuated the age-complexity relationship. There is some evidence that RT is influenced by general health (Abrahams & Birren, 1973; Spieth, 1964) and physical fitness level (Baylor & Spirduso, 1988; Rikli & Busch, 1986; Spirduso, 1975). However, such factors appear to reduce rather than remove age differences.

A number of researchers using CRT have been interested in group differences in the regression function relating RT to the degree of choice. Consistent with Hick's Law (Hick, 1952) RT is a linear function of the amount of information (expressed in terms of bits) for both young and old subjects (Suci, Davidoff & Surwillo, 1960). The focus of research has been on whether group differences are best expressed in terms of the slope of the function or whether age adds a constant amount to all degrees of choice. The equation relating RT

to choice is given below (Equation 1), and a discussion of the various parameters may be found in Welford (1977, p 467).

$$RT = A + BX \quad (1)$$

where A reflects the time taken by peripheral processes concerned with input and output rather than choice; B reflects central decision processes concerned with the link between signals and responses; and X reflects the degree of choice available.

Early empirical evidence regarding whether age primarily affects parameter A (peripheral processes) or parameter B (central processes) was equivocal. Some workers reported an increase in A rather than B (Crossman and Szafran, 1956; Botwinick, Robbin, & Brinley, 1960; Szafran, 1966). Others found a rise in B (Birren & Botwinick, 1955a; Griew, 1959, 1964; Suci, Davidoff & Surwillo, 1960; Talland & Cairnie, 1961). Welford (1977) suggested that such findings can be reconciled by considering the amount of time the stimulus array was available to the subject for examination. Elderly adults tend to be disproportionately slower where the stimulus exposure duration is long, but less differential slowing is noted when very short exposure durations are used. These findings suggest that where information is available, elderly adults will continue to sample from the stimulus display, reflecting their adoption of more cautious strategies for decision making. This interpretation is consistent with the notion introduced in section 2.2.1 that elderly adults may adopt response criteria that compensate for increasing levels of noise.

The existence of this speed-accuracy trade-off has, however, led to methodological and interpretive difficulties when RT measures are adopted as dependent variables. RT differences may be misinterpreted as reflecting differences in basic speed of information processing if speed-accuracy criteria are not taken into account (Pachella, 1974). In response, some researchers have examined speed of processing using procedures where the experimenter rather than the subject controls the duration for which stimuli are available for processing. The measure of the rate of information processing thus derived from accuracy as a function of stimulus duration is independent of the speed of responding; the index of processing efficiency is provided by response accuracy. Visual masking and

tachistoscopic presentation are two such procedures that have been utilised to examine age differences in speed of processing.

2.3.2 Visual masking and tachistoscopic presentation studies

The visual masking procedure is based on the assumption of a brief sensory store as the earliest stage in the information processing system (following Sperling, 1960). Information from the environment is assumed to first enter this sensory buffer which in the visual modality is referred to as the iconic store. Initial registration involves a representative sensory trace of brief duration, from which information is encoded when transferring to short-term memory. In a typical visual masking study, the subject must discriminate or identify a particular target stimulus. The exposure duration of the target stimulus is manipulated by superimposing a masking stimulus, the presence of which has been assumed to halt processing from the sensory register (Kahnemann, 1968; Felsten & Wasserman, 1980).

The locus of the visual masking effect has been delineated by Turvey (1973), who argued that the mask can either integrate with the target at an early peripheral stage, thereby degrading further processing; or it can interrupt processing at a later central level. For peripheral masking to occur, the mask must have a higher energy level than the target, and target and mask should be presented in succession to the same eye. In such cases the level of target energy is multiplicatively related to the interstimulus interval (ISI) required to escape masking. Central masking, however, is dependent of the similarity of the target and mask and the relationship between target energy and ISI is additive (Walsh, Williams & Hertzog, 1979). Felsten and Wasserman (1980), however, while acknowledging that Turvey's (1973) mathematical formulations are valid in certain conditions, have argued that all masking is integrative.

Mode of target and mask presentation can be varied: if both are presented to one eye, masking is monoptic; if they are presented to both eyes, it is binocular; and if the target goes to one eye and the mask to the other, presentation is said to be dichoptic. Although central masking may occur in any of these presentations, peripheral masking is

not possible with a dichoptic procedure. The researcher manipulates the target duration and the time between target offset and mask onset (ISI). Stimulus-onset-asynchrony (SOA) refers to the time separating the onset of target and the onset of the mask (SOA = target duration plus ISI); and researchers measure the critical SOA required to reach a preset level of accuracy.

Research has examined whether the effects of ageing are more pronounced for peripheral or central processes. Walsh, Till and Williams (1978) used a monoptic presentation with a random noise mask and examined SOA as a function of target energy. SOAs were found to be longer for elderly subjects leading to the conclusion that they processed the stimuli more slowly at all target energy levels. Because masking was assumed to be operating peripherally, the result suggests a slowing in the speed of peripheral processing with age. Kline and Szafran (1975) also used a monoptic presentation and found that elderly (mean age, 66) subjects were susceptible to peripheral masking effects over longer ISIs than were the young (mean age, 23). Till and Franklin (1981) used a monoptic presentation and found age changes in performance with both random noise and patterned stimuli masks. They interpreted this outcome as reflecting a small but reliable age difference in peripheral processing and a more pronounced rate of decay in central processing. Kline and Birren's (1975) finding of masking over longer ISIs among elderly adults (mean age, 69) than the young (mean age, 23) using a dichoptic presentation is consistent with this suggestion of substantial slowing of central processes. These workers also found that mean ISI threshold of middle aged adults (mean age, 47) was intermediate, suggesting that slowing with age occurs gradually across the lifespan.

Walsh (1976) examined the magnitude of central slowing and found elderly adults' SOAs were 24% longer than those of the young. The data of both groups were well described by the additive rule, consistent with a central masking effect. Walsh, Williams and Hertzog (1979) found 33% slowing in elderly adults using a dichoptic procedure. Cerella, Poon and Fozard (1982) found a 20% to 30% increase in backward masking threshold between young and elderly adults for their letter identification task. Similar

slowing with age is reported by Eriksen and Steffy (1964) and Cramer, Kietzman and Van Laer (1982), who used more complex stimuli.

There is some evidence that this decline in speed of processing is not due simply to differential practice effects. Hertzog, Williams and Walsh (1976) showed that age differences in central masking performance remained after five days of practice. Practice did reduce SOA both within and across days but the magnitude of the effect was equivalent for both young (mean age, 18) and elderly (mean age, 66) adults.

Di Lollo, Arnett and Kruk (1982) examined the performance of adults in four age groups (19-31; 45-57; 58-70; 71-83 years) on backward masking and temporal integration tasks. The former was thought to reflect central and the latter peripheral processes. They found a progressive slowing with age in the critical ISI required for 75% accuracy in the masking tasks, consistent with a gradual decline in speed of central processing across the full range of ages, from early adulthood to old age. Visual persistence impairments, however, did not occur until after 60 years of age, suggesting that separate mechanisms underlie the two types of processing; and that diminished peripheral processing is not generally a problem until beyond the fifth decade.

Visual masking studies have also examined changes in cortical functioning and rates of hemispheric deterioration with age (Byrd & Moscovitch, 1984; Nebes, Madden & Berg, 1983). The performance of elderly adults is generally poorer than that of the young in such tasks. Others workers have compared elderly adults with Alzheimer's disease to young and normal elderly adults (Coyne, Liss & Geckler, 1984; Schlotterer, Moscovitch and Crapper-McLaughlin, 1984). Results indicate an accelerated rate of decay in central visual functioning among Alzheimer's patients, over and above that found in normal ageing. Such findings provide convergent support for the notion that the slowing in central processing found with normal ageing may be related to physiological changes occurring in the nervous system.

An index known as Inspection Time (IT) uses the backward masking procedure to isolate the critical SOA required to reach near perfect response accuracy on a forced two-choice discrimination task (Vickers, Nettelbeck & Willson, 1972). Unpublished data (cited

by Nettelbeck, 1982) has suggested that IT is longer in the elderly. This is consistent with the work reviewed above on other masking procedures, which has suggested age-related slowing in the processing of information and with a recently published study on the relationship between IT and cognitive performance in the elderly by Nettelbeck and Rabbitt (1992).

Performance on tachistoscopic perception tasks is poorer in the elderly (Rajalakshmi & Jeeves, 1963; Salthouse, 1976; Schonfield & Wenger, 1975) and there is some evidence from visual masking studies that elderly subjects require longer exposure durations for the perception of unmasked stimuli (Coyne 1981; Kline & Szafran, 1975; Till 1978; Walsh, Till & Williams, 1978). Eriksen et al. (1970) found an age-related decline in the ability of elderly adults to identify a briefly exposed stimulus, even when age groups were equated for sensory thresholds. Results of such studies are consistent with the suggestion that ageing is associated with a decline in the speed of encoding information (Hines, Poon, Cerella & Fozard, 1982; Simon & Pouraghabagher, 1978).

A number of studies have examined iconic memory as a function of age (Charman, 1979; Salthouse, 1976; Walsh & Thompson, 1975). Gilmore, Allan and Royer (1986), however, have argued that most attempts to measure iconic memory in elderly adults using partial report procedures have suffered from methodological flaws. Their own study showed that this procedure could be used successfully and that, consistent with earlier studies, under conditions where SOA was controlled, young adults achieved higher accuracy in a partial report procedure than the elderly.

Thus, evidence from backward masking and tachistoscopic presentation studies suggests (i) that both peripheral and central processes are slowed with age, the latter more markedly than the former; (ii) that central decline is gradual and progressive across the adult age span whereas peripheral decline occurs after about 60 years of age; and (iii) that results are not due simply to differential practice effects. Similar conclusions concerning speed of processing were reached on the basis of RT studies reviewed in section 2.3.1. Recent work has examined decline with age in speed of processing using more complex paper and pencil tests such as the Digit Symbol Substitution (DSS) subtest from the WAIS-

R (Wechsler, 1981) and indices of perceptual speed derived from the Educational Testing Services Reference Kit (ETS) (Ekstrom, French, Harman & Derman, 1976). This work is reviewed in the section to follow.

2.3.3 Clerical speed and the Digit Symbol Substitution test

Salthouse (1985b) suggested that the DSS be employed as a standardised test of speed of processing because associated age effects are both reliable and well documented. In the DSS test subjects are presented with a code key in which the numbers from one to nine are each associated with a particular symbol; below this, boxes showing numbers but not symbols are presented and the subject's task is to reproduce as many of the symbols as possible in 90 seconds.

Of the eleven subtests of the WAIS-R, the DSS shows the most marked decline with age (Wechsler, 1981). Correlations between age and DSS performance have been reported as approximately $r = -.50$ (Birren & Morrison, 1961; Kaufman, Reynolds & McLean, 1989; Salthouse, 1978, 1992a). Somewhat higher correlations have been found in studies employing a version of the DSS in which digits are reproduced for symbols rather than vice versa (Gilmore, Royer & Gruhn, 1983; Royer, Gilmore & Gruhn, 1981). Salthouse (1992a) found that age is associated with a shift in the distribution of DSS scores but not with an increase in variance. He interpreted this as evidence for the view that the decline with age is normative rather than simply reflecting the impact of a small number of extreme scorers among the elderly group.

A number of studies have examined possible causes for the decline in DSS performance with age. Age differences have been found at various levels of practice (Erber, 1976; Erber, Botwinick & Storandt, 1981; Grant, Storandt & Botwinick, 1978; Salthouse, 1978). Beres and Baron (1981) examined 100 administrations of the DSS over a five day period and found that although the performance of young and elderly women improved both between and within test sessions, groups differences remained. Grant, Storandt and Botwinick (1978) manipulated incentive levels and found that differential levels of motivation levels were unlikely to account for the age effect. Similarly, Erber et

al. (1981) found that the decline was not accounted for by "over cautiousness" (that is, rechecking responses against the coding key) on the part of the elderly.

Storandt (1976) found that in both young and elderly adults, only 50% of the time taken to complete the DSS task was taken up by psychomotor components, suggesting that group differences cannot be explained solely in terms of this factor. This finding was supported by Erber (1986) and Salthouse (1988a, 1992a) who showed that the time taken to write symbols was similar in groups of young and elderly adults, and by Salthouse, Kausler and Saults (1988a) who found that age differences remained when responses involved simply indicating whether particular pairings of digits and symbols were correct.

Salthouse (1978) suggested that memory factors are responsible for only a very small part of the age declines found. This is consistent with Erber et al's (1981) finding, that groups differences remained after participants were trained to equal criterion levels on the task. Although acknowledging that sensory and motor mechanisms contribute to DSS performance, Salthouse (1992a) suggested that the main cause of DSS slowing is centrally located.

Consistent with work on DSS, a decline in speed of perceptual processing was found by Salthouse (1991) using a paper and pencil test with same/different judgements for letter and pattern pairs. Other tests utilised to examine speed of perceptual comparisons include the Finding As and the Identical Pictures tests of the Educational Testing Services Reference Kit (ETS) (Ekstrom, French, Harman & Derman, 1976). Elderly adults have been found to be slower on such indices (Cornelius, Willis, Nesselroade and Baltes, 1983; Cunningham, 1987; Cunningham, White & Smook, 1985; Hertzog, 1989; Schaie, 1989).

2.3.4 The slowing hypothesis

From the foregoing, it is clear that evidence from a range of procedures has consistently shown that ageing is associated with a decline in speed of processing, which is not accounted for simply by recourse to conceptual or methodological considerations such as practice effects. There are, however, exceptions to this slowing - automatic linguistic functions, for instance, are thought to show minimal declines with age (Cerella & Fozard,

1984). The pattern of age decline has been described as minimal for certain linguistic functions, moderate for input and encoding and severe for central and intentional processes (Cerella DiCara, Williams and Bowles, 1986). The ubiquitousness of the slowing-with-age phenomenon has led to the development of *the slowing hypothesis*.

The slowing hypothesis assumes that the main consequence of ageing is a reduction in the speed of information processing and this, in turn, is based on a number of assumptions. The first is that the decline in speed is general rather than specific in application; that is, all stages of processing are constrained by this limitation. Empirical attempts to isolate the stage responsible for age-related decline provide evidence consistent with this assumption. Deficits have been found in stimulus encoding (Adamowicz, 1976; Hines, Poon, Cerella & Fozard, 1982; Simon, 1968; Simon & Pouraghabagher, 1978), central comparison (Anders & Fozard, 1973; Cerella, Poon & Fozard, 1981; Gaylord & Marsh, 1975) and response selection and organisation (Gaylord & Marsh, 1975; Vrtunski, Patterson & Hill, 1984; Waugh, Fozard, Talland & Erwin 1973). Indeed, Salthouse and Somberg (1982a) found that age interacted with manipulations designed to influence all of these processing stages.

The second assumption is that the speed decline is maturational in nature; that is, it reflects biological limitations of the ageing individual and aspects of performance such as strategy use and motivation are assumed not to account for the decline. Some workers, however, have suggested that apparent age differences in speed of processing may be the result of differential strategy use, rather than physiological deterioration (Jacewicz & Hartley, 1979; Macht & Buschke, 1984). Certainly there is evidence that elderly adults are (i) more cautious in decision making (Botwinick, Brinley & Robbin, 1958; Okun 1976; Rees & Botwinick, 1971; Rush, Panek & Russel, 1986); (ii) tend to adopt less efficient processing strategies than the young (Craik, 1977; Salthouse & Somberg, 1982b); and, (iii) are less efficient at executing strategies that have a high processing load (Cohen & Faulkner, 1983). Denney (1980) has suggested that the elderly may have more efficient strategies in their repertoires than they actually use. Higher levels of anxiety among elderly adults are also thought to contribute to age differences in speed (Mueller, Kausler,

Faherty & Oliveri, 1980). However, studies reviewed in section 2.3 were consistent with the notion that, although factors like practice, motivation and strategy use contribute to group differences, they are not sufficient to account for them. Differences are attenuated but not removed when such factors are taken into account.

Researchers have distinguished between the strong and the weak versions of the slowing hypothesis. The former postulates the existence of a single generalised deficit which controls the timing of all behavioural variables (Birren, 1964, 1974; Birren, Woods & Williams, 1980; Salthouse, 1982), whereas the latter considers that multiple independent deficits may be operating on different subsystems in the information processing system. Distinguishing empirically between the two versions of the theory should be straightforward: a single mechanism should produce a proportional amount of slowing with age across a variety of tasks; multiple mechanisms should produce a pattern which varies from task to task. Indeed, the focus of recent debate has been on delineating appropriate techniques for isolating the type of slowing one is dealing with in a particular task (Kliegl & Mayr 1992; Salthouse, 1992b; Schaie 1992).

Following Brinley (1965), a number of attempts have been made to model speed changes in terms of a function which describes the performance of elderly adults in relation to the performance of young adults. Salthouse (1985a) differentiated between two models that have received attention in the literature. Ageing can have either an additive (Welford, 1981) or a multiplicative effect (Birren et al., 1980) on latencies. The former model emphasises changes in sensory motor factors and the latter, central or decision making factors.

Some workers have found that task latencies among elderly adults are well described as a multiplicative function of those of the young, with no recourse to task demands being necessary (Salthouse, 1978; Cerella, Poon & Williams, 1980). Others, however, have found that data do not necessarily fit one multiplicative function. Cerella (1985) evaluated 189 information processing tasks and was able to account for 90% of the variance in elderly latencies by assuming a single multiplicative factor (slowing by 36%); however data were best explained by two multiplicative functions which differentiated

sensory motor and higher order slowing, with the latter being more severely affected than the former. Ninety six percent of the variance was accounted for with slowing by 25% and 50%, for sensory motor and higher order factors, respectively. Smith, Poon, Hale and Myerson (1988) analysed data from Cerella et al. (1986) and found linear functions were also appropriate for plotting medians and other percentile points in young and elderly adults. Hale, Myerson and Wagstaff (1987), however, suggest that, where difficult tasks are involved, power functions may be more appropriate than linear functions for summarising age effects.

Cerella (1991) has argued for the existence of one general rather than many specific mechanisms; that is, he assumes that neither additive nor proportionate slowing factors vary across tasks. Cerella (1991) reinterpreted data from a visual search study by Fisk and Rogers (1991) and suggested that age effects found in visual search performance could be accounted for by task independent slowing, with no need to postulate the existence of attentional deficits. In other words, he suggested that ageing effects are uniform (a generalised slowing of all processes) rather than task dependent. Other workers, however, have found age-related changes on visual search tasks that are independent of generalised slowing (Allen, Weber & May, 1993; Madden, 1990a).

Recent debate in the literature has concerned whether proportionate slowing does in fact vary with the type of task administered (Baron & Matilla, 1989; Cerella, 1991; Fisk & Rogers, 1991; Hertzog, Raskind & Cannon, 1986; Rogers & Fisk, 1990). Many workers acknowledge the necessity of postulating both general and specific mechanisms which may be affected by age (Kail, 1991, Myerson, Hale, Wagstaff, Poon & Smith, 1990). Hertzog, Raskind and Cannon (1986), for example, found that speed of access to semantic memory was independent of nonverbal CRT - both showed a mean difference with age but different patterns of correlations were found in young and elderly groups, suggesting independent effects in different functional subsystems and individual differences in the degree of slowing. The conclusion that slowing is not universal across all functions is also consistent with a recent study by Nettelbeck and Rabbitt (1992) in which speed was found to predict performance with age on tests of fluid ability but not aspects of memory performance.

The divergent conclusions reached by researchers concerning the strong and weak versions of the slowing hypothesis mean that the issue must still be considered unresolved. There is, however, no doubt that strong empirical support exists for the notion that one of the primary effects of ageing is a reduction in the speed with which processing occurs. A second focus for debate concerning reduction in the resources available for processing with age has concentrated on attentional indices of performance.

2.4 Attentional indices of processing resources

Attention has been viewed as both a structural property and a dynamic limitation within the information processing system (see Salthouse, 1982, for a review). It is a multifaceted concept and attempts to provide operational definitions have covered a wide range of interpretations (Parasuraman & Davies, 1984). Some common themes do emerge, however. Stankov (1988) isolated six experimental procedures used to examine attention: (i) concentration; (ii) visual search; (iii) divided attention; (iv) selective attention; (v) vigilance; and, (vi) attention switching. Similarly, Cornelius, Willis, Nesselroade and Baltes (1983), who examined the convergence of attentional variables with psychometric intelligence in the elderly, operationally defined attention in terms of (i) decoding or access to over-learned codes; (ii) selectivity; (iii) switching; and, (iv) concentration.

Kinsbourne (1980) has suggested that CNS changes such as neuronal depletion and focal damage may compromise the integrity of such attentional processes in the elderly. Consistent with this, Stankov (1988) found age-related declines in three aspects of attentional functioning: search, concentration and attentional flexibility. Theorists have argued that ageing is associated with either a decline in the amount of attentional resources available for processing or in a less efficient allocation of such resources (Hunt & Hertzog, 1981). The latter interpretation is consistent with the notion that declines with age are the result of less effective control processes (Gottsdanker, 1982).

Attempts to measure the capacity available for processing have typically involved the use of dual task procedures. Craik (1977), for example, suggested that where capacity is taken up by programming the division of attention, elderly adults will have less available

for processing. There is some evidence that the performance of the elderly on dichotic listening tasks is poorer than that of the young (Clark & Knowles, 1973; Parkinson, Lindholm & Urell, 1980;). Some studies suggest that the elderly are less able in general to divide attention across activities (Broadbent & Heron, 1962; Burke & Light, 1981; Craik, 1977; Parkinson, Lindholm & Urell, 1980; Wright, 1981). Others, however, report no age decrement in dual-task performance (Braune & Wickens, 1985; Salthouse & Somberg, 1982b; Stankov, 1986; Wickens, Braune & Stokes, 1987). Salthouse (1982) has questioned the assumptions underlying dual-task studies and has urged caution when such data are interpreted in terms of a reduction in processing resources.

Decrements in selective attention with age have been noted (Hoyer, Rebok & Sved, 1979; Jordan & Rabbitt, 1977; Layton, 1975; Madden, 1990b; Rabbitt, 1965, 1979). These findings have been interpreted in terms of an age-related reduction in either the ability to ignore irrelevant stimuli (Rabbitt, 1964, 1967) or the ability to discriminate relevant from irrelevant stimuli (Wright & Elias, 1979). It has been suggested that such effects are responsible for age-related visual search effects (Plude & Hoyer, 1986). As was indicated in section 2.2.1, attempts have also been made to account for increased distractibility and certain visual search effects by recourse to increasing levels of internal noise among elderly adults (Allen 1990; Allen, Groth, Weber & Madden, 1992). Indeed, Allen, Weber and May (1993) suggest that an internal noise model provides a more parsimonious account of visual search effects than does a selective attention model. Although these workers were not able to distinguish empirically between these two models, they did find that visual search effects were not accounted for simply by generalised slowing.

Rabbitt and Vyas (1980) have accounted for certain selective attention findings by distinguishing between data-driven and memory-driven selective processes. The former are thought to involve control by external events and are relatively unaffected by age; the latter involve the use of previous experience to adjust selectivity actively and are associated with an age-decrement. Madden (1984), however, suggested that age differences in selective attention are not completely due to memory-driven processes. There is some support for the suggestion that certain processes conceptualised as "automatic" (that is, not

directly dependent on conscious control) appear to operate independently of capacity allocation (Kahnemann, 1973; Schneider & Shiffrin, 1977), and that such processes remain relatively intact with age (Hasher & Zacks, 1979).

The well-documented age-complexity effect is consistent with the notion that ageing is associated with a decline in capacity (Wright, 1981). Similarly, evidence of age-related decline in the rate of search on consistent and varied mapping tasks has been interpreted as evidence for an age-related reduction in the amount or allocation of processing resources (Plude, Kaye, Hoyer, Post, Saynisch & Halin, 1983). However, no age differences have been reported in the development of automatic processes (Berg, Hertzog & Hunt, 1982; Madden & Nebes, 1980; Plude & Hoyer, 1981); the ability to allocate attention to a cue (Madden, 1985; Nissen & Corkin, 1985); or focussed attention (Nebes & Madden, 1983). Support for the notion that ageing is associated with an attentional deficit, then, remains somewhat equivocal.

Salthouse (1982) has provided a critique of the procedures that have been used to measure processing resources in terms of attentional capacity, both directly and indirectly, and suggested that findings are unclear, with interpretation constrained by methodological shortcomings. Additionally, he suggested that the task dependent nature of the deficits obtained in studies of attentional indices of resources can be more parsimoniously accounted for in terms of the slowing hypothesis (see also Cerella, 1991). However, in a recent paper which examined speed mediation of performance on certain memory, reasoning and spatial tests, Salthouse stated that "it is not yet apparent whether cognitive operation speed is a fundamental construct or whether it is a consequence of something even more basic, such as a reduction in certain attentional processes" (Salthouse, 1993, p737). Thus, although the evidence for a reduction in processing resources has been expressed in terms of both attentional and speed indices, and it is clear that support for the latter is stronger than the former, both conceptualisations remain worthy of consideration.

2.5 Are cognitive changes a consequence of reduced processing resources ?

Although the reduction in processing resources occurring with age is well documented in the literature, it is the impact of this phenomenon on broader aspects of cognitive functioning that has provided the focus for recent research. There is a large body of evidence concerning changes with age in cognitive abilities and a number of reviews of this area are available (Cunningham, 1987; Denney, 1982; Horn & Donaldson, 1980; Schaie, 1983; Salthouse, 1982). A brief overview of the main findings of work on intellectual functioning will be given here and the utility of speed and attention in accounting for age-related changes will be considered.

2.5.1 The pattern of cognitive changes (psychometric work)

Both longitudinal and cross-sectional studies have reported what Botwinick (1977) calls the "classic" pattern of ageing; that is, a marked decline in abstract reasoning and performance abilities but relatively little change in verbal abilities, at least until the seventh decade of life (Horn & Cattell, 1967; Rabbitt, 1990; Salthouse, 1982; Siegler, 1983). It has been suggested that such changes are independent of generational differences (Schaie & Hertzog, 1983, 1986). However, although similar patterns of change have been documented in both longitudinal and cross-sectional studies, the former report later age of onset and less severe rates of decline than the latter (Denney, 1982).

Salthouse (1982) reviewed studies that have examined performance on the WAIS and WAIS-R (Wechsler, 1955, 1981), providing a summary of the patterns of performance with age across the eleven subscales. He suggested that there is no evidence for systematic decline with age in verbal abilities. Perceptual-motor speed, memory and spatial abilities, however, all show decline in performance beginning after about the third decade of life. Declines of 5% per decade have been noted for the Object Assembly and Picture Completion subtests; Block Design and Picture Arrangement showed declines of 8% and 10%, respectively. Consistent with evidence cited in section 2.3.3, a decline of 10% per decade was found for the Digit Symbol Substitution test. Subtests on the WAIS and WAIS-R can be used to produce composite scores for Performance and Verbal IQ, with the former showing more of an age decline than the latter (Sattler, 1982).

Marked declines with age have also been noted in tests of analogical reasoning such as Raven Progressive Matrices (Cerella, Di Cara, Williams & Bowles, 1986; Cunningham, Clayton & Overton, 1975; Mergler & Hoyer, 1981; Raven, 1948). It has been suggested that the decline begins after the fourth decade of life and proceeds at a rate of approximately 10% per decade (Salthouse, 1982). Declines with age in Raven's Coloured Progressive Matrices have also been found after the effects of education level have been controlled statistically (Panek & Stoner, 1980). Salthouse (1985b) has reviewed a number of studies concerned with reasoning and problem solving, reporting negative correlations with age ranging from $r = -.12$ (Arenberg, 1974) to $r = -.64$ (Heron & Chown, 1967), with a median correlation of $r = -.36$.

A descriptive framework that incorporates the well-documented developmental changes is provided by the Horn-Cattell model of intelligence (Cattell 1971, Horn, 1976, 1982; Horn & Donaldson, 1976, 1980). The model is based on second-order factor analysis of primary mental abilities and distinguishes between two broad ability factors referred to as fluid (Gf) and crystallised (Gc) general intelligence. The former is concerned with drawing inferences, abstract reasoning, problem solving and the integration of new material and is thought to be related to the neurophysiological status of the individual. Gc is concerned with the accumulation of knowledge over time and is reflected in tests such as vocabulary and verbal comprehension. Gc is assumed to reflect educational attainment and the process of acculturation.

Fluid intelligence has been found to increase until early adulthood and thereafter decline whereas crystallised intelligence remains stable or increases throughout adulthood, at least until the sixties (Hayslip & Sterns, 1979; Horn & Cattell 1967; Horn, 1985). The rise in Gc over the life span is thought to be approximately equal in magnitude to the decline in Gf, so that on a composite measure, no systematic rise or fall would be expected in intelligence (Horn & Cattell, 1967). The Gf-Gc dichotomy provides a useful descriptive system for summarising age changes in performance. Salthouse (1982, p70), however, is critical of the fact that the classification of abilities appears to be based on *ad hoc* rather than *a priori* considerations. In an attempt to increase the explanatory power of the model,

Horn (1975) has suggested that Gf and Gc might be based on diffuse and specific neural activity, respectively.

Consistent with this, Salthouse (1985b) has argued that the effects of ageing on both speed of processing and cognitive performance are superficially similar to the impact of diffuse brain damage and thus reflect gradual biological processes occurring as part of "normal" rather than "pathological" ageing. Certainly, there is evidence that certain neuronal degenerative changes associated with forms of dementia are also found to a lesser extent in nonclinical populations of elderly adults (see La Rue & Jarvik, 1982, for a review).

One interpretation of ageing effects suggests that apparent group differences in cognitive performance in cross-sectional studies are the result of averaging artefacts resulting from the inclusion of individuals suffering from CNS pathologies (Rabbitt, 1990; Siegler, 1975). It has been suggested that, instead, cognitive decline occurs as a "terminal drop" rather than a gradual decline (Kleemeier, 1962; Riegel & Riegel, 1972, Rabbitt, 1990). Functioning is assumed to remain fairly stable until the five-year period immediately prior to death, with distance from death thus correlating with intellectual capacity. There is some support for the view that individual differences in health and lifestyle may mediate the increase in variability and the decline in cognitive performance found with age (Field, Schaie & Leino, 1988; Perlmutter & Nyquist, 1990). There is disagreement, however, regarding whether the terminal drop effect is pervasive or restricted to specific abilities (Birren, 1965; Blum, Clark & Jarvik, 1973; Johansson & Berg, 1989; Manton, Siegler and Woodbury, 1986; Siegler, McCarty & Logue, 1982).

White and Cunningham (1988) examined terminal drop effects on measures of vocabulary, numerical ability and perceptual speed and found that the decline occurred within two years of death and was restricted to verbal abilities. This finding is consistent with the work of Birren (1965), who suggested that vocabulary scores but not speed of processing will show a terminal drop. It is likely then that although declining health is undoubtedly related to the observed age changes in cognitive functioning, the terminal drop phenomenon is restricted to those abilities that are relatively immune to the effects of

ageing. A moderate position then would be to consider that its effects are specific rather than pervasive; and that they occur in addition to, rather than in place of, the gradual biological changes that are part of normal ageing.

According to the slowing hypothesis, gradual biological changes occurring with age lead to a reduction in the resources available for processing, which in turn constrain cognitive functioning. This claim can be tested empirically and recent work has examined the relationship between measures of speed and attention and the intellectual functioning of both young and elderly adults.

2.5.2 The relationship between age, cognitive performance and speed of processing.

A number of theorists have suggested that speed of information processing reflects the efficiency of the CNS (Eysenck, 1987; Hendrickson & Hendrickson, 1980; Vernon, 1987; Weiss, 1986) and that speed is thus a major contributor to intelligence (Anderson, 1992; Carroll, 1980; Hunt, 1983). Differences in the rate of information processing have been included in a number of accounts of individual differences in intellectual functioning (Eysenck, 1967; Furneaux 1960; Thurstone, 1938). Similarly, group differences in processing speed have been linked to group differences in cognitive functioning - for instance, in comparisons of intellectually retarded and nonretarded persons (Brand & Deary, 1982; Jensen, 1982; Nettelbeck 1985; Nettelbeck & Brewer, 1981).

The suggestion that slowing is the primary cause of cognitive decline in the elderly is supported by (i) the decline found with age in indices of both speed and cognition discussed in sections 2.3 and 2.5.1; (ii) the correlations found between speed and intelligence across the life span (see Eysenck, 1987; Salthouse, 1985b for reviews); and, (iii) studies which suggest that age-cognition correlations are severely attenuated after variance due to speed is partialled out.

Consider firstly then the relationship between measures of timed performance and intelligence. Numerous studies have reported negative correlations between measures of intelligence and various parameters of reaction time performance in children and young adults (Cohn, Carlson & Jensen, 1985; Frearson & Eysenck, 1986; Jensen, 1980a,b;

1982a,b; 1985; Jensen & Munro, 1979; Levine, Preddy & Thorndike, 1987; Smith & Stanley, 1983; Vernon & Jensen, 1984; Vernon, 1983). Vernon (1986) suggested that higher correlation between RT and intelligence are found as RT complexity increases. It has been suggested that various parameters of RT tasks can account for up to 20% of the variance in IQ (Paul, 1984). In addition, correlations remain when intelligence tests are done without time constraints (Vernon, 1987; Vernon & Kantor, 1986; Vernon, Nador & Kantor, 1985). However, the extent to which such correlations are due simply to rate of processing rather than higher-order cognitive processes has been questioned (Longstreth, 1984).

A number of studies have examined the relationship between intelligence and indices of speed of processing derived using backward masking procedures. A great deal of work has been conducted using the Inspection Time (IT) index. A review of such work by Nettelbeck (1987) estimated that the true correlation between IT and a normally distributed range of IQ scores is of the order of $r = -.5$. Many studies have either found substantially higher correlations as a result of the inclusion of intellectually handicapped subjects; or, somewhat lower correlations as a result of attenuation in the IQ range (university students have typically been selected). However, Kranzler and Jensen (1989) have essentially confirmed Nettelbeck's (1987) conclusion on the basis of a meta-analysis of IT studies.

Attempts to examine the relationship between speed and intelligence have also been conducted among elderly adults. Negative correlations have been reported between susceptibility to backward masking and performance on the Information subtest of the WAIS-R and with rated levels of cognitive functioning among sufferers of Alzheimer's disease (Coyne, Liss & Geckler, 1984). Similar results have also been reported for nonclinical populations. Cerella, DiCara, Williams & Bowles (1986), for instance, found that although lexical processing remained intact with age, CRT and abstract reasoning ability declined. The intercept of the CRT function was found to correlate with abstract reasoning scores. Measures of perceptual speed have also been found to correlate with fluid intelligence in the elderly (Cornelius, Willis, Nesselroade & Baltes, 1983). Other

workers, however, have found information processing correlates for verbal but not abstract intelligence (Cerella & Fozard, 1984).

Clear support for the suggestion that speed mediates age-related decline in cognition is found in the attenuation of the age-cognition correlation by statistical control of speed of processing (Horn, Donaldson & Engstrom, 1981; Hertzog, 1989; Nettelbeck & Rabbitt, 1992; Salthouse, 1991; Salthouse & Babcock, 1991; Salthouse, Kausler & Saults, 1988b; Salthouse & Mitchell, 1990; Schaie, 1989). Salthouse (1993) summarised six studies that had at least 200 participants and an age range at least 35 years and suggested that variance in speed accounts for 80% of the variance in fluid abilities. However, controlling for speed is thought to have a smaller effect on certain aspects of memory performance (Nettelbeck & Rabbitt, 1992; Salthouse, 1993).

Attentional resources have also been the focus of attempts to account for individual differences in intelligence. It has been suggested that intelligence is related to either the ability to monitor multiple inputs or individual differences in the allocation and deployment of attentional resources (Hunt, 1980; Stankov, 1983). While there is some support for the suggestion that primary-secondary task performance is correlated with ability level (Hunt & Lansman, 1982; Lansman & Hunt, 1982), other workers have not found evidence establishing a link between attention and intelligence (Raz & Willerman, 1985; Stankov, 1987)

A number of studies have examined the relationship between attention and intelligence in the elderly. Botwinick and Storandt (1974), for instance, suggested that declines in fluid abilities are the result of deficits in concentration. Horn, Donaldson and Engstrom (1981) summarised a series of studies concerned with cognitive performance. Indices of attention derived from such work show a decline with age and are related to declines in fluid abilities (Horn, 1986). Cornelius, Willis, Nesselroade and Baltes (1983) examined the hypothesis that attentional measures would converge with factors of psychometric intelligence in elderly. These workers found that individual differences in attentional processes were more highly related to perceptual speed than to other major factors of intelligence. Stankov (1988) examined age changes in performance on 17

measures of attention and 19 psychometric tests. Statistical control of three attentional factors - search, concentration and flexibility - attenuated age-related declines in fluid abilities. The search factor isolated by Stankov (1988) is, essentially, an index of speed of processing indicating that *both* speed and attention may need to be considered in accounting for age-related cognitive changes.

2.6 Summary

Chapter 1 presented a simple reductionist model in which it was argued that age-related changes in the CNS lead to an increase in noise which, in turn, reduces the speed with which information processing occurs. Various changes in cognitive functioning associated with ageing are assumed to be a consequence of this decline in speed. This model is based upon the strong version of the slowing hypothesis. The preceding review has considered the empirical basis for this theoretical position. It has been shown that there is strong support for the suggestion that the primary behavioural manifestation of ageing is a decline in the speed of information processing and that this is related to cognitive performance. Revealing the nature of cognitive ageing will thus undoubtedly involve explicating the role of speed of processing.

A second strand of research reviewed has argued that age-related changes in attentional processes are responsible for changes in cognitive functioning in the elderly. Clearly, this argument has intuitive appeal for explaining the differential effects of age illustrated in the dichotomy between crystallised and fluid general intelligence. It has been shown, however, that support for the view that ageing is associated with a decline in attentional resources is more equivocal than that available on the link between age and speed. Clearly, both speed and attentional decline are consistent with the view that ageing is associated with a reduction in the resources available for processing but it is not clear which is the more "fundamental construct" (Salthouse, 1993, p737) or how such resources can best be conceptualised. The terms "attention", "capacity" and "resources" have tended to be used interchangeably by workers, resulting in a less clear distinction between these constructs than is desirable.

Workers adopting the slowing hypothesis have attempted to account for virtually all age-related declines in performance by recourse to speed. Clearly, however, support for the strong version of the slowing hypothesis is not unanimous and recent work by Stankov (1988) is consistent with the view that both speed and attention make unique contributions to the prediction of cognitive functioning in the elderly. Thus, neither speed nor attention may be sufficient, by themselves, to account for age-related changes in cognitive performance.

Decline in speed is certainly consistent with the notion that ageing is associated with an increase in internal noise in the CNS, although results of attempts to test the link between age and noise empirically have been rather more equivocal. Workers have utilised noise to account for aspects of both timed performance (Raz, Willerman, Ingmundson & Hanlon, 1983; Raz, Willerman & Yama, 1987; Salthouse, 1985a; Welford, 1977, 1980) and selective attention (Allen, 1990; Allen, Namazi, Patterson, Crozier & Groth, 1992), suggesting that the noise construct may have high explanatory power, being related to notions of both speed and attention.

In a reductionist analysis, noise and speed are assumed to represent different levels of an explanatory framework. Although evidence reviewed is undoubtedly consistent with the view that slowing of speed of response occurs to compensate for an increase in noise, it is also clear that other features, for example, strategic considerations, motivation, practice and general health also contribute to slowing with age. In addition, speed does not appear to be a unitary construct. It is far from clear what "speed" means; whether or not slowing is found depends, to some extent, on the nature of the task examined.

In Chapter 1 it was suggested that the impact of noise on performance is mediated by the level of redundancy in the information or structures associated with processing. This is consistent with the work on attention and indeed, suggests that, despite there being a causal link between noise and speed, these constructs may also produce independent effects on cognitive performance. Arguments that noise and speed of processing can be measured independently using a backward masking procedure (Vickers et al., 1972) and that the impact of noise on visual search performance occurs independently of generalised slowing

(Allen, Madden, Groth & Crozier, 1992; Allen, Weber & May, 1993) are consistent with this view.

Thus, while age differences found in speed of processing should be reduced when noise is controlled statistically, it is also suggested that, where noise can be measured independently of speed, the constructs should make unique contributions to predictions of cognitive performance in the elderly. To summarise then, the simple model outlined in Chapter 1 argued that age-related changes in cognitive performance can be reduced to speed of processing and that speed in turn can be reduced to the level of noise in the system. Evidence reviewed suggests that, consistent with the weak version of the slowing hypothesis, noise and speed, although causally linked, may also have independent impacts on cognitive performance and further, that their impact may be mediated by, and occur in addition to, attentional changes. The empirical work to be presented examines this model by (i) testing the strong version of the slowing hypothesis; (ii) attempting to derive independent indices of speed and noise; and (iii) examining whether such performance parameters make independent contributions to the prediction of cognitive performance among elderly adults.

CHAPTER THREE

OPERATIONALISING SPEED OF PROCESSING AND INTERNAL NOISE: ISSUES OF MEASUREMENT AND INTERPRETATION

3.1 Introduction

The aim of this chapter is to provide operational definitions for two of the constructs that were reviewed in Chapters 1 and 2. Specifically, noise as a limiting factor within the information processing system and an index of speed of processing known as Inspection Time (IT) will be considered, both being used in the empirical work presented in this thesis. Both IT and noise are assumed to reflect basic limitations in the discriminative capacity of the information processing system. Originally derived within the context of an accumulator model of psychophysical discrimination (Vickers, 1970, 1979), the indices were, however, selected because of demonstrated empirical robustness rather than on the strength of the theoretical underpinning of the accumulator model¹.

The selection of IT to test the hypothesis that age-related changes in cognitive functioning are the result of decline in speed of processing was based on a number of advantages to be gained in the use of backward masking procedures for comparisons of young and elderly adults; and on empirical work using IT that has demonstrated both developmental trends and a moderate relationship between the index and intellectual performance. This chapter will outline the techniques used to measure IT and noise. Consideration will be given to the advantages to be gained from using masking procedures for comparisons of young and elderly adults and to the way in which various conceptual and methodological issues that may constrain interpretation of IT findings have been addressed in this thesis. Finally, Experiment 1, a pilot study that compared estimates of IT and noise in young and elderly adults, will be presented.

¹ An overview of the accumulator model and the historical context within which indices of IT and noise were originally developed can be found in Vickers (1979).

3.2 Measuring Inspection Time (IT) and internal noise

IT is an index of speed of processing derived from response accuracy on a forced two-choice discrimination task presented using a backward masking procedure. The index is based on the idea that the duration required to make a correct judgement implies duration, and hence speed, of information processing. In the original IT task designed by Vickers, Nettelbeck and Willson (1972), the subject indicated which of two visually presented vertical lines was the longer. Line lengths were 28.8 mm and 38.4 mm for the shorter and longer lines, respectively and the position of the long line, either on the right or the left side, varied randomly from trial to trial. Lines were positioned 9.6 mm apart and viewed from a distance of 66 cm so that the difference between them subtended a visual angle of approximately 0.8 degrees. A backward mask was superimposed over the stimulus after a given exposure duration in an attempt to halt the accumulation of information from the sensory store. The mask is assumed to interrupt processing of the stimulus so that processing can only occur prior to mask onset (Kahnemann, 1968; Felsten & Wasserman, 1980). This period between the stimulus onset and mask onset is referred to the stimulus-onset-asynchrony (SOA). Thus, IT is the critical SOA required to reach a particular level of accuracy.

During trials, the discriminial difference between the stimulus lines is held constant while the exposure duration is varied and subsequently plotted against resulting response accuracy. Vickers et al. (1972) suggested that the theoretical function so derived will be negatively accelerating with an intercept of zero; that is, chance responding will occur when exposure duration is equal to zero. The curve is assumed to reflect the upper portion of a cumulative normal ogive. IT is then extrapolated to the exposure duration at which a subject's accuracy level reached 97.5% - a more conservative probability level for error-free performance which allows for subjective factors such as momentary lapses in attention (Vickers et al., 1972).

Developmental evidence suggests that IT decreases with age during childhood, reaching asymptote in adolescence (Nettelbeck & Wilson, 1985; Wilson & Nettelbeck,

1986). Consistent with evidence of age-related slowing found in other studies employing visual masking procedures, recent work suggests that estimates of IT lengthen in the elderly (Nettelbeck & Rabbitt, 1992). In addition, a number of studies have examined the relationship between IT and intellectual functioning. It has been suggested that the correlation between IT and a normally distributed range of IQ scores is of the order of $-.5$ (Kranzler & Jensen, 1989; Nettelbeck, 1987). On the basis of such findings, IT appears to be a promising prospect for examining the relationship between speed of processing and intellectual functioning in the elderly.

In addition, as an index of individual difference, IT appears to be reliable although it is undoubtedly subject to improvement over time, particularly at early levels of practice. Nettelbeck (1987) reviewed studies which adopted a range of different tasks and psychophysical procedures to estimate IT and reports test-retest correlations ranging from $r=.21$ (Nettelbeck, Hiron & Wilson, 1984) to $r=.92$ (Nettelbeck, Evans & Kirby, 1982) for samples of intellectually handicapped adults. Ranges for university students were similar: $r=.25$ (Nettelbeck et al., 1982) to $r=.91$ (Raz, Willerman, Ingmundson & Hanlon, 1983); and somewhat smaller for children: $r=.52$ to $r=.87$ (Nettelbeck & Wilson, 1985). Nettelbeck (1987) suggested that $r=.70$ was the best estimate of the test-retest correlation for IT estimates across the various groups and procedures examined.

A second index of perceptual performance described by Vickers et al. (1972) was concerned with the measurement of internal noise. They suggested that, following the phi-gamma hypothesis of classical psychophysics, noise is reflected in the standard deviation of the function derived by plotting response accuracy against objective stimulus difference for a forced two-choice discrimination task where exposure duration is held constant and discriminial difference systematically varied.

The phi-gamma hypothesis holds that the function derived by plotting values of the probability of producing a correct response (ϕ) against the mean perceived stimulus difference (γ) on a discrimination task will be a cumulative normal ogive. This follows an assumption common to classical psychophysics that, during processing, stimuli are superimposed onto and interpreted against a background of noise derived from various

sources. The suggestion that combining multiple noise sources, both extrinsic and intrinsic to the observer, will produce neural activity that approximates a normal distribution has been generally accepted for 40 years.

The difficulty associated with two particular discriminations at a given exposure duration will differ depending on the quality of the evidence sampled - this depends on the fluctuating signal-to-noise ratio of the processing system. Vickers et al. (1972) argued that, under certain conditions, the level of noise which is affecting the interpretation of stimulus information will be reflected in the variability associated with response accuracy. The conditions specified in the Vickers et al. (1972) formulation were concerned with ensuring that two well-documented features of discrimination performance did not confound estimates of noise. The first is the existence of response bias; that is, the criterion for deciding that evidence favours one response rather than another can change as a result of subjective factors. The second is the existence of differential levels of caution reflected in the adoption of different speed-accuracy functions by observers.

Vickers et al. (1972) adopted an "optional stopping" model of discrimination performance and assumed that, during decision making, fluctuations in sensory effect occur and are sampled *within* rather than *across* trials. Sampling is assumed to occur at a steady rate with each sample taking a constant amount of time. A response is produced when evidence for one alternative or another reaches a preset criterion level. In the original formulation, IT was assumed to reflect the time required for one sample of stimulus information to occur. This was based on the assumptions that i) during the task the two response outcomes were equiprobable; and ii) the discrimination was so easy that a correct response could be made on the basis of one observation of stimulus information.

Vickers et al. (1972) argued that, during the noise task, setting the stimulus exposure duration equal to the time required for one inspection of stimulus information by using a backward mask would avoid confounding differential levels of caution, response bias, speed of sampling and noise estimates. Under such conditions, the standard deviation of the psychometric curve is assumed to reflect that of the underlying distribution of stimulus differences being sampled. These workers assumed that, consistent with their

estimates, the mean value for IT would not differ substantially from 100 ms and so adopted this value across individuals as the exposure duration for the noise task. The existence of individual differences in IT, however, will require exposure of the stimuli for a period equal to the IT calculated for each individual.

In summary then, in the original formulation IT and noise were assumed to reflect independent thresholds. IT was assumed to be equal to the time required to take one sample of stimulus information; in other words IT was equated with the sampling period. Noise was operationalised as response variability when the exposure duration on the task was set at that required for the achievement of near perfect performance and discriminability was varied. Theoretically, estimates of IT and noise, as operationally defined, provide independent indices of performance. IT establishes a threshold duration required to solve a simple discrimination problem; providing stimuli are presented for this duration, discriminative performance should be unaffected until some threshold reflecting the level of internal noise is reached. The suggestion that noise and IT represent independent thresholds is consistent with a network model of information processing in which performance is influenced by both the firing threshold (noise) and the number and rate of operation of connections (speed) between units within a hierarchical system. The findings of early empirical work were consistent with the suggestion that IT and noise, reflected in the mean and the standard deviation of the psychometric function respectively, are indeed independent indices (Nettelbeck 1972, 1973; Vickers et al., 1972).

IT and internal noise are thus promising prospects for examining the view that cognitive changes with age are the result of decline in speed of processing. In addition, there are a number of advantages to be found in using backward masking procedures for comparisons of young and elderly adults. One advantage of the backward masking procedure is that it avoids difficulties associated with the interpretation of RT data. Response accuracy can be controlled by the subject, by manipulating the time spent on decision making. RT differences may therefore be the result of subjects adopting different speed-accuracy criteria. In Chapter 2 it was suggested that elderly adults are more cautious in decision making, tending to sample for longer periods than the young when stimulus

information is continuously available. IT, by controlling the duration that stimuli are available for processing, provides a procedure for measuring speed of processing that avoids this confounding factor. A second advantage of the backward masking procedure used in the IT task is that the offset of the target stimulus can be concurrent with mask onset, thus maximising the energy level of the stimulus. This form of presentation favours elderly adults by off-setting the well-documented sensory decline found in the visual system with age (see Kline & Schieber, 1985 for a review of age-related changes in the visual system).

However, a number of commentators have questioned both the conceptual assumptions upon which the indices were based (Vickers & Smith, 1986; White, 1993) and the methodology utilised in the measurement of IT (Irwin, 1984; Levy, 1992). Such issues may constrain the interpretation of age-related changes in speed and noise and thus, attempts to predict cognitive performance from these indices. Although the development of a new model for measuring speed and noise is beyond the scope of this thesis, the way in which these concerns have been addressed in the empirical work to be presented will be considered in the following section.

3.3 Methodological and conceptual issues

3.3.1 Achievement of the boundary conditions

Vickers and Smith (1986) have argued for the adoption of a number of procedures during IT measurement to ensure that the boundary conditions discussed in section 3.2 are achieved. In order to interpret IT as the time required to make one observation of sensory input as described by Vickers et al. (1972), it is necessary that two conditions are met. These are, firstly, that the observation required clearly favours the correct response; and, secondly, that the information gained from this observation exceeds the response threshold.

The first condition will be met when the mean and standard deviation of the distribution of discriminial differences are equal to 2 and 1, respectively. In accordance with the table of cumulative normal probabilities, under such conditions the likelihood that one observation will favour a correct response approaches unity. To ensure this, IT tasks

have typically presented stimuli which differ by at least 0.8 degrees of visual angle - that is 2.67 times the upper estimate of the standard deviation (or noise) that was derived by Vickers et al. (1972) from a reanalysis of the data of Botwinick, Brinley and Robbin, (1958). It is possible, however, that the upper estimate of 0.32 degrees derived may be an underestimation of noise in some individuals - indeed, Nettelbeck (1973) reported individual estimates as high as 0.48 degrees. Certainly, presenting stimuli that are consistent with the first condition is an issue of concern when elderly adults are being compared to the young. Therefore, in the empirical work to be presented in this thesis substantially higher levels of discriminability (at least 1.43 degrees of visual angle) have been adopted for the IT task, in an attempt to ensure that both young and elderly adults groups could make a correct judgement on the basis of a single observation of the target stimulus.

The second condition is met by ensuring that the mean of the distribution of discriminational differences is large compared to the response threshold. An attempt to keep response thresholds low is achieved by the use of the backward masking procedure which restricts the information available for decision making. Evidence sampled after mask onset can be regarded as noninformative, additional noise. A number of recent studies, however, have questioned the effectiveness of the backward masking procedure in restricting stimulus information; these studies and the way in which the issue of strategy use has been dealt with in this thesis will be outlined in section 3.3.2.

Vickers and Smith (1986) also draw attention to a feature of discriminative performance that may result in artificially long ITs. In the original formulation of the accumulator model it was assumed that the criterion against which evidence is evaluated is represented by a fixed referent point set equal to zero. Recent work, however, has questioned this assumption and it has been suggested, firstly, that the referent can move up or down in response to sensory factors such as relative stimulus frequency and relative discriminability (Vickers, 1985); and secondly, that the referent is more aptly conceptualised as a region of indifference rather than a single point (Vickers & Smith, 1986). The indifference region formulation considers that, during decision making, some

observations may be discarded, particularly where discriminability is low. As a result, there may be a reduction in the number of trials on which one observation is sufficient to make a response. Artificially long ITs may be the result.

Vickers and Smith (1986) suggested that researchers should (i) adopt high levels of discriminability; (ii) ensure that effective backward masking procedures are used; and, (iii) ensure that instructions to subjects emphasise the equal likelihood of both response alternatives during IT tasks. Such procedures are necessary to ensure that the two conditions specified above are met; and, in addition, will reduce the impact of the indifference region on decision making. All of these features have been taken into account in the empirical work to be presented.

3.3.2 Strategy use

As suggested in section 3.3.1, the effectiveness of the backward masking procedure is an issue of concern in the measurement of IT. The function of the mask is to limit the amount of time for which the target is available for processing and thus the amount of stimulus information available to the subject (Averback & Coriell, 1961). The possibility exists, however, that subjects may use subtle post-masking cues to obtain information about the target stimulus (Nettelbeck, 1982). The adoption of strategies that reduce the effectiveness of the mask will thus confound the measurement of IT by producing artificially fast scores.

Nettelbeck (1982) identified two post masking cues which subjects may use to reduce the effectiveness of the mask: (i) apparent movement; and, (ii) brightness cues. The former refers to the fact that the shorter of the two stimulus lines appears to "grow" when the mask is presented. The latter refers to subtle differences in the brightness associated with the stimulus lines which are the result of the temporal integration of target stimulus and masking stimulus energy levels (Michaels & Turvey, 1979). The impact of such strategies on IT has been the focus of concern of a number of researchers (Egan, 1986; Evans & Nettelbeck, 1993; Lubin & Fernandez, 1986; Mackenzie & Bingham 1985; Mackenzie & Cummins, 1986; Nettelbeck, Evans & Kirby, 1982).

The use of apparent movement cues has been reported in 50% of the university students examined (Brebner & Cooper, 1986; Mackenzie & Bingham, 1985; Mackenzie & Cummins, 1986; Nettelbeck, 1987). The use of strategies by such participants may confound the interpretation of IT findings. As an example, the inclusion of strategy users has been found to reduce the correlations typically found between IT and intelligence. Typically, higher correlations between IT and IQ have been found for subjects identified as nonusers of mask-avoiding strategies (Alexander & Mackenzie, 1992; Mackenzie & Bingham, 1985; Mackenzie & Cummins, 1986). However, a recent study by Egan and Deary (1992) contradicts this, suggesting IT-IQ correlations in both user and nonuser groups, with larger correlations in the former. The possibility that high IQ subjects might be more likely to use strategies has been used to account for the nonlinear relationship between IT and IQ scores in this group (Egan, 1986; Longstreth, Walsh, Alcorn, Szeszulski & Manis, 1986).

Recent research has focussed on the testing and development of a number of different masks in an attempt to reduce the use of strategies in IT tasks (Evans & Nettelbeck, 1993; Knibb, 1992). Knibb (1992), for example, reports some success with his "dynamic" mask and finds higher IQ-IT correlations using this than for studies using the mask most commonly used, following Vickers et al. (1972). Similarly, the "lightening" mask developed by Evans and Nettelbeck (1993) has been found to reduce the occurrence of apparent motion cues during the task. In addition, Vickers (1993) has attempted to develop an index of speed of processing from an expanded judgement task that he argues can provide an estimate of IT that is not contaminated by the use of apparent motion and brightness cues.

In Chapter 2 it was suggested that elderly adults may adopt less efficient strategies than the young during information processing tasks. Additionally, the finding that up to 50% of young adults adopt perceptual strategies that reduce the effectiveness of the backward masking procedure raises concern when the performance of young adults is compared to that of the elderly. Certainly, differential use of apparent motion and brightness cues must be eliminated as an explanation for any group differences found in IT

measures when young and elderly adults are compared. In the empirical work to be presented the lightening mask developed by Evans and Nettelbeck (1993) has been used in an attempt to minimise cue usage. The adoption of apparent motion and brightness cues has been identified on the basis of subjects' self-report and the impact of this feature on IT performance examined. If strategy use contributes to but does not account for group differences in IT then such differences should be attenuated but not removed when this feature is taken into account. In addition, an attempt has been made to compare the estimates of IT obtained using the "traditional" procedures followed for two decades by Nettelbeck and others with those derived using the expanded judgement task derived by Vickers (1993), the theoretical rationale for which is outlined in Chapter 5.

3.3.3 Curve-Fitting and Statistical Assumptions

A further area of concern for the effective measurement of IT involves the curve-fitting and statistical assumptions adopted during measurement, it being argued that absolute values of IT are dependent upon the curve-fitting procedures used (Levy, 1992). This is an issue of concern in the empirical work to be presented because individual estimates of IT will be used to determine stimulus exposure durations during subsequent attempts to derive estimates of noise in young and elderly adults.

Early studies, beginning with Vickers et al. (1972), estimated IT using the method of constant stimuli (MCS). This procedure involves presenting stimuli at a number of exposure durations with a fixed number of trials being presented at each duration. Response accuracy is then plotted against exposure duration and a least-squares procedure is used to fit the data to a cumulative normal ogive. Chance responding is assumed to occur at an exposure duration equal to zero so curve fitting has typically involved forcing the data through the zero point. IT is then extrapolated from this cumulative normal ogive.

One issue of concern raised by Levy (and earlier by Brebner and Cooper (1986)) involves the appropriateness of the least-squares curve-fitting procedure when performance errors occur after the psychometric function has reached asymptote. If the observer makes an error at an exposure duration which is longer than that at which they have already

produced completely accurate responding, then the estimate of IT obtained is likely to be inflated. Irwin (1984) has also argued that IT scores estimated from the flat portion of the psychometric function are poorly defined. Levy (1992) expressed concern regarding the use of both unweighted and weighted least-square estimates in curve fitting procedures.

One means of addressing this is available through the Probit analysis procedure of the Statistical Package for the Social Sciences (SPSS) program (1990). This program uses maximum-likelihood-estimation in calculating the error function in curve fitting, a procedure which Levy (1992) recommends as providing a less biased estimate than the least-squares method. This procedure has therefore been used to estimate IT in the empirical work to be presented in this thesis.

It has also been argued that when IT is estimated using a fixed number of trials (as in the method of constant stimuli) the standard error of measurement varies as a function of the magnitude of IT. In other words, longer IT scores will be measured less reliably than short ones (Levy, 1992). This methodological problem and also Irwin's (1984) concern about IT being measured in the area of the curve associated with error-free performance can be addressed by the use of adaptive measurement techniques. A number of such procedures have been used to measure IT (e.g., Irwin, 1984; Mackenzie & Bingham, 1985; Nettelbeck, 1982). The adaptive method most commonly used by researchers in measuring IT is *parameter estimation by sequential testing* (PEST), a procedure derived by Taylor and Creelman (1967). An alternative form of an adaptive procedure is provided by Wetherill and Levitt (1965). The statistical basis for this procedure is derived from the binomial distribution; and, Wetherill and Levitt (1965) have argued that the technique is not critically dependent on the mathematical form of the underlying psychometric distribution. The procedure involved the presentation of a series of discrimination trials, the difficulty level of which was based on a simple up-and-down rule: the level of the stimulus was varied in steps of a given size with the level of a particular trial determined by the response accuracy of the previous trial. An example of such a rule is:- three correct trials at one level will be followed by an decrease in discriminability level, whereas an error will result in an increase in discriminability level. After a series of such runs the

pattern of responses obtained is characterised by a series of peaks and troughs where the discriminability level has reversed. The average value of these peaks and troughs then provides an index of discriminative performance.

An advantage of adaptive procedures is that they focus most of the trials around the exposure duration of interest and thus make maximum use of the observations obtained. Typically, reliable estimates can be obtained from fewer data points, thereby reducing the impact of factors such as fatigue and concentration span. As these features are likely to have a greater impact on elderly adults, adaptive procedures are advantageous when young and elderly adults are compared. Additionally, no specific assumptions concerning the form of the psychometric function are necessary and estimates of IT can be derived from the steeper portion of the psychometric function.

It is also likely that the procedure is more robust than its parametric counterparts because it is less sensitive to spurious errors, although clearly the reversal level following an error will be higher than if it had not occurred. There is some support for the suggestion that estimates of IT obtained using PEST and MCS do not differ significantly from one another (Nettelbeck & Wilson, 1985). Indeed, Nettelbeck's (1987) review of IT work suggests that both MCS and PEST provide reliable estimates of performance, with test-retest correlations of $r=.76$ and $r=.71$, respectively.

In an attempt to avoid the curve-fitting issues raised by Levy (1992) and to reduce the impact of features such as fatigue, concentration and motivation, the empirical work to be presented in this thesis has used the adaptive "staircase" procedure of Wetherill and Levitt (1965) for determining exposure duration during the IT task. Additionally, as indicated earlier, estimates of IT have also been extrapolated from the psychometric function so derived using maximum likelihood estimates in the Probit procedure of SPSS. As the two procedures are expected to provide similar outcomes, a comparison of estimates of IT derived using both procedures has been used as a means of checking the reliability of the measure. In addition, the test-retest reliability of IT estimates for both young and elderly adults has been examined.

3.3.4 The role of attention

As was indicated in section 3.3.3, estimates of IT can be extended by errors at long exposure durations. The ability to concentrate on the task and to attend to the stimulus when it is presented are thus essential if valid estimates of IT are to be obtained. A number of studies have examined the impact of attentional variables on IT performance (Anderson, 1989; Chaiken, 1993; Nettelbeck, Hirons & Wilson, 1984; Nettelbeck, Robson, Walwyn, Downing & Jones, 1986). Typically, group differences in IT found between normal and intellectually handicapped adults do not reflect differences in distractibility (Nettelbeck, Hirons & Wilson, 1984; Nettelbeck et al., 1986). Nevertheless, Nettelbeck et al. (1984) have argued that they may be the result of dysfunction in some central attentional resource which is not under voluntary control.

The effect of varying the foreperiod in an IT task has been examined in intellectually handicapped adults (Nettelbeck & McLean, 1984) and in children (Anderson, 1989). Although such a manipulation has been found to increase estimates of IT, there is no evidence that it accounts for differences in IT obtained either developmentally or from comparisons of groups of disparate intellectual ability. Indeed, Anderson (1989) argued that such manipulations introduce task variables that allow more scope for strategic differences in performance and thus serve to reduce the correlations typically found between IT and IQ. The impact of attentional factors on IT performance in the elderly, however, has not been addressed. This issue will be examined in the empirical work presented in Chapter 5.

In the experiments to be presented, IT estimates were derived from tasks that incorporated both constant and variable intertrial intervals in an attempt to examine the impact of this manipulation on age-related changes in IT performance. Additionally, IT performance was examined under dual-task conditions in an attempt to determine whether group or individual differences are the result of differences in the amount of processing resources that are available to be allocated to the task.

3.4 Experiment 1 (Pilot study)

3.4.1 Estimating inspection time and noise in young and elderly adults

This experiment was conducted as a pilot study, the aim being to compare estimates of IT and internal noise in young and elderly adults using procedures outlined in section 3.2. The digit symbol substitution (DSS) subtest of the WAIS-R (Wechsler, 1981) was also administered, following Salthouse's (1985b) suggestion that it provides a simple, reliable index of speed of processing. Estimates of the level of noise were derived using the procedures recommended by Vickers et al. (1972) and outlined in section 3.2. Noise is operationally defined as the standard deviation of the function relating response accuracy to discriminability on a forced two-choice task where exposure duration is limited to the time required to take one sample of perceptual information. These workers suggested that, as IT is likely to be of the order of 100 ms, this be adopted as the exposure duration for the task. As was suggested in Chapter 2, however, an exposure duration that is held constant across subjects assumes that the rate of perceptual sampling remains constant across the life-span. The existence of individual differences or, more importantly, age-related differences in the rate of sampling would confound this interpretation.

In the current study the exposure duration of stimuli in the IT task was derived using the staircase method of Wetherill and Levitt (1965); maximum likelihood estimates were used in curve fitting and IT, the exposure duration required to reach 97.5% accuracy, was extrapolated from the psychometric function. Two estimates of internal noise were derived from the standard deviation of the function relating accuracy to discriminability - one estimate was made following the method recommended by Vickers et al. (1972), where the stimulus exposure duration was held constant at 100 ms. For the second estimate of noise stimulus exposure duration was equal to the IT estimate for each individual.

On the basis of work reviewed in Chapter 2, it was expected that higher levels of noise and slower speed of processing would be found in the elderly adults. Specifically, it was expected that elderly adults would have higher estimates of internal noise, longer ITs and lower DSS scores than young adult subjects. It was also argued that age-related decline in speed of processing is, in part, a consequence of an increase in internal noise.

Therefore, some level of correlation between noise and DSS was expected. However IT, the threshold duration required to solve a simple problem, has been assumed to require a discrimination that is well above the level of noise in the system. On this basis therefore, it was expected that estimates of IT and internal noise would be independent that is, not significantly correlated. Consistent with these predictions, age differences on DSS were expected to be attenuated, though not removed, when noise was controlled statistically.

3.4.2 Method

(i) Subjects

Eighteen young adults (13 women and 5 men) and eighteen elderly adults (12 women and 6 men) participated in the study. The mean age of the young adults was 20.6 years (SD=4.71; range: 17-30) and they were recruited from the first-year subject pool of the Psychology Department at the University of Adelaide. The mean age of the elderly adults was 68.0 years (SD=4.80; range: 60-80). All were community-dwelling residents and were recruited through the Australian Retired Persons Association (ARPA). Elderly participants were each paid \$5.00 for their participation. All participants reported free of ocular pathology and had normal or corrected-to-normal visual acuity of at least 6/9 assessed using the Snellen eye chart. All reported having either good or very good health.

(ii) Apparatus and procedure

The experiment was conducted in two half-hour sessions between one and three weeks apart. Subjects were tested individually; the young adults at the university and the elderly adults in a quiet room at their community club. In the first session, subjects completed the IT task and the Digit Symbol Substitution subtest (DSS) of the WAIS-R. In the second session, the two noise tasks were administered; these are hereafter referred to as $NOISE_{100}$ and $NOISE_{IT}$; being the noise measures made with stimulus exposure durations equal to 100 ms and to the individual's IT, respectively. The order of administration of these tasks was balanced across subjects.

(a) **Inspection Time**

The IT task and the noise tasks were presented on the screen of an EGA monitor which was linked to an IBM compatible computer. The refresh scan rate of the monitor screen was 16.74 ms. (Although actual exposure durations were necessarily multiples of this number, for simplicity, exposure durations are referred to as multiples of 20 ms). The target stimulus for the IT task consisted of two vertical lines, one 35 mm and the other 25 mm in length, joined at the top by a line 15 mm in length. When viewed from a distance of 40 cm the difference between the vertical lines subtended a visual angle of 1.43 degrees. The position of the short line, either on the left or the right side, varied randomly across trials. The masking stimulus was as described by Evans and Nettelbeck (1993), consisting of two vertical lines which resembled lightning bolts (refer to Figure 3.1).



Figure 3.1 An example of the target together with the mask used in the IT task in Experiment 1

On each trial, a fixation cue (a small dot) was presented in the centre of the screen for 500 ms to indicate the onset position of the stimulus. The target stimulus onset occurred at cue offset, the target remaining visible for a variable duration. The exposure duration of the target was terminated by the onset of the mask, which was presented for 500 ms. Responses were made on a two-switch keypad and, on each trial, subjects indicated which of the target lines was the shorter. Thirty practice trials were first given; 10 at an exposure duration of 500 ms to ensure that task requirements were understood,

followed by 10 trials at both 260 ms and 100 ms. Subjects had to achieve 100% accuracy on the trials exposed for 500 ms to be included in the study.

IT was then estimated using the staircase procedure to determine the 90% accuracy level (following Wetherill & Levitt, 1965). Exposure duration of the stimulus began at 300 ms and then decreased in steps of 20 ms, either until three out of any six trials were incorrect, or until the exposure duration reached 60 ms. After this point, exposure duration was raised or lowered in 20 ms steps according to response accuracy. An error was followed by an increase in duration whereas a decrease occurred after six consecutive correct responses at one level. The procedure terminated after eight reversals of the direction of the exposure duration sequence had occurred. (As an example, if six correct responses occurred at a duration equal to 100 ms, the duration would then reduce to 80 ms; and, following six correct responses at 80 ms, would further reduce to 60 ms. One error at this duration would be followed by an increase back to 80 ms. The change from a reducing to an increasing exposure duration at 60 ms constitutes a reversal).

The duration associated with 90% accuracy, hereafter referred to as SOA_{90} , was estimated by averaging across the eight exposure durations at which reversals occurred. In addition, the Probit procedure of SPSS was used to determine the function relating accuracy to exposure duration for the data collected after commencement of the up-down rule. The value of SOA_{90} was also derived from this function as a reliability check. IT, defined following Vickers et al. (1972) as the exposure duration required to reach 97.5% accuracy, was extrapolated from the function for each individual and was subsequently used as the exposure duration for the $NOISE_{IT}$ task.

(b) Noise

Two noise tasks, $NOISE_{100}$ and $NOISE_{IT}$, were completed by each participant. In the former, the exposure duration of the target stimulus was held constant across individuals at 100 ms; in the latter it was equal to the estimate of IT, rounded to the closest multiple of the screen refresh rate. In both tasks the discriminial difference between the target lines was varied across trials.

The target stimulus was composed of two vertical lines, as in the IT task. The length of the shorter line, however, varied across trials in multiples of 0.7 mm^2 . The masking stimulus consisted of two vertical lines (40 mm long) joined across the top by a vertical line (20 mm long). These lines were thicker than those of target stimulus (refer to Figure 3.2). This mask was adopted in preference to the lightning mask because the length of the short line was longer than that used in the traditional task and thus the area from which movement or brightness cues were likely to be obtained would not have been covered by the thick segment of lightning bolt.



Figure 3.2 An example of the target together with the mask used in the noise task in Experiment 1

As in the IT task, each target stimulus was preceded by a warning stimulus (500 ms) and terminated by mask onset. Thirty practice trials were given either at exposure durations equal to the estimate of IT or at 100 ms, depending on condition. During the experimental task, the staircase method was used to vary the difference between the lines on each trial, based on calculating the discriminational difference required to achieve 80% accuracy on the task. This procedure was used because it was less likely to result in ceiling effects for accuracy that are typically found when discriminability is determined using the method of constant stimuli. The adaptive procedure was based on the 80% level rather

² Line lengths were measured by the number of pixels of which they were constituted, with one pixel equal to 0.35 mm.

than the 90% level because the former typically involves fewer trials and thus reduces the impact of fatigue on the repeated estimates of noise within one session.

The discriminial difference commenced at 10.5 mm and on the second trial, increased by 0.7 mm if an error occurred or reduced to a difference of 0.7 mm if the first response was correct. The difference then varied in steps of 0.7 mm; it increased following an error and decreased following 3 correct responses at one level. The procedure of starting at the more difficult discrimination was adopted in an attempt to maximise performance of elderly adults by reducing the impact of fatigue. The procedure terminated after eight reversals had occurred. The Probit procedure of SPSS was used to determine the function relating accuracy to discriminial difference, the standard deviation providing an estimate of internal noise.

3.4.3 Results

Table 3.1 presents descriptive summaries for the four dependent variables DSS, IT, $NOISE_{IT}$ and $NOISE_{100}$. The noise indices represent the standard deviations of the best-fitting ogives derived for each individual using the Probit procedure of SPSS. Valid estimates could not be determined for three young and 10 elderly participants for $NOISE_{100}$ and for one elderly adult for $NOISE_{IT}$. In each case the curve fitted had a negative slope, suggesting that the measures were not reliable. These data have not been included in the analyses.

Unrelated samples t-tests were used to test the hypotheses that elderly adults would produce higher estimates of noise and slower speed of processing. A significant difference was found between the DSS scores of the two groups ($t(34)=8.19$; $p<0.05$; one-tailed) with, as expected, elderly adults completing fewer digit-symbol substitutions than the young. Although estimates of IT appeared to be slightly longer in the elderly, the difference between the groups was not statistically significant ($p>0.05$).

Table 3.1 Mean estimates of noise and speed of processing for young and elderly adults.

VARIABLE	YOUNG	ELDERLY
DSS (raw score)	70.5 (5.1)	47.9 (11.0)
IT (ms)	139.5 (57.9)	162.9 (70.7)
NOISE _{IT} (degrees of visual angle)	0.44 (0.39)	0.19 (0.21)
NOISE ₁₀₀ (degrees of visual angle)	0.34 (0.68)	0.20 (0.33)

(SD in parentheses)

Contrary to expectations, NOISE_{IT} was found to be higher in the young participants ($t(33)=2.38$; $p<0.05$). No difference was found for the Noise₁₀₀ estimate ($p>0.05$). As NOISE₁₀₀ appeared to be subject to floor effects for accuracy and findings for NOISE_{IT} were clearly not consistent with expectations, it was not considered appropriate to use either of the noise estimates to examine further the interrelationship between age, speed of processing and noise as was outlined in section 3.4.1.

Instead, an attempt was made to check the reliability of the IT procedure. Estimates of SOA₉₀ derived using the peak-trough averaging technique of Wetherill and Levitt (1965) and the Probit procedure of SPSS were compared. The relationship was examined using correlational techniques and by comparison of the absolute estimates obtained. Table 3.2 presents mean SOA₉₀ estimates for young and elderly adults determined using the two procedures.

Wetherill and Levitt and Probit estimates were highly correlated in both young ($r=.98$; $p<0.05$; one-tailed) and elderly ($r=.94$; $p<0.05$; one-tailed) adults. In the young group, moderate negative correlations were found between DSS and both Wetherill and Levitt estimates ($r=-.51$, $p<0.05$; one-tailed) and Probit estimates ($r=-.52$; $p<0.5$; one-tailed). Similarly, in the elderly group, DSS was negatively correlated with both Wetherill

and Levitt estimates ($r=-.47$; $p<0.05$; one-tailed) and Probit estimates ($r=-.40$; $p=0.05$; one-tailed). Absolute estimates of SOA_{90} were examined using two-way analysis of variance with one between subjects variable (age group: young or elderly) and one within subjects variable (estimation procedure: two levels). Results of this analysis are included in Appendix A. A significant main effect for estimation procedure was found ($F(1,34)=7.82$; $p<0.05$), indicating that Wetherill and Levitt estimates were shorter than Probit estimates. The group x procedure interaction was not significant ($p>0.05$).

Table 3.2 Mean estimates for SOA_{90} derived using either Wetherill and Levitt or the Probit procedures

VARIABLE (ms)	YOUNG	ELDERLY
SOA_{90} (W & L)	99.5 (32.9)	114.4 (29.9)
SOA_{90} (Probit)	104.7 (38.0)	122.2 (42.5)

(SD in parentheses)

As can be seen from Table 3.2, although statistically significant, the difference between the mean values obtained using the two procedures were within 20 ms of one another suggesting that, given the refresh scan rate of the monitor, the outcomes for the two procedures were close. Individual estimates of SOA_{90} were also examined and discrepancies of more than 20 ms between estimates were found for only one young and one elderly adult. Deletion of both IT and $NOISE_{IT}$ data for these two participants did not change the results of the group comparison reported above, suggesting that findings for IT and noise are unlikely to be due to unreliability in the Probit procedure.

The Probit procedure also provided the intercept of the psychometric function and goodness-of-fit chi-square values and associated degrees-of-freedom for each IT data set for each individual. These values were examined to determine whether, as assumed by Vickers et al. (1972), the psychometric functions obtained were well-represented by the

upper portion of a cumulative normal ogive with chance responding occurring at an exposure duration of zero ms.

The mean durations at which chance responding occurred were 3.72 ms (SD=1.24) and 3.47 ms (SD=1.53) for young and elderly adults, respectively, with an unrelated samples t-test finding no significant difference between the two groups ($p > 0.05$). Although significant departures from zero were found for the intercept values for both young ($t(17)=12.74$; $p < 0.05$; two-tailed) and elderly adults ($t(17)=9.95$; $p < 0.05$; two-tailed), the absolute magnitude of the estimates was not considered to be of practical significance, given the refresh scanning rate of the video monitor.

To determine the goodness-of-fit of the psychometric functions, chi-square values and associated degrees of freedom were summed across individuals and the associated probability level determined. Individual functions for both young (overall $\chi^2(61)=60.6$; $p > 0.05$) and elderly (overall $\chi^2(70)=47.1$; $p > 0.05$) adults were found to be well fitted by the Probit procedure, with all individual function for young and elderly adults meeting the criterion for acceptability ($p > 0.05$).

3.4.4 Discussion

The aim of this study was to compare estimates of speed of processing and internal noise in young and elderly adults using backward masking procedures and to examine the interrelationship between variables. Consistent with work reviewed in Chapter 2 on age-related decline in speed of processing, the elderly were found to be slower when assessed using the DSS test. No attempt was made to examine whether this group difference was attenuated by covarying levels of internal noise because findings regarding estimates of noise were problematical.

The nonsignificant difference found between IT estimates for the groups is not consistent with previous work which has examined age-related decline in backward masking performance. One possible explanation for this is concerned with the composition of the elderly group. Twelve of the 18 participants were aged between 60 and 69 and it is

possible that marked declines on IT performance may not be evident until the 70s. Further studies examining IT across a wider age range in elderly adults are required to test this.

A more plausible explanation for the finding is revealed by examination of the distribution of IT estimates for the young adults. Examination of the raw data revealed that five of the young participants obtained an IT estimate that was more than one standard deviation above the group mean; in the elderly group this occurred for only one person. It is possible that these estimates markedly skewed the distribution of young scores and certainly, the standard error of the mean will be large with a small sample. As Wetherill and Levitt and Probit estimates for SOA_{90} resulted in virtually identical outcomes, it is unlikely that these data sets reflected unreliability in curve fitting procedures. Rather, it appears that the inclusion of a small number of extreme scorers in the young group may have masked age differences. Clearly, the nonsignificant difference obtained was counter intuitive and, indeed, inconsistent with work using backward masking procedures reviewed in Chapter 2. Rather than dismissing IT as an index of speed on the basis of this pilot study, the comparison of age-related differences on estimates of IT is considered to be worthy of further consideration and is examined with larger samples and a wider range of ages in the empirical work to be presented in Chapter 5.

A second finding that was contrary to both expectations and a wealth of previous research was that the estimate of noise derived from the standard deviation of the function when exposure duration was set at IT revealed higher noise estimates for the young. It is possible that higher noise estimates in the young may have been the result of an underestimation of IT in *some* members of this group, despite the inclusion of the young subjects with extreme IT scores. Underestimation of IT could result from the adoption of apparent motion cues during the task. Such an outcome would result in higher performance variability because the use of apparent motion cues would be less likely during the noise task when the difference between stimulus lines was very small.

Underestimation of IT among the young could also result from rounding errors given the refresh rate of the video monitor. Clearly, rounding down to the nearest 20 ms is likely to have greatest impact where IT is short. The plausibility of these explanations is

reduced somewhat by the nonsignificant difference between group mean IT estimates. The question of differential strategy use was not addressed in this study but is considered further in Chapter 5 (Experiment 4). Additionally, Experiment 4 will attempt to measure noise using a LED display where the exposure duration of the stimulus can be controlled to within 1 ms, thus avoiding rounding errors that may occur with the video monitor.

The most plausible procedural explanation for the higher noise estimates found among young adults, however, derives from the fact that the adaptive procedure for the noise tasks commenced at a very low level of discriminability. This was done in an attempt to maximise the performance of elderly adults by reducing the impact of fatigue on performance. The mean discriminational difference required to reach criterion on the noise tasks was available but not examined here in the results section because it was not immediately relevant to the hypotheses being tested. However, examination of these data (Appendix B) revealed that elderly adults required a larger mean discriminational difference than the young to reach performance criterion on both the NOISE_{IT} and NOISE_{100} tasks. As the adaptive procedure commenced at a low level of discriminability, it is likely that the estimates of noise for young adults were derived from curves fitted through fewer data points than was the case for the elderly. In other words, the estimate of noise for the young participants may have been inflated as a result of being derived from fewer data points. Clearly, the issue of group differences in estimates of noise remains worthy of further consideration and is addressed in Chapter 5 (Experiment 4) using a LED display and the method of constant stimuli, with random presentation of discriminability levels included in an attempt to avoid procedural difficulties.

One issue of concern in analysing the data obtained was that the Probit procedure was unable to determine valid estimates of the standard deviation for 10 of the elderly adults on the NOISE_{100} task. In these cases the curve relating response accuracy to discriminability was found to have a negative slope, indicating that performance was better at more difficult levels of discrimination. The adaptive procedure used to determine estimates at the 80% level required only three correct responses in a row for a step down.

This means that the procedure may be more susceptible to "lucky guessing"; three correct responses in a row as a result of chance being more likely than six, as is required when the 90% level is used.

It is possible that performance on the NOISE_{100} task was the result of "lucky guessing" by subjects on this task. A number of the elderly participants reported that they found the task to be extremely difficult and that they had guessed on most of the trials. This finding suggests that the NOISE_{100} task was subject to floor effects for accuracy among the elderly, consistent with the suggestion that speed of perceptual sampling is slower among this group than the young. This finding suggests that future attempts to estimate noise should examine performance at levels appropriate to each individual subject, as has been attempted in the NOISE_{IT} task. The success of using IT estimates as criteria for performance on a noise task, however, is dependent on these indices being independent, an issue which the current study was unable to address.

In conclusion, consistent with previous work reviewed in Chapter 2 this study has found evidence for slowing with age on the DSS test. Findings concerning IT, however, were inconclusive; a number of possible confounding factors were considered in an attempt to explain the nonsignificant group effect. The Probit procedure used in estimating IT appears to be reliable in that estimates are close in absolute value to those derived using the Wetherill and Levitt procedure and both sets of estimates are highly correlated. In addition, data sets for both young and elderly adults were consistent with the view of Vickers et al. (1972) that the function obtained reflects the upper portion of a cumulative normal ogive with chance responding occurring at zero ms. (Although statistically significantly different from zero, an intercept of 3-4 ms was not considered to be practically different from zero). The attempt to measure noise using the procedure advocated by Vickers et al. (1972) was not successful, findings being contrary to both theory and empirical studies reviewed in Chapter 2. It was suggested, however, that various procedural concerns may have contributed to this finding. The issue of group differences in both IT and internal noise and the relationship between these parameters and

cognitive functioning in the elderly remain worthy of further consideration. These issues are addressed further in empirical work to be presented in Chapter 5, where an attempt is made to address the procedural shortcoming identified in this pilot study.

CHAPTER FOUR

EXAMINING SPEED AND NOISE USING A VISUAL SEARCH PROCEDURE

4.1 Introduction

In Chapter 3 an attempt was made to compare estimates of internal noise and speed of processing from young and elderly adults using backward masking procedures. The attempt to measure internal noise was unsuccessful, because contrary to expectations, lower levels were found among elderly adults than among the young. In the empirical work to be presented in this chapter, age-related changes in noise, speed and attentional processes have been examined using a visual search procedure. One aim of the empirical work was to determine whether, despite the unsuccessful attempt to measure noise directly in Experiment 1, convergent support could be obtained for the view that ageing is associated with an increase in noise, by testing predictions derived for visual search performance. This represents a shifting level of explanation, because, instead of examining the noise-speed link, it concentrates on the relationship between internal noise and attentional processes.

The second aim of the research presented here was to test the strong version of the slowing hypothesis, by determining whether generalised slowing alone provides a sufficient explanation for age-related changes in visual search performance. In Chapter 2 evidence for age-related decline in attentional processes was discussed and it was suggested that both speed of processing and attention might have an impact on cognitive performance in the elderly. Although cognitive performance was not tested in the experiments to be presented in this chapter, if both speed and attention are crucial to an understanding of age-related changes in processing, then visual search data should be consistent with this.

Finally, noise has been linked to various aspects of visual search performance via its impact on the discriminability of target-distracter combinations. Experiment 3 examined the viability of deriving a parameter which would reflect the level of noise influencing visual search performance. This was thought to be a useful way to proceed, because, if

such a measure could be derived, it could be used to check the validity of noise estimates subsequently derived using the backward masking procedures outlined in Chapter 3.

Selective attention is concerned with the ability to distinguish between relevant and irrelevant information for processing (Madden, 1990b). A decline in selective attentional processes is thought to occur with old age (Layton, 1975; Madden, 1990b; Rabbitt, 1965) and this may be manifest as a decreasing ability, either to ignore irrelevant information (Rabbitt, 1964), or to decide on the relevance of particular stimuli (Wright & Elias, 1979). This decline in ability presumably reflects structural changes, although explanations for performance which invoke the notion of perceptual noise have not linked this decline to specific CNS changes.

In visual search tasks with "consistent mapping" (that is, where stimuli are always dealt with in a similar manner across trials), elderly adults have been found to show a lower level of performance than the young (Fisk, McGee & Giambra, 1988). Other work, however, has not demonstrated poorer performance among elderly adults (Madden, 1982; Madden & Nebes, 1980), with some evidence suggesting that age differences in visual search are reduced or eliminated with increasing amounts of practice (Plude et al., 1983; Plude & Hoyer, 1981). The impact of irrelevant stimuli on performance is largest when search through a display is required, group differences being reduced when the location of the target is precued (Madden, 1983; Nissen & Corkin, 1985; Plude & Hoyer, 1986; Wright & Elias, 1979). Whether age differences in visual search performance are found depends on the level of selectivity required in the task, attentional selectivity being crucial in distinguishing relevant from irrelevant information for processing.

Prior to presentation of a cue, attention is assumed to be distributed uniformly across the display, with a build-up of attentional resources occurring at the location of the cue after onset. Madden (1990a) has argued that this concentration of resources requires time and that, independent of generalised slowing, this process takes longer in elderly adults than the young. The view that changes occur in attentional processes that are independent of generalised slowing is consistent with Stankov's (1988) model which

incorporates both speed and attentional indices in accounting for age-related changes in fluid abilities.

A number of workers have invoked an internal noise model to account for age-related effects on visual search tasks (for example, Allen, 1990), the argument being based on the notion of interference. Essentially, an increase in noise is assumed to result in an increase in the similarity between target and distracter stimuli. As a result, individuals may indulge in more rechecking of stimuli; or, they may need to use a serial search procedure, rather than parallel processing of the visual display, in order to locate targets. In both cases, an increase in internal noise will be associated with an increase in nontarget interference during visual search performance.

Allen and his coworkers have examined visual search performance using a redundancy gain procedure (Allen, Madden, Groth & Crozier, 1992; Krueger & Allen, 1987). "Redundancy gain" refers to the finding that the effect of distracter letters in a visual display is reduced as target redundancy is increased; and, it has been argued that this is the result of a reduction in perceptual noise (Grice & Gwynne, 1987). Allen, Madden, Groth and Crozier (1992) found that elderly adults showed a larger reduction in RT than the young as target redundancy in a visual display was increased. Additionally, it has been found that reducing the number of distracter letters present in the display facilitates performance more than simply increasing the redundancy associated with the target (Allen, Madden & Crozier, 1991). Such findings are consistent with the notion that additional distracters in a visual display have a relatively greater impact on elderly adults due to an increase with age in internal noise. In addition, Allen and his co-workers have argued that the impact of internal noise on performance on the redundancy gain task occurs independently of generalised slowing (Allen, Madden, Groth & Crozier, 1992).

The work of Treisman and her colleagues has focussed on the distinction between attentive and preattentive processing. This distinction was derived from the work of Neisser (1967), who argued that attentional selectivity is composed of both an automatic and an intentional component. Preattentive processing is assumed to be automatic and to involve parallel input of stimulus information. Attentive processing, which is assumed to

follow this, is thought to involve limited capacity serial search processes. The visual search procedure has been used to indicate whether visual scanning occurs serially or in parallel. An assumption underlying this work is that perceptual processes are selective and that the focus of selectivity varies from moment to moment. Attention can be allocated to different locations in the visual field in much the same way that capacity models suggest it can be allocated to different tasks (Eriksen & Hoffman, 1972; Jonides, 1980, 1983).

Parallel processing is the result of an even distribution of attention across the visual display (Eriksen & Spencer, 1969; Schifffrin & Gardener, 1972), whereas serial or item-by-item search indicates a concentration of processing resources (Eriksen & Yeh, 1985; Prinzmetal & Banks, 1983). Work by Treisman and her colleagues has examined a model in which attention can range from broadly spread to narrowly focussed (Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Souther, 1985).

The group scanning hypothesis has been invoked to account for the size of the display that can be scanned in parallel and the point at which search becomes serial. Where the target contains a unique feature or is highly discriminable from the background distracters, parallel processing is assumed to occur. As the difference between the target and distracters becomes unreliable relative to the noise in the system, search becomes serial so as to compensate for unreliability. This conceptualisation is similar to the two-process model of Hoffman (1978, 1979), where initial input of a display is assumed to occur in parallel. If the task is well practiced or the target highly discriminable, a response can be made on the basis of this stage alone. Otherwise, a second serial rechecking process is undertaken where stimuli which are confusable with the target are reconsidered.

According to Treisman and Gormican (1988), discriminability reflects Weber's Law where the size of the just-noticeable-difference between two stimuli is a constant ratio of the level of background activation in feature detectors. Stimuli that produce activity on an overlapping set of feature detectors will have low discriminability. Detecting the presence of a target relies on the presence of activity in a particular feature detector while identifying the target is determined by the ratio of activity in different detectors. The Weber fraction is

based on the discriminability of a given number of items considered with and without a target present.

Discriminability will be reflected in the slope of the array size/RT function for a visual search task. A flat function indicates that search is parallel and the target is said to "popout" from the background distracters. On the other hand, serial search is reflected in a linear function, each additional item being scanned resulting in constant progress and hence a linear increase in RT. The former type of search is assumed to be automatic and the latter intentional. Popout can be encouraged by presenting a target among nonconfusable distracters, whereas serial search will occur when target and distracters are confusable.

A two-stage model of processing was introduced in Chapter 1 (Figure 1.1). The first stage was concerned with input processes and the second with central processes. The impact of an age-related increase in internal noise on the first stage of this model can be examined using the visual search procedure. The level of target-distracter discriminability determines whether search is parallel or serial and whether particular distracters are similar enough to the target to require the rechecking process of Hoffman's model. An age-related increase in noise would result in serial processing occurring at a higher level of discriminability; that is, where the objective difference between target and distracters is relatively large. During visual search elderly adults would be expected to take smaller samples from a visual display and to scan them at a slower rate. In other words, the focus of attention is assumed to narrow to compensate for increasing levels of internal noise.

This conceptualisation is similar to that introduced in Chapter 2, where it was suggested that age-related decline in the rate of information processing occurs to compensate for noise. Indeed, according to the strong version of the generalised slowing hypothesis, any decline found with age in visual search performance could be accounted for by recourse to this decline in speed, with no need to postulate task specific mechanisms. As has been indicated, however, researchers have argued that changes in internal noise and thus attentional selectivity, have an impact that is not explained by generalised slowing.

If task independent slowing is responsible for age effects then group x task interactions will disappear when analyses are conducted on data which have been subjected

to natural logarithm transformations (Cerella, 1985; Salthouse, 1988b). This argument is based on the notion that task manipulations simply represent a form of task complexity - the absolute magnitude of the change for elderly adults being greater than that of the young, the proportional change remaining constant. Thus, any group x task interaction that remains following logarithmic transformation suggests that the group effect is not a consequence of scaling differences. In other words, decline in specific task components independent of generalised slowing must be occurring.

4.2 Experiment 2

This study had two aims. The first was to examine convergent support for the idea that ageing is associated with an increase in noise by testing predictions for visual search performance. The second was to test the strong version of the generalised slowing hypothesis by examining whether decline in components of visual search and selective attention occur independently of slowing with age.

The experimental task included two conditions: selective attention and visual search. In both conditions subjects had to identify a target letter that was presented in a matrix of distracter-letters. In the selective attention condition, the target was presented with eight distracters and the location of the target was precued. In the search condition change in RT as a function of the size of the visual display was examined, the target being presented with either 2, 5 or 8 distracters, but without precuing of the target location. The efficiency of selective attention processes was examined by comparing mean RT in the selective condition to mean RT from the search condition (with 8 distracters). This experimental design had been previously been used to examine the impact of attentional selectivity on schizophrenia (Bowes, 1988).³

Within both the selective attention and visual search conditions target-distracter confusability was manipulated. A nonconfusable target-distracter combination was expected to encourage parallel processing (popout) while a confusable target-distracter combination was likely to induce serial processing. A number of predictions based on the view that ageing is associated with an increase in noise were tested. Firstly, elderly adults

³ The number of distractors was varied in the search condition so that the array-size/RT functions could be examined. In the selective condition the target was always presented with 8 distractors because it was assumed that cue usage would have most impact with a large array size.

were expected to take longer to identify the target letter, thus significant group effects were expected for both confusable and nonconfusable target-distracter combinations. Secondly, during search among confusable target-distracter combinations but not nonconfusable combinations, elderly adults were expected to scan the display at a slower rate, as a result of the need to recheck stimulus information. This was expected to lead to a significant group x array size interaction for the confusable combination only. Thirdly, following Madden (1990a, b), a decline in selective attention processes among elderly adults was expected to result in a significant group x trial type interaction when cued and noncued RTs were compared. To test whether changes in components of attention occur independently of slowing with age, analyses were conducted on raw and logarithm transformed data. The strong version of the generalised slowing hypothesis predicts that any group x array-size interaction found for the visual search condition and any group x trial type interaction found for the selective attention condition will disappear following natural logarithm transformations.

4.2.1 Method

(i) Subjects

Forty six adults participated in this study - 14 were aged between 17 and 27 years (mean=22.1, SD=3.43); 16 between 63 and 74 years (mean= 68.1, SD= 3.81); and, 16 between 75 and 90 years (mean= 81.3 , SD=4.60). The young adults were recruited through a social work program at the University of South Australia. Elderly adults were community-dwelling residents recruited through bowling clubs and senior citizens groups. All participants reported themselves to be in either good or very good health and were free of ocular pathology. Visual acuity was assessed using the Snellen eye chart, all participants having normal or corrected-normal visual acuity of at least 6/9.

Crystallised general intelligence was assessed using the vocabulary subtest of the Cattell Ability Battery. Mean scores out of 15 were 12.0 for the young subjects (range 8-15; SD=2.29); 12.4 for 63-74 year olds (range 9-15; SD=2.00); and, 12.6 for 75-90 year olds (range 9-15; SD=1.90). A one-way analysis of variance revealed that differences were

not significant ($p > 0.05$), indicating that groups were equivalent with respect to crystallised ability (see Appendix C for Anova table).

(ii) Apparatus

The visual search task was presented on an EGA monitor attached to an IBM compatible computer. Stimuli were 3, 6 or 9 letters, each 10 mm high and 5 mm wide, which were presented in the centre of the screen in a 3x3 matrix (25 mm wide by 40 mm high). Target stimuli were the letters T and F. Distracter stimuli were the letters O and C in the nonconfusable condition; and, L and E in the confusable condition. Responses were made on a two-switch key pad; the letter F was assigned to the left-hand key and the letter T to the right.

(iii) Procedure

Subjects were tested individually in a quiet room; the session took approximately forty minutes. The task examined performance in two conditions: (i) visual search and (ii) selective attention. In the visual search condition the target stimulus (either T or F) was presented either with confusable (letters L and E) or nonconfusable (letters O and C) distracters. Half of all trials involved confusable distracters. On each trial a warning cue (x) was presented in the centre of the screen for 300 ms. Following an interstimulus interval of 200 ms, the letter matrix appeared and remained visible until a response was made. The matrix presented 3, 6 or 9 letters in rows of 3. In other words, the target was presented with 2, 5 or 8 distracters. Subjects used a key press to indicate whether the target letter was a T or an F. Feedback, indicating RT and whether the response was correct, was presented on the screen and remained visible for 1000 ms. The intertrial interval subsequent to provision of feedback was 2000 ms.

In the selective attention condition the target was always presented in a row of nonconfusable distracters which were the letters O and C; the other two rows were confusable (L and E) on half of the trials and nonconfusable (O and C) on the other half. In other words, the target was always presented with 8 distracters. The procedure was

essentially the same as for the search condition except that, following fixation cue offset, two triangles were presented for 500 ms before matrix onset at both ends of the row in which the target was to be presented. Sixty practice trials were given.

To reduce practice effects the search and selective attention trials were presented together in random order. One hundred and eighty trials were administered over three blocks of 60, with a pause between each block to allow subjects to initiate onset of the next block. The number of trials presented at each array size were 37 for array size 3; 36 for array size 6; 55 for array size 9 and 52 for the selective condition (array size 9).

On both search and selective trials, subjects were instructed to respond as quickly and as accurately as possible.

4.2.2 Results

The mean RTs obtained by subjects in the three age groups for the search condition are presented in Table 4.1. These values represent means of the mean RT obtained for individuals in the search condition with confusable and nonconfusable target-distracter combinations presented separately. Array size indicates the total number of letters presented (that is, target plus distracters).

Table 4.1 Mean RT (ms) by array size and distracter type for three age groups.

GROUP	NONCONFUSABLE			CONFUSABLE		
	3	6	9	3	6	9
17-27 yrs	545 (92)	566 (97)	606 (113)	584 (101)	719 (149)	815 (191)
63-74 yrs	627 (42)	638 (49)	684 (70)	634 (70)	802 (94)	856 (133)
75-90 yrs	690 (92)	719 (91)	772 (85)	736 (99)	972 (180)	1146 (208)

(SD in parentheses)

RT in the visual search condition was examined using a 3-way repeated-measures analysis of variance for the variables age-group (between-subjects: 3 levels), confusability (within-subjects: confusable versus nonconfusable), and array size (within subjects: 3 levels). A significant age group main effect was found ($F(2,43)=15.9$; $p<0.01$), with, as would be expected, RT increasing with age. Overall mean RTs were 639.4 ms ($SD=118.6$), 706.8 ms ($SD=63.3$) and 839.1 ms ($SD=109.9$), for ages 17-27, 63-74 and 75-90, respectively. A significant confusability main effect was found ($F(1,43)=249.4$; $p<0.01$), indicating that RT was longer in the presence of confusable distracters. Overall mean RTs were 652.9 ($SD=99.2$) and 811.7 ms ($SD=162.3$), for nonconfusable and confusable combinations respectively. A significant array size effect was found ($F(2,86)=188.6$; $p<0.01$), with longer RT associated with increasing number of distracters. Overall mean RTs were 639.2 ms ($SD=99.6$), 740.0 ms ($SD=133.2$) and 817.7 ms ($SD=162.7$), for array sizes 3, 6 and 9, respectively.

Significant interactions were found between group x array size ($F(4,86)=7.40$; $p<0.01$); confusability x array size ($F(2,86)=68.7$; $p<0.01$); group x confusability ($F(2,43)=11.95$, $p<0.01$); and, the group x confusability x array size effect ($F(4,86)=4.24$; $p<0.01$). The impact of array size on RT increased with age and was higher in the confusable condition. The three-way interaction indicated that the elderly groups were more disadvantaged as array size increased in the confusable condition. (See Appendix D for complete Anova table).

To confirm this, the confusable and nonconfusable target-distracter combinations were then examined separately using two-way analysis of variance and the array size effect was decomposed into single-degree of freedom polynomial contrasts. (See Appendix E for complete Anova tables). For the nonconfusable combination, both the group ($F(2,43)=14.4$; $p<0.01$) and the linear component of the array size effect ($F(1,43)=77.7$; $p<0.01$) were significant. RT increased with age; overall mean RTs were 572.6 ms ($SD=98.9$), 649.4 ms ($SD=45.8$) and 726.7 ms ($SD=84.4$) for ages 17-27, 63-74 and 75-90, respectively. Similarly RT increased with array size; overall mean RTs were 623.9

(SD=96.7), 643.9 (SD=100.6) and 690.8 (SD=110.8), for array sizes 3, 6 and 9, respectively. There was, however, no significant group x array size interaction ($p>0.05$).

For the confusable combination, significant main effects were found for group ($F(2,43)=15.91$; $p<0.01$) and the linear component of the array size effect ($F(1,43)=238.2$; $p<0.01$). Slowest reaction times were found in the oldest group (75-90 years); overall mean RTs were 706.2 (SD=141.5), 764.2 (SD=90.9) and 951.4 (SD=140.9), for ages 17-27, 63-74 and 75-90, respectively. A significant linear component for the group x array size interaction was found ($F(2,43)=11.1$; $p<0.01$) thereby confirming the finding that elderly adults were more disadvantaged as array size increased in the confusable condition. These findings are illustrated in figures 4.1 and 4.2. and are reflected in the estimates of the rate of scanning obtained.

Rate of scanning was determined by comparing RTs obtained for array-size 3 and array-size 9 and determining the change in RT associated with the additional letters. In the nonconfusable condition the three groups appeared to have similar scanning rates. These were 10 ms per letter for age groups 17-27 and 63-74, and 14 ms per letter for age group 75-90. In the confusable condition the rate of scanning was similar for age groups 17-27 and 63-74 (38 ms and 37 ms per letter, respectively), although in age group 75-90 it was slower (68 ms per letter).

To test the slowing hypothesis, RT data were subjected to natural logarithm transformations and the two-way analysis of variance for the confusable condition was redone. Significant main effects remained for group ($F(2,43)=14.9$; $p<0.01$) and array size ($F(2,86)=221.5$; $p<0.01$). The group x array size effect remained significant ($F(4,86)=3.69$; $p<0.01$), suggesting that the findings were not accounted for simply by generalised slowing. (See Appendix F for complete Anova table).

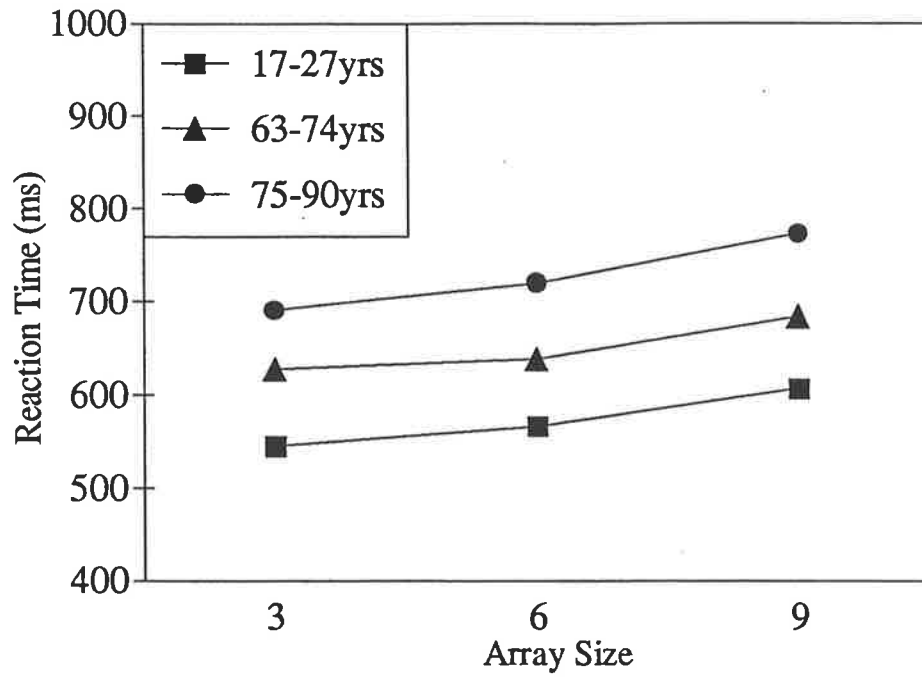


Figure 4.1 Reaction time - array size functions for nonconfusable target-distracter combinations

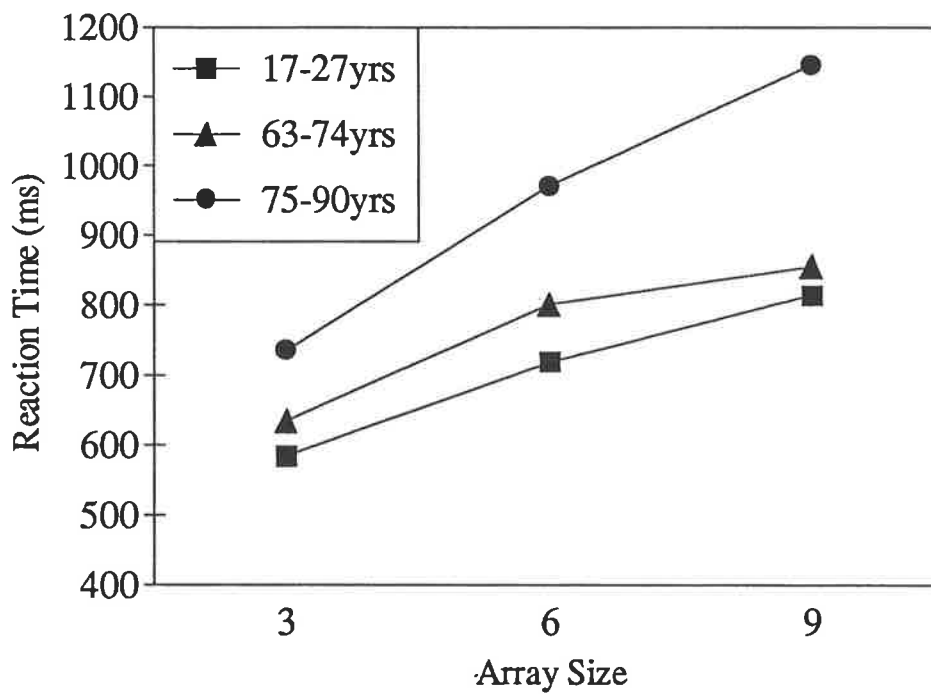


Figure 4.2 Reaction time - array size function for confusable target-distracter combinations

Because interpretation of RT data is constrained by the existence of the speed-accuracy trade-off, error rates were examined. Table 4.2 shows the mean number of errors produced in the visual search condition for confusable and nonconfusable target-distracter combinations. A two-way repeated measures analysis of variance was conducted on the variables age-group (between subjects: 3 levels) and confusability (within subjects: 2 level). Results indicate significant main effect for both confusability ($F(1,43)=7.01$, $p<0.05$) and group ($F(2,43)=3.37$; $p<0.05$). The confusability effect was the result of more errors being made in the confusable condition. Mean number of errors produces were 3.7 (SD=2.3) for the nonconfusable and 4.9 (SD=4.0) for the confusable combinations. Age group 63-74 produced a relatively high number of errors (mean=11.4, SD=6.9) compared to age group 17-27 (mean=5.5, SD=4.4). (Mean for age group 75-90=8.6, SD=7.1). No significant interaction was found for the group x confusability effect ($p>0.05$). (See Appendix G for complete Anova table).

Table 4.2 Mean number of errors from 180 responses for three age groups for search condition.

GROUP	Nonconfusable	Confusable
17-27 yrs	2.14 (2.0)	3.21 (3.2)
63-74 yrs	5.19 (3.5)	6.19 (4.3)
75-90 yrs	3.50 (3.5)	5.12 (4.0)

(SD in parentheses)

The ability of subjects to effectively utilise the selective attention cue was analysed by comparing RTs obtained in the selective attention condition (array-size=9) with those from the search condition (array-size=9); data were combined across confusability

manipulations. Successful use of the cue was expected to reduce RTs in the cued (selective attention) condition. Table 4.3 presents the mean RTs for the selective attention condition for distracter types separately and Table 4.4 presents the mean RT for the selective attention condition (combined across distracter types) and the mean RT for the search condition where array-size was 9 (combined across distracter types).

Table 4.3 Mean RT (ms) by distracter type for three age groups in selective attention condition.

GROUP	Nonconfusable	Confusable
17-27 yrs	529 (69)	568 (100)
63-74	613 (66)	785 (173)
75-90	735 (96)	1074 (303)

(SD in parentheses)

Table 4.4 Mean RT (ms) for three age groups in selective attention condition and in search condition (array-size=9).

GROUP	Selective Attention (cue provided)	Visual Search (no cue provided)
17-27 yrs	549 (83)	711 (1469)
63-74	699 (110)	770 (88)
75-90	904 (190)	959 (137)

(SD in parentheses)

A repeated measures analysis of variance was conducted on RT for the variables: group (between subjects: 3 levels) and trial type (within subjects: 2 levels). A significant group effect was found ($F(2,43)=24.4$; $p<0.01$) with, as expected, RT increasing with age. Overall mean RTs were 629.8 ms (SD=110.3), 734.4 ms (SD=83.5) and 931.7 ms (156.5) for ages 17-27, 63-74 and 75-90, respectively. A significant trial type effect was found ($F(1,43)=39.1$; $p<0.01$) with RT being faster when target location was cued. Mean RTs were 724.7 ms (SD=198.8) for cued and 817.7 ms (SD=162.7), for noncued trials. The group x trial type effect was significant ($F(2,43)=4.57$; $p<0.05$) indicating that the ability to reduce RT by using the cue reduced with increasing age. To test the slowing hypothesis, data were reanalysed following natural logarithm transformations. Both main effects for group and trial type and the group x trial type interaction remained significant (see Appendix H for complete Anova tables)¹.

4.2.3 Discussion

The aim of this study was to test the generalised slowing hypothesis and to determine whether convergent support could be obtained for the view that ageing is associated with an increase in noise. A comparison was made of performance with target-distracter combinations that were designed to encourage serial (confusable distracters) or parallel search (nonconfusable distracters). Additionally, the ability of subjects to utilise a selective attentional cue was examined.

The finding that there was no group x array size interaction in the visual search condition when the target and distracters were dissimilar suggests that preattentive processes remain intact even amongst the oldest adults (aged 75-90 years). Indeed, the rates of scanning rates were identical for the young and the young-elderly adults (10 ms per letter) and only marginally longer among the older-elderly adults (14 ms per letter). The significant linear array-size effect suggests that although the target-distracter combination may have encouraged popout, this effect did not hold when array-size increased to 9 letters.

¹ These findings were replicated when the two analyses were redone, comparing RT in the cued condition with RT in the search condition where array-size=3 for nonconfusable target-distracter combinations.

4.2.3 Discussion

The aim of this study was to test the generalised slowing hypothesis and to determine whether convergent support could be obtained for the view that ageing is associated with an increase in noise. A comparison was made of performance with target-distracter combinations that were designed to encourage serial (confusable distracters) or parallel search (nonconfusable distracters). Additionally, the ability of subjects to utilise a selective attentional cue was examined. The finding that there was no group x array-size in the visual search condition when target and distracters were dissimilar suggests that preattentive processes remain intact even amongst the oldest adults (75-90 years). Indeed, the rates of scanning were identical for the young and the young-elderly adults (10 ms per letter) and only marginally longer among the oldest-elderly adults (14 ms per letter). The significant linear array-size effect suggests that although the target-distracter combination may have encouraged popout, this effect did not hold when array-size increased to 9 letters.

Consistent with expectations, the significant group effect in the visual search condition with nonconfusable target-distracter combinations reflected the fact that the groups differed at all array-sizes, with RT increasing with age. This is likely to have been the result of the time taken by the target identification process in deciding whether the target was a T or an F. Treisman and Gormican (1988) suggested that target identification is dependent upon the ratio of activity in particular feature detectors. Noise increases the level of spurious activity and thus the randomness associated with such activity, the result being to increase confusability between these letters and the need for rechecking - and thus decision time. The significant group effect is thus consistent with the view that elderly adults have noisier information processing systems and that this has an impact on target identification processes.

The findings for the serial search condition with confusable target-distracter combinations suggest that the elderly were disadvantaged as the number of distracter letters in a display was increased. Examination of the scanning rates, however, revealed that this disadvantage occurred mainly among the oldest adults (74-90 years of age). Interpretation of these data is constrained, however, by the finding that the young-elderly adults made more errors than the young. It is possible that the scanning rate of 37 ms per item overestimated the performance of this group. This confounding of speed and accuracy illustrates one of the interpretive difficulties of RT data. The significant group main effect illustrates again the likely effect of noise on the target identification process.

Analysis of the selective attention condition revealed that presentation of a cue reduced RT in both young and elderly subjects. The smallest RT saving occurred for the oldest group and the largest for the young. Although it *appears* that the elderly received less benefit from the cue, it is possible that this was the result of a difference in how the task was perceived by the different age groups. The relatively large saving made by the young may have been the result of the fact that in both the confusable and nonconfusable cued conditions the row in which the target was presented was always nonconfusable. It is possible that as well as being adept at using the location cue, the young adult also recognised that the cued task was always nonconfusable, thus their approach to the task may have been different.

Regarding the two-stage model introduced in Chapter 1 (Figure 1.1), the fact that there was no group x array-size interaction in the nonconfusable condition together with the similarity in scanning rates across the groups suggests that the automatic components of the input stage are unimpaired with age. In other words, it is the intentional components of input and central processes that are slowed with age. Findings suggest then that preattentive processes are intact while attentive processes show a decline in speed of serial search. Consistent with the noise hypothesis, significant group effects were found for RT for visual search with both confusable and nonconfusable target-distracter combinations. The selective attention cue was utilised less efficiently by the elderly adults and this is most likely a function of the manner in which such trials were presented.

Analysis of data following natural logarithm transformations did not remove the group x trial type interactions in the selective attention condition. Similarly, for the visual search condition, the transformation did not remove the group x array-size interaction found for confusable target-distracter combinations. This suggests that results cannot be accounted for by generalised slowing alone. This finding is consistent with the work of Madden (1990a) who argued that age-related attentional changes occur independently of slowing. Allen et al. (1993) also found that group interactions which they obtained in a redundancy-gain visual search task were not removed after data were log-transformed. These workers interpreted their findings in terms of an internal noise model, implying that this model and the generalised slowing model are independent. Clearly, these researchers, although not viewing noise and attention as synonymous, consider that noise may be responsible for certain age-related changes in attentional processes. The findings of the current study are thus consistent with the view that although an increase in noise leads to an increase in response time, noise and speed of processing also produce independent effects on performance.

It is possible that the impact of noise is mediated by the level of redundancy, either in the stimulus or in the structures associated with processing. This would be consistent with the notion that differential slowing with age occurs across various subsystems, with those likely to remain immune to the effects of ageing being those in which there is a high

level of redundancy. Certainly, the findings of this study regarding the two confusability conditions are consistent with this interpretation.

The findings of this study provide support for the weak version of the slowing hypothesis and suggest that noise through its impact on attention may have an effect that is independent of generalised slowing. Neither the current study nor the work of Allen et al. (1993) has measured noise according to the operational definition provided by Vickers et al. (1972). Despite this, the finding that visual search effects occur in addition to generalised slowing suggests that the constructs noise, attention and speed may all be relevant to the understanding of age-related changes in performance. This issue is considered further in Chapter 5 where the question of whether, in fact, these constructs do make unique contributions to the prediction of fluid ability in elderly adults is examined.

4.3 Experiment 3

It has been argued that visual search performance reflects the level of noise in the processing system. Noise, through its impact on discriminability, determines whether search occurs in parallel and the time required for target identification. Findings of Experiment 2 were consistent with the notion that, as a result of an increase in noise, elderly adults scan and identify items more slowly than the young. The high level of discriminability used in Experiment 2 led young and elderly adults to adopt a parallel processing strategy during visual search with nonconfusable distracters. It was suggested, however, that higher levels of noise among the elderly may lead them to switch from parallel to serial processing at a lower level of discriminability than the young. This study follows-up that suggestion.

Treisman and Souther (1985) have suggested that, in a visual search task where array-size is increased gradually, the point at which the shift from parallel to serial processing occurs may be estimated by examining the array-size/RT function. This point is assumed to reflect discriminability and thus the level of noise in the system. Following Experiment 2, parallel processing is likely to occur at a rate of 10 ms per item. Analysis of

the increase in RT with each additional item in a display with a moderate level of target-distracter confusability should thus indicate the number of items being scanned in parallel.

In this thesis noise has been operationally defined using a backward masking procedure following Vickers et al. (1972). The visual search procedure, however, provides a means of testing the validity of noise estimates derived. The aim of the current study was to determine whether the point at which search switches from parallel to serial can be isolated for individuals during the visual search procedure. If this proves to be a viable procedure, it will be used as a check of the validity of noise estimates derived subsequently using the backward masking techniques outlined in Chapter 3. Clearly, because one reflects the level of target-distracter discriminability and the other measures noise directly, they should be positively correlated. Because the aim of this study was to test the viability of a procedure rather than a specific theory, it was conducted as a pilot study with a sample of young adults and at this stage, no attempt was made to include an age-based comparison.

4.3.1 Method

(i) Subjects

The 18 young adults who had previously participated in Experiment 1 took part in this study. Between two and three months had elapsed between Experiment 1 and the current study. Details of these subjects can be found in Chapter 3 (section 3.5.2).

(ii) Apparatus

The visual search task was presented on an EGA monitor attached to an IBM compatible computer. Target stimuli were the letters T and F, distracter stimuli were the letters I and E. The letters were 10 mm high by 5 mm wide and they were presented in 3 by 3 matrix, 25 mm wide and 40 mm high. Responses were made on a two-switch panel; the left key corresponding to target stimulus F and the right key to T.

(iii) Procedure

Participants had previously taken part in Experiment 1, in which they were administered an IT task, the DSS and two tasks from which estimates of internal noise were derived. Procedural details are to be found in section 3.5.2.

Experiment 3 involved completion of a visual search task where participants indicated which of two target stimuli (T or F) was present in a visual display. The target was presented either alone or with 1, 2, 3, 4, 5, or 8 distracters letters. The onset position of the target and the distracters was random across a 3 x 3 matrix. On each trial a fixation cue (X), 2.5 mm by 2.5 mm, was presented in the centre of the screen for 300 ms. Following an interstimulus interval of 200 ms the letter matrix was presented and remained visible until a response was made. Feedback concerning accuracy and RT was presented for 2000 ms subsequent to provision of feedback and an intertrial interval of 2000 ms was used. Prior to testing 20 practice trials were given. 144 experimental trials were administered in two blocks of 77 with 22 trials per distracter condition.

4.3.2 Results and discussion

Visual search performance was examined by fitting a linear function to the RT data as a function of array size for each of 18 subjects. Table 4.5 presents the mean RT obtained for each array size.

Table 4.5 Mean RT(ms) and standard deviation for target alone or with 1, 2, 3, 4, 5 or 8 distracters.

No of distracters	0	1	2	3	4	5	8
Mean	462	482	501	549	588	649	729
SD	52	66	66	79	85	125	142

These data were well fitted by a linear function (regression coefficient=.98; intercept=413; slope=35.6). Slope and intercept values were also obtained for the linear function fitted to each individual's data. The regression coefficients indicating the goodness-of-fit for the linear functions obtained when individual data points were fitted ranged from .33 to .99. Fifteen of the 18 regression coefficients were above .80, indicating that, overall, the data were well described by linear functions. Estimates of slope ranged from 14.6 ms to 57.1 ms per letter, indicating that, although most participants were engaged in a serial search of items, some were undoubtedly indulging in a parallel search of the display.

An attempt was made to isolate the number of items being scanned in parallel by examining the increase in RT as each additional letter was added; following Experiment 2, parallel processing was estimated to occur at a rate of 10 ms per item. As an example, subject number 15 produced RTs of 451, 449 and 454 ms for array-size 1, 2 and 3, respectively; RT for array-size 4 was 542 ms. These data suggest that this subject was processing 3 letters in parallel. Examination of data for other subjects, however, revealed that, for most, no clear point at which transition from parallel to serial processing occurred could be identified. (Raw data are included in Appendix I).

The aim of the study was to examine whether the point at which search switches from parallel to serial could be unequivocally determined by examination of RT data. Clearly, this was unsuccessful. Given the good fit obtained for the linear functions it is clear that most subjects were using a serial scanning process even at very small array-sizes. Examination of raw data (Appendix I) indicated that for some subjects RT decreased after initially increasing with array-size. As was discussed in Chapter 2, the existence of differential speed-accuracy criteria leads to interpretive difficulties when RT data are examined. Clearly, strategic differences between individuals will confound attempts to utilise RT scores. The high level of variability displayed in such RT data makes it unlikely that a reliable index of performance can be derived using this technique, regardless of the

level of confusability employed in the display. No further attempt was therefore made to estimate the point at which search switches from parallel to serial using RT data and visual search parameters have not been examined further in empirical work associated with this thesis.

CHAPTER FIVE

RELATIONSHIPS BETWEEN NOISE, SPEED OF PROCESSING AND COGNITIVE PERFORMANCE

5.1 Introduction

The aim of the current chapter was to determine whether age-related decline in fluid abilities can be accounted for wholly in terms of speed of processing. Following Experiment 2 and work reviewed in Chapter 2, it was expected that findings would be consistent with the weak version of the slowing hypothesis. In other words, it was expected that multiple independent deficits would be operating on different subsystems of the information processing system and that this would be evident through the independent contribution made by a number of tests of speed of processing to the prediction of fluid ability. Following Chapter 2, because ageing has been found to affect both noise and attention, and Vickers et al. (1972) have argued that noise can be measured independently of speed, these constructs were also considered likely to make contribution to the prediction of fluid ability. Following the unsuccessful attempt to measure noise in Experiment 1, improved procedures were used to derive estimates of noise and determine whether noise and speed can indeed be measured independently using a backward masking procedure.

As discussed in Chapter 2, Salthouse (1985b) considered age-related decline in speed of processing to be a causal factor underlying the qualitative as well as quantitative changes occurring in cognitive performance with age. Work reviewed in section 2.3.3 examining the relationship between IQ and paper-and-pencil indices of speed of processing was consistent with this interpretation. The negative correlations typically found between IT and IQ among young adults are also consistent with the view that individual differences in intellectual functioning are due in part to differences in the speed of basic processes (for reviews see Brand & Deary, 1982; Nettelbeck, 1987).

The digit-symbol substitution subtest of the WAIS-R (DSS: Wechsler, 1981), IT and the backward masking procedure for estimating internal noise will be used to test the hypothesis that a decline in information processing rate is responsible for age-related decline in cognitive functioning. Certainly, if speed is a causal factor in cognitive changes with age, then any correlations between age and cognitive performance should disappear when variance due to speed is partialled out. Multiple regression will be used to test the hypothesis that indices of speed of processing make independent contributions to the prediction of fluid ability. The hypothesis that speed can be reduced to noise will be tested by (i) determining whether IT and noise provide independent indices of performance and (ii) determining whether age differences in DSS are removed by covarying noise.

A methodological problem associated with measuring IT involves the use of strategies which reduce the effectiveness of the backward mask. Artificially short ITs can be obtained when subjects utilise apparent motion or brightness cues (Brebner & Cooper, 1986; Egan, 1986; Mackenzie & Bingham, 1985; Mackenzie & Cummings, 1986; Nettelbeck, 1982). This work has been reviewed in Chapter 3. Empirical work to be presented in this chapter examines whether any group difference found in estimates of IT reflects differential use of peripheral cues rather than a difference in speed of information processing. This possibility was examined in Experiment 4 by comparing estimates of IT derived for subjects who reported using apparent motion and brightness cues during the task to those of subjects who did not report using such cues.

One recent attempt to deal with issues of strategy use during the IT task has involved the development of an alternative index of limitations to temporal processing, using an expanded judgement task. The Frequency Accrual Speed Task (FAST) is an expanded judgement task in which the observer judges which of two randomly flashing lights is the more frequent (Vickers, 1993; Vickers & McDowell, 1990). Subjects are presented with a series of flashes from two lights with the probability of onset of a flash and the flash duration controlled by the experimenter. Accuracy in this task is held to reflect the rate of perceptual sampling - in effect, the speed at which information required to make a decision is accrued. The index is based on early work by White (1963) who

suggested that a limitation exists in the rate at which information can be assimilated from the environment. This suggestion was based on White's (1963) research into counting successive flashes.

Accuracy on the FAST task depends on the number of flashes registered by the subject on a trial. According to Vickers (1993) the individual is assumed to be taking discrete samples of information - if two flashes occur in the same sampling period they are recorded as one. Where the rate of presentation of flashes exceeds the rate of sampling, fewer flashes will be effectively registered and in consequence, accuracy on the relative frequency judgement will decrease.

The probability of producing a correct response on the relative frequency judgement used in the FAST task is based on the binomial model of probability. The experimenter manipulates the probability of onset of both the left and right-hand stimulus lights, essentially sampling with replacement from an infinite population. Vickers argues that the sequence of flashes represents a sequence of Bernoulli trials (for example, left, left, right, left, right, right ...). In the case where the right light is the more frequent and all flashes are registered, the probability of a correct response is based on the binomial probability associated with encountering a majority of right flashes, plus half the probability of encountering an equal number of left and right flashes ((Vickers, 1993, p3) further details of mathematical formulation are included in Appendix J). If the subject encounters only one flash, then the probability of a correct response is equal to the onset probability. As the number of flashes perceived increases, response accuracy increases. Vickers (1993, p19) provides a table based on the binomial distribution showing the probability of making a correct response for various onset probability levels on the basis of different numbers of flashes observed. Performance on the task is measured in terms of the number of correct responses obtained. Vickers (1993) has also suggested that estimates of IT can be derived from this task parameter (Vickers, 1993) and this possibility is considered further in section 5.2. Vickers and McDowell (1990) have argued that accuracy on the FAST task provides a reliable index of speed of processing, because the rate at which sampling occurs is directly related to the number of flashes perceived and thus

accuracy on the task. Consistent with other work on the relationship between speed of processing and intelligence, these workers have reported moderate correlations between FAST and scores obtained from 8 to 10 year old children on the Wechsler Intelligence Scale for Children (WISC-R; Wechsler, 1974). Because FAST is assumed to reflect speed of processing, elderly adults would be expected to produce a lower level of performance than the young. The inclusion of the FAST test in the empirical work to be presented was based upon firstly, its status as an index of speed of processing which is relatively immune to the effects of task strategies and secondly, the suggestion by Vickers (1993) that it could be used to provide estimates of IT.

5.2 Experiment 4

The aim of this study was to test the hypothesis that age-related changes in fluid ability are the result of decline in speed of processing. A comparison was made of estimates of internal noise, IT and DSS in a sample of young and elderly adults. It was expected that elderly adults would produce higher estimates of noise, longer ITs and lower DSS scores. Additionally, the use of apparent movement and brightness cues which reduce the effectiveness of the backward mask was examined to determine whether higher estimates of IT in the elderly were the result of differential use of peripheral cues. The reliability of IT in young and elderly adults was examined by comparing successive estimates and, following Experiment 1, by comparing Probit and Wetherill and Levitt (1965) estimates. A further aim of this experiment was to pilot the use of the FAST task as an index of speed of processing with elderly adults, previous use of the task having been restricted to children (Vickers & McDowell, 1990).

A number of procedural difficulties isolated during the attempt to measure noise in Experiment 1 were addressed in this study. Firstly, measures of internal noise were derived using the method of constant stimuli and with the stimulus exposure duration in the task set at each individual's IT. This was done to reduce the likelihood that estimates of noise would be confounded by individual differences in the number of points available for curve-fitting as appeared to be the case in Experiment 1 when the adaptive procedure starting at a

low level discriminability was used. Secondly, in an attempt to avoid methodological problems associated with the refresh rate of computer monitors, an LED display was used to present IT and noise stimuli. This mode of presentation allowed the exposure duration of the stimuli to be controlled to within one millisecond and so reduced the impact of rounding errors which are likely to have greater impact on short estimates of IT than on long ones when IT is used as the exposure duration in the noise task. Thirdly, to ensure that estimates of IT were derived using a stimulus where the discriminial difference was above the level of noise in the processing system, a difference of 1.7 degrees of visual angle was used in this experiment, compared to 1.43 degrees in Experiment 1.

A further aim of Experiment 4 was to pilot a task that is thought to be susceptible to attentional deployment to be used subsequently in a dual-task procedure in Experiment 6, where the role of attentional resources in IT performance and the age-cognition relationship is considered. The task is the random number generation (RNG) procedure of Evans (1978). This task involves the production of a sequence of random numbers and it has been found to be sensitive to the attentional demands of skill acquisition (Evans & Graham, 1980). The task would be considered appropriate for use in the dual-task procedure if both young and elderly adults were capable of completing it.

Thus, this study examined the relationship between indices of speed of processing, internal noise and fluid ability in elderly adults. Following the argument that noise and speed are not synonymous and the weak version of the slowing hypothesis, it was expected that IT, DSS, FAST and noise would make independent contributions to the prediction of fluid ability assessed using Raven's Progressive Matrices (PM). It was expected that elderly adults would be slower when their performance on DSS, IT and FAST was compared with young adults. Further, it was expected that the mean level of noise would be higher in the elderly than the young, and that although this index would be independent of IT, group differences in FAST and DSS would be attenuated but not removed when noise was covaried.

5.2.1 Method

(i) Subjects

Fifty six adults participated in the study. The young group (N = 20: 13 female, 7 male) were all students in a social work program at the South Australian Institute of Technology (now University of South Australia). Their mean age was 22.4 years (SD = 3; range 18-28) and they had completed 13 years of education. The elderly subjects (N = 36; 21 female, 15 male) were recruited through senior citizens groups. Their mean age was 67.5 years (SD = 5.5; range 60-83) and they had completed between 7 and 11 years of education. All participants reported themselves to be in either good or very good health. All had normal or corrected normal visual acuity of at least 6/9 (assessed using the Snellen eye chart) and reported free of ocular pathology.

Subjects completed the vocabulary subtest of the WAIS-R (Wechsler, 1981). An unrelated samples t-test revealed that there was no significant difference ($p > 0.05$) between the scores of young (mean = 48.3; SD = 7.7) and elderly adults (mean = 49.2; SD = 8.5) indicating that groups were equated for crystallised ability.

(ii) Apparatus and procedure

The three psychophysical tasks (IT, FAST and internal noise) were controlled by an IBM compatible personal computer.

(a) FAST

The FAST task involved indicating, on a two-switch response pad, which of two intermittently flashing lights was the most frequent. Stimuli were two red lights (12 mm in diameter) mounted 52 mm apart in a matt black panel. Each trial presented 20 flashes where each light was randomly illuminated according to a preset probability level. As a pilot test, the parameters used by McDowell (1989) were followed with 16 of the elderly adults. On each trial, the probability of illumination for one light was $p = 0.65$ and for the other, $p = 0.35$; each flash was composed of a 70 ms illumination followed by a 70 ms gap. One hundred and four trials (4 blocks of 26) were given, preceded by 20 practise trials.

Trials were balanced and the intertrial interval was 2000 ms. Accuracy rather than speed was stressed.

Performance was measured in terms of number of correct responses out of 104. Response accuracy for the pilot test was high (mean=91.3%) indicating a ceiling effect for accuracy. For the rest of the elderly sample (n=20) and for the young (n=20) the test was thus made more difficult, the test parameters being set at $p=0.6$ for one light and $p=0.4$ for the other with each flash consisting of a 60 ms illumination followed by a 60 ms gap.

(b) Inspection Time (IT)

Stimuli in this two-choice discrimination task were two vertical lines presented on an LED panel. On each trial subjects viewed a long (74 mm) and a short (50 mm) line separated by a distance of 25 mm (side of short line presentation, left vs right, was balanced). Stimuli were viewed from a distance of 80 cm so that the difference of 24 mm subtended a visual angle of approximately 1.7 degrees. Stimuli were terminated by a backward mask composed of two lines both 100 mm in length, displayed for 500 ms. Intertrial interval was set at 2000 ms. The subject's task was to indicate, using a two-switch response panel, on which side of the display the short line was located. Accuracy rather than speed was stressed.

Using the staircase procedure, following Wetherill and Levitt (1965), stimulus presentation time began at 300 ms, decreasing in steps of 20 ms until either three out of any six trials were incorrect or exposure duration reached 60 ms. Exposure duration was then raised or lowered in steps of 5 ms, according to response accuracy, until eight reversals in the direction of change to exposure duration had occurred. Exposure duration decreased following six consecutive correct responses and increased following an error. The average exposure duration at which reversals occurred (that is, 8 "peaks" and "troughs" in the profile) provided an estimate of the 90% accuracy level (SOA_{90}) for the task. Inspection Time, defined as the exposure duration required for 97.5% accuracy, was extrapolated from the 90% accuracy level using normal probability tables. This procedure was considered appropriate, because Experiment 1 had revealed that, consistent with the supposition of

Vickers et al. (1972), the psychometric function was well described by a cumulative normal ogive with an intercept that did not differ in practical terms from zero. Subjects were given 25 practise trials; five at 500 ms to ensure that they understood the task requirements and then 20 at 150 ms. Subjects had to achieve 100% accuracy at the 500 ms exposure to be included in the study. Following Experiment 1, the Probit procedure of SPSS was also used to derive an estimate of SOA_{90} . A comparison of estimates of SOA_{90} derived using this procedure and those derived using the Wetherill and Levitt (1965) procedure was made to check reliability of the curve-fitting procedure. After testing, the subjects were questioned about whether or not they had used apparent motion and brightness cues during the IT task (examples of questions asked are included in Appendix K).

(c) Noise

Noise was estimated using the same apparatus as for IT but with stimulus discriminability level varying. Exposure duration was held constant at the estimate of each individual's IT. The use of the LED display allowed exposure duration of the stimulus to be controlled to within one millisecond, a much finer level of precision than was possible in Experiment 1 where stimuli were presented on a video monitor. Using the method of constant stimuli, 100 trials, 20 at each of five discriminability levels, were presented in random order. The long line was 74 mm in length, and the shorter was either 72, 68, 64, 60 or 44 mm. The mask and intertrial interval were identical to those used for IT. Again, the subject's task was to indicate which line was the shorter. Thirty practise trials were given, 10 at an exposure duration of 500 ms to ensure that subjects could discriminate between the lines and then 20 at the individual's IT. For each individual, the number of correct responses at each discriminability level was recorded and an estimate of noise was derived from the standard deviation of the function relating accuracy to discriminability using the Probit procedure of SPSS.

In addition to psychophysical tests, subjects also completed Raven's Standard Progressive Matrices (PM) according to standard procedures. This provided a measure of

fluid general intelligence. Two subtests of the WAIS-R were administered; vocabulary (to ensure groups were equivalent with respect to crystallised ability) and DSS (to assess speed of information processing). In addition, a measure of incidental memory was obtained from the DSS task following Hart, Kwentus, Wade & Hamer (1987), in order that the contribution of recall to any group differences in DSS could be examined. According to standard procedures, DSS score was recorded as the number of substitutions completed in 90 seconds. Following this, subjects completed all substitutions in the test and were then presented with the nine digits and asked to reproduce each corresponding symbol from memory. The number of correct reproductions was recorded.

The Random Number Generation (RNG) task (Evans, 1978), designed to provide a behavioural index of attentional deployment, was also completed. This task involved producing 100 numbers at random using the numbers between 1 and 10, inclusive. Subjects said numbers aloud at a rate of one per second, using a metronome to keep time. A measure of sequential response bias was obtained by comparing the frequency of particular number pairs, modified by an adjustment related to marginal frequency. The randomisation index obtained was a number ranging from 0 to 1, with a high score being associated with poor randomisation and thus poor attentional deployment (see Appendix L for scoring formula).

Subjects were tested individually in a quiet room either at the university (in the case of the young subjects) or at their Senior Citizens' club. Where possible, the test battery was administered in two blocks, each lasting approximately 40 minutes. The first contained IT, DSS and Raven's PM. The second contained FAST, vocabulary, RNG and noise estimation. A second IT task was administered two months later so that the test-retest reliability of IT estimates could be examined.

5.2.2 Results

The aim of this study was to compare estimates of speed of processing and noise in young and elderly adults and to test whether these constructs were sufficient to account for changes in fluid ability among elderly adults. Results for IT and the impact of apparent

movement cues on group differences will be presented first, followed by results of the group comparison of noise estimates. Following this, group differences on other dependent variables (that is, PM, FAST, DSS, recall, and RNG) will be presented and the interrelationships between noise, speed and cognitive performance examined.



IT was, where possible, the mean of the first and second IT estimates. However, six elderly and three young adults did not complete the second IT measures and in these cases IT was determined by the single estimate. Four IT scores obtained from three elderly adults were over 330 ms and markedly skewed the distribution, these data and the noise estimates derived where the first IT was over 330 ms have been omitted from the analyses. Exclusion of these data did not change the outcome of group comparisons of IT or noise estimates. Table 5.1 presents mean ITs for the first and second estimates separately and combined.

Table 5.1 Mean estimates of IT (ms) for young and elderly adults across sessions.

VARIABLE	YOUNG	ELDERLY
IT(1)	101.2 (34.3)	142.7 (67.5)
IT(2)	82.9 (42.3)	105.8 (42.0)
IT(average)	92.2 (36.4)	126.4 (52.9)

(SD in parentheses)

To determine whether elderly adults had longer IT estimates than the young and to check reliability of the measure, a repeated measures analysis of variance was conducted on the variables group (between subjects: young or elderly) and estimate number (within subjects: first versus second estimate) for IT estimates. (Complete Anova table is presented in Appendix M). A significant group main effect indicated that, as expected, estimates of IT were significantly longer for elderly adults than for the young ($F(1,43)=5.15, p<0.05$).

Although both groups showed an improvement between the first and second IT measures ($F(1,43)=21.9$, $p<0.01$), the nonsignificant group x estimate number interaction ($p>0.05$) indicated that the magnitude of the improvement was similar in young and elderly adults (18% and 26%, respectively). In addition, correlations between the two measures were $r=.73$ ($p<0.01$; one-tailed) in the elderly and $r=.69$ ($p<0.05$; one-tailed) in the young, suggesting that the measures achieved acceptable reliability, consistent with previous research (Nettelbeck, 1987).

To confirm the reliability of the curve-fitting procedure used in measuring IT, estimates of SOA_{90} derived using Wetherill and Levitt (1965) and the Probit procedure were examined for each data set using correlational techniques and by comparison of absolute estimates. Data sets from both first and second estimates of IT were examined. Estimates derived were compared using two-way analysis of variance on the variables age group (between subjects: young versus elderly) and estimation procedure (within subjects: Probit or Wetherill & Levitt). Results of the analysis are included in Appendix N. Briefly, a significant main effect was found for estimation procedure ($F(1,82)=6.84$; $p<0.05$), indicating that Wetherill and Levitt estimates of SOA_{90} were shorter than the Probit estimates. However, as can be seen from Table 5.2 estimates within the groups using the two procedures were within 14 ms of one another. The group x procedure interaction was not significant ($p>0.05$).

Table 5.2: Mean estimates of SOA_{90} (ms) derived using Probit and Wetherill & Levitt procedures for young and elderly adults.

VARIABLE	YOUNG	ELDERLY
SOA_{90} (W & L)	63.8 (23.5)	82.5 (39.2)
SOA_{90} (PROBIT)	77.6 (64.9)	89.4 (63.3)

(SD in parentheses)

Although the correlation between the two procedures was high ($r=0.76$; $p<0.01$ and $r=0.89$, $p<0.01$ among young and elderly adults, respectively), a number of data sets were not well-fitted by the cumulative normal ogive. Data sets from one young adult and 12 elderly adults produced negative regression coefficients for the curves relating response accuracy to duration so that reliable estimates of SOA₉₀ could not be derived for these subjects using Probit. For one elderly adult the estimate of SOA₉₀ from Probit was inflated (2,766 ms) and for an additional three data sets from this study, chi-square goodness-of-fit analyses revealed that data were not well-fitted by the cumulative normal ogive. However, these data sets have been included in subsequent analyses, because their removal did not change outcomes.

To determine whether the group difference in IT estimates was the result of more young adults using apparent movement and brightness cues which reduced the effectiveness of the backward mask, IT estimates of "users" and "nonusers" of peripheral cues were compared. Subjects were designated either "user" or "nonuser" of cognitive strategies during IT measurement on the basis of their response to questions summarised in Appendix K. Because there was a marked difference in the proportion of cue users in each group - 50% of the young reported using apparent motion and brightness cues while only 24% of the elderly did so - unrelated samples t-tests were used to examine data. The use of such strategies during the task significantly reduced IT in both the young ($t(18)=1.76$, $p<0.05$; one-tailed) and the elderly groups ($t(32)=1.87$, $p<0.05$; one-tailed). This reduction was equivalent across groups (26% in the young and 28% in the elderly). When only nonusers of strategies were compared, the group difference in IT was weakened but remained significant nonetheless ($t(34)=1.64$, $p=0.05$; one-tailed). Among strategy users, however, the difference between the groups was small and failed to reach statistical significance ($p>0.05$). These results suggest that the group difference found in estimates of IT was not the result of young adults using peripheral cues that reduced the effectiveness of the mask. Table 5.3 presents mean ITs for the two groups classified according to strategy use.

Table 5.3 Mean IT (ms) with age groups subdivided into users and nonusers of task strategies .

	YOUNG	ELDERLY
STRATEGY USERS	78.6 (40.9) n=10	96.9 (36.9) n=8
NONUSERS	105.8 (26.5) n=10	135.5 (54.3) n=26

(SD in parentheses)

The noise task yielded the number of correct responses (out of 20) for each of five discriminability levels. An estimate of internal noise was derived for each individual from the standard deviation of the best fitting cumulative ogive obtained by plotting response accuracy against stimulus difference using the Probit procedure of SPSS. Table 5.4 presents mean noise estimates for raw scores and after a number of corrections had been applied to the data. Firstly, one elderly and one young subject attained 100% accuracy at the fourth discriminability level (stimulus difference = 14 mm) but then dropped below 100% at the easiest level. Because this led to inflated estimates for the standard deviation, their noise estimate was calculated from the first four data points only. Data from four subjects (one elderly and three young) were excluded from analysis - two young subjects because their high level of accuracy on the task led to too few data points being available for curve fitting, one subject from each group because their estimates of noise were extreme (over 2.5 standard deviations above group means).

Table 5.4 Mean estimates of noise expressed in degrees of visual angle for young and elderly adults

VARIABLE	YOUNG	ELDERLY
UNCORRECTED noise estimate	0.72 (0.38)	1.04 (0.73)
CORRECTED noise estimate	0.64 (0.29)	0.90 (0.58)

(SD in parentheses)

The significantly higher noise levels found among elderly adults for uncorrected (raw) estimates ($t(49) = 1.74$; $p < 0.05$; one-tailed) remained after correction for asymptote and exclusion of two extreme scorers ($t(46) = 1.72$; $p < 0.05$; one-tailed). Corrected noise estimates ranged from 0.22 to 1.39 for the young group and .24 to 2.23 for the elderly group indicating that a wider distribution of estimates was found among elderly adults.

Table 5.5 presents descriptive summaries of the scores obtained by young and elderly adults on other dependent variables examined in this study. FAST data were measured for all of the young adults and 20 of the elderly adults (pilot data being discarded); additionally, six elderly adults did not complete the PM test. DSS score indicates the number of substitutions completed in 90 seconds; incidental recall is the number of digit-symbol pairs recalled out of nine; FAST and Raven's PM refer to the number of correct responses produced out of 104 and 60, respectively.

Table 5.5 Mean scores for young and elderly adults on dependent variables.

VARIABLE	YOUNG	ELDERLY
DSS	64.5 (9.9)	43.1 (9.6)
Incidental Recall	7.2 (1.8)	6.1 (2.3)
Random Number Generation	.293 (.05)	.306 (.04)
FAST	85.4 (8.0)	81.5 (9.6)
Raven's PM	46.9 (5.5)	34.5 (9.1)

(SD in parentheses)

Group differences were examined using unrelated samples t-tests. As predicted, elderly adults had lower PM scores ($t(48)=5.46$; $p<0.01$; one-tailed) than the young, consistent with the view that ageing is associated with a decline in fluid ability. Contrary to expectations, no group difference was found for accuracy scores on the FAST test ($p>0.05$). Consistent with work on age-related changes in speed of processing and findings regarding IT, elderly adults completed fewer digit-symbol substitutions on DSS ($t(54)=7.90$; $p<0.01$; one-tailed) than the young and, in addition, subsequently recalled fewer digit-symbol pairs ($t(54)=1.86$; $p<0.05$; one-tailed). To determine whether the poorer performance of elderly adults on the DSS was the result of group differences in incidental recall during the test, DSS scores were compared using an analysis of variance, with recall as a covariate. A significant group effect ($F(1,55)=54.9$, $p<0.01$) indicated that slowing with age found in DSS scores was not simply the result of differences in recall. (See Appendix O for complete Anova table). Random Number Generation (RNG) scores were similar in both groups ($p>0.05$), suggesting that the task is appropriate for

subsequently examining dual-task performance in young and elderly adults. Thus, results of group comparisons were promising; as expected, elderly adults produced lower PM scores, longer ITs, higher noise estimates and poorer DSS performance than the young. These findings were consistent with previous work on age-related changes in speed and cognitive functioning.

A correlational analysis was conducted to test whether IT and noise provided independent indices of performance. If these constructs were based on the same underlying functions then a positive correlation would be expected. However, in the elderly but not the young, a negative correlation was found between IT and the estimate of noise ($r=-0.32$; $p<0.05$) indicating that, for some elderly subjects, long ITs were associated with low noise estimates and vice versa. This outcome suggests that estimates of noise and IT were confounded during measurement. Therefore, to determine whether age-related group differences in noise accounted for differences in speed of processing, estimates of IT and DSS scores were compared using an analysis of variance, with noise entered as a covariate. The significant group effect found for both DSS scores ($F(1,47)=45.8$, $p<0.01$) and IT ($F(1,45)=5.93$, $p<0.05$) after noise had been controlled statistically indicated that, as predicted, the two constructs, noise and speed, are not synonymous. (See Appendix O).

It was expected that indices of speed of processing (DSS, IT and FAST) would be related to one another but, in addition, that each would make an independent contribution to the prediction of PM. Contrary to expectations, no relationship was found between IT and DSS in either the elderly ($r=-0.26$; $p>0.05$) or the young ($r=-0.10$; $p>0.05$) groups. FAST was not related to IT ($r=-0.24$; $p>0.05$) or DSS ($r=.13$; $p>0.05$) among elderly subjects. Among the young, however, FAST was positively correlated with DSS ($r=.55$; $p<0.05$) and negatively correlated with IT ($r=-0.47$; $p<0.05$), indicating that high FAST accuracy was associated with completing more digit-symbol substitutions and shorter ITs.

The hypothesis that noise and indices of speed of processing would make unique contributions to the prediction of PM scores among elderly adults was tested by examining Pearson's correlation coefficients and by entering the variables DSS, IT, noise and age into

a multiple regression equation with PM as the dependent variable. Simple correlations revealed that age and PM score were related ($r=-.48$; $p<0.01$), indicating that, as expected, fluid ability decreased with age. As expected, IT ($r=-0.31$; $p=0.05$) and DSS score ($r=.62$; $p<0.01$) predicted PM. Consistent with the nonsignificant group difference found for FAST scores, this variable was not related to PM among elderly adults ($r=-.15$; $p>0.05$). FAST was therefore not examined further, because only 20 elderly adults had completed the experimental task and, despite being a moderate predictor of PM in the young ($r=.42$; $p<0.05$), FAST was not related to PM among the elderly. A standard multiple regression was conducted with age, noise, DSS, and IT entered as independent variables and PM as the dependent variable. Table 5.6 presents simple correlations between the variables, standardised regression coefficients (β), R and R^2 . This combination of variables accounted for 45% of the variance in PM; however only DSS contributed significantly to the prediction of PM. This suggests that the relationships found between PM and both IT and age revealed in the simple correlations were in fact mediated by DSS.

Table 5.6 Standard multiple regression of speed and noise indices on PM⁴

Variables	IT	AGE	DSS	PM	β
NOISE	-.32*	.27	-.10	.03	.15
IT		.22	-.26	-.31	-.10
AGE			-.54**	-.48**	-.19
DSS				.62**	.49*
					$R^2 = .45$
					$R = .67$

* $p<0.05$; ** $p<0.01$ (Two-tailed).

Because the simple correlation had indicated that incidental recall was related to PM ($r=.34$, $p<0.01$) but not to DSS ($r=.15$, $p>0.05$) the multiple regression was rerun after including this variable. Although the inclusion of recall accounted for an additional 4% of the variance in PM scores ($R^2=.49$), the beta weighting for recall was not significant and

4 Variables were entered as a block.

contributions from DSS, noise, IT and age remained essentially unchanged (see Appendix P).

5.2.3 Discussion

Consistent with work reviewed in Chapter 2 on age-related decline in fluid ability, elderly adults were found to have lower PM scores. The similarity of vocabulary scores between groups was expected and is consistent with the minimal deficit found in verbal skills with age (Botwinick, 1977). This finding suggests that groups were equivalent with respect to crystallised ability. The finding that RNG scores of older subjects did not differ from those of the young indicates that for the elderly subjects, the ability to deploy attention had not decreased with age. This suggests that the RNG task may be appropriate for examining dual-task performance in young and elderly adults; this issue is examined further in Experiment 6.

Of the three measures of processing speed (IT, DSS and FAST), only the FAST index did not differentiate between the age groups. This may be due to a ceiling effect, because both groups had mean accuracy scores above 80%. FAST was considered as an alternative index of speed, because Vickers (1993) has argued that is likely to be more "pure" - that is, less contaminated by strategy use than IT. Among the young subjects, using convergent logic, the significant positive correlation between FAST and both IT and DSS suggests that FAST is tapping some aspect of temporal processing limitations. In the young sample FAST appeared to provide an index of individual differences in fluid ability consistent with McDowell's (1989) findings for children. Although no significant correlation was found between FAST and PM in the elderly sample, it is likely that this was a result of a ceiling effect for accuracy and the index appears worthy of further consideration. An attempt to compare young and elderly adults on FAST and to derive estimates of IT from this task is made in Experiment 5 where task parameters that influence the level of difficulty of the task are manipulated.

Although the group difference between IT scores in Experiment 1 did not reach statistical significance, the current study has demonstrated a difference with age which

remained when only nonusers of peripheral cues were examined. This implies that the difference in performance between the two groups was not due simply to differential use of apparent movement and brightness cues, despite the fact that a higher proportion of young subjects reported using such cues. Because strategy use has been linked to a reduction in the strength of an IT-IQ relationship, this may be one reason for the moderate negative correlation found between IT and PM among elderly but not young subjects.

Although they appeared not to influence the outcome of analyses, a number of data sets produced during the IT task were not well fitted using the Probit procedure. The LED display used in the current study may be particularly prone to the use of apparent movement and brightness cues, suggesting that, despite concern with the refresh rate of the video monitor, future attempts to measure IT should use video presentation of stimuli rather than the LED display.

Consistent with expectations, higher estimates of internal noise were found among the elderly. This difference remained when data were corrected for both extreme scorers and methodological problems associated with the curve fitting procedure. This suggests that groups can be differentiated using this index. The variance associated with group means in the current experiment was larger in the elderly group indicating that the group difference was a consequence of a wider distribution among the elderly. This finding is consistent with the view that ageing, particularly CNS ageing, is not a uniform process. Clearly, some individuals were "noisy" while others were not. Increased variability is also consistent with evidence that some subjects adopted task strategies based on apparent movement which reduced the effectiveness of the mask in the IT task, and presumably, in the noise task also.

In the young group, while acknowledging that the small sample size restricts interpretation, the negative correlation found between noise and DSS is consistent with the notion that noise is related to speed of processing. The finding that this was not the case among the elderly may be the result of contamination of noise estimates by IT in this group -slower speed of processing (longer IT) being associated with lower noise estimates. The estimate of noise derived for the young may have been more "pure" and the negative

relationship found between IT and noise estimates from elderly subjects suggests that, for some elderly adults, IT and performance on the noise task were confounded. Despite a group difference in noise then, it is likely that individual differences within the elderly group were not valid. It is possible that sensory acuity had an impact on performance in both the IT and noise tasks, despite attempts to equate groups on this variable. The variable discriminability task used to measure noise may be particularly prone to contamination by visual acuity. In an attempt to avoid this difficulty, Experiment 6 examines group differences on performance variability (that is, the number of errors) on a task using constant discriminability and constant exposure duration.

The suggestion that speed can be reduced to noise was examined by determining whether group differences in both IT and DSS remained after covarying noise. Although conclusions are necessarily tentative, the finding that group differences in both DSS and IT remained following this manipulation suggests that speed of processing cannot be accounted for simply in terms of internal noise.

Although the finding that incidental recall was predicted by PM but not speed is not consistent with the slowing hypothesis, a number of intercorrelations between measures for the elderly subjects appeared to be consistent with the view that the speed factor increases in importance with age. In the elderly group both IT and DSS were moderate predictors of PM. However, the multiple regression indicated that although speed and cognitive ability were related, neither noise nor IT made a significant contribution to the prediction of PM once speed assessed by DSS had been considered. This finding and the finding that the correlation between IT and DSS was not statistically significant, suggest that IT fails as an index of speed. It is possible, however, that the relationship between IT and PM was reduced by the presence of individuals who used apparent movement and brightness cues to reduce the effectiveness of the backward mask. Whether or not DSS and IT do make independent contributions to the prediction of fluid ability thus remains worthy of consideration and is examined further in Experiment 6, where the IT task was presented on a video monitor with the lightening mask used in Experiment 1 in an attempt to reduce strategy use. Clearly, the finding that only DSS made a unique statistically significant

contribution to the prediction of fluid ability suggests that, consistent with the strong version of the slowing hypothesis, this variable accounts for the relationship found between age and PM.

In conclusion then, elderly adults were found to be slower when assessed using the DSS test and this was not due to differential recall during the test. The longer mean IT found in the elderly group was also indicative of a reduction in information processing efficiency with age, not accounted for by differential use of apparent movement and brightness cues. IT variability was also higher in this group reflecting the increased heterogeneity in the processing speed decline in elderly individuals. However, interpretation of the age difference in noise is constrained by the same confounding of IT and noise estimates in the elderly group. Although elderly adults were found to be noisier, estimates of certain individuals within the elderly group may have been invalid because, for these individuals, initial overestimation of IT led to a reduced difficulty level and thus shorter estimates being obtained on the noise task. Findings therefore suggest that noise cannot be measured independently of processing efficiency within the backward masking procedure. Partial support was provided for the view that age-related decline is the result of slower processing, interpretation being constrained by procedural difficulties associated with the measurement of backward masking indices. The relative contribution of IT and DSS to the prediction of fluid ability remains worthy of consideration and is examined further in Experiment 6. Following Stankov (1988) and the finding that 55% of the variance in PM scores remained unaccounted for after age, speed and noise were considered, the contribution of attention to the prediction of fluid ability will also be considered in Experiment 6.

5.3 Experiment 5

FAST has been proposed as an alternative to IT as an index of speed of processing (Vickers, 1993). It was included in Experiment 4 on the grounds that (i) it is thought to be immune to the effects of task strategies and (ii) it has been suggested that estimates of IT can be derived from accuracy on the task. Experiment 4 compared FAST performance in

young and elderly adults when the probability associated with light onset was $p=0.60$ and the duration of each flash was 60 ms followed by a 60 ms gap. Mean accuracy on this task did not differ between young and elderly adults and, as discussed in section 5.1.3, it was suggested that this may be the result of a ceiling effect for accuracy on the task. Because Experiment 4 suggested that IT and noise may be confounded during measurement, the current study examined performance on the FAST task to determine whether it could be used to replace the IT task in deriving the exposure duration for use in the noise task. The aims of the study were to determine (i) whether a group difference on FAST accuracy scores could be established; (ii) whether FAST is a more reliable index of speed of processing than IT; and (iii) whether estimates of IT could be derived from accuracy on the FAST task.

FAST performance was compared under various parameter manipulations in an attempt to vary the difficulty level of the test and so reduce the likelihood of ceiling effects. Two probability levels and two exposure durations were examined across blocks within the task. In addition, in an attempt to determine whether the index of speed derived is reliable, FAST scores were compared across two sessions. Vickers (1993) has argued that estimates of IT can be derived from FAST performance by following formula 2.

$$IT_{FAST} = (n1/n2).E \quad (2)$$

where $n1$ is the number of flashes presented to the subject, $n2$ is the number effectively registered and E is the flash exposure duration. The number of flashes effectively registered ($n2$) can be determined from the percentage of correct responses achieved on the task for a given onset probability using the binomial probability table presented in Vickers (1993, p19). Vickers assumes that a sequence of left (l) or right (r) flashes can be represented as a sequence of Bernoulli trials (eg l,l,l,r,r,l,r,r,r...) with the probability that one light will be lit equal to p and the probability that the other side will be lit equal to $1-p$, on each trial. The probability that the observer will respond "right" when the right light was, in fact, the more frequent and assuming that all flashes were registered, is given by the

probability of encountering a majority of right flashes in the sequence of Bernoulli trials, plus half the probability of encountering an equal number of left and right flashes (further details of mathematical formulation are given in Appendix J). Vickers assumes that during the FAST task an observer takes discrete samples of sensory information, if two flashes occur within one sampling period they are registered as one. In the current study estimates of IT_{FAST} were compared with estimates of IT derived using the traditional lines discrimination task to determine whether reliable estimates of IT could be derived from the expanded judgement task. The successful estimation of IT from the FAST task would mean that this task could be used to derive an independent index for the exposure duration of any subsequent attempts to estimate internal noise using a backward masking procedure.

5.3.1 Method

(i) Subjects

Participants in this study were 16 young adults (3 men and 13 women) aged between 18 and 30 years (mean= 20.8, SD=3.5) and 16 elderly adults (4 men and 12 women) aged between 65 and 83 years (mean=74.6, SD=4.9). Young subjects were first year student nurses and elderly adults were recruited through senior citizens groups. Elderly adults were paid \$5-00 for their participation.

There was no difference between WAIS-R vocabulary scores for the young and elderly adults (mean=50.2 in both cases, SDs=6.3 and 5.2, respectively) indicating that groups were equivalent with respect to crystallised ability. All participants reported free of ocular pathology and had normal or corrected normal visual acuity of at least 6/9 (assessed using Snellen chart).

(ii) Apparatus and procedure

Subjects were tested in two sessions, each lasting between 30 and 40 minutes, from one to three weeks apart. In the first session, the vocabulary subtest of the WAIS-R was administered and estimates of IT and FAST were derived. The order of presentation of the two psychophysical tasks was balanced. In the second session, the DSS subtest of the WAIS-R was administered and the two psychophysical tasks were administered again.

The apparatus used to present the FAST task was the same as that employed in Experiment 4. Task parameters were manipulated: two illumination durations (40 ms with a 40 ms gap and 50 ms with a 50 ms gap) and two onset probability levels were examined ($p=0.6$, that is, 12 versus 8 flashes; and, $p=0.55$, that is, 11 versus 9 flashes) this produced four stimulus combinations. Trials were presented in four blocks of twenty, each block presenting one stimulus sequence. The order of presentation of the blocks was randomised across subjects. The task involved judging which of the two randomly flashing lights was the more frequent. The number of correct responses produced was recorded. Following the completion of the second session, subjects were asked whether they could identify particular strategies that had helped them to judge which light was the more frequent.

The IT task was presented on an EGA monitor attached to an IBM compatible computer. The computer presentation was used in preference to the LED display used in Experiment 4, because the LED had been found to be prone to the adoption of apparent movement and brightness cues that reduced the effectiveness of the backward mask. Target and masking stimuli were identical to those used in Experiment 1. On each trial a fixation cue (a small dot) was presented in the centre of the screen for 500 ms. The target stimulus was then presented for a variable duration, being terminated by the onset of the masking stimulus. This remained in view for 500 ms and an intertrial interval of 2000 ms was adopted. Subjects indicated on which side of the target stimulus the short line was situated by pressing a key on a two-switch response pad.

The 90% accuracy level for the IT task (SOA_{90}) was derived by averaging the 8 reversal levels obtained using the Wetherill and Levitt (1965) staircase procedure. Exposure duration commenced at 300 ms and then reduced in steps of 20 ms either until 3 out of 6 trials were errors or exposure duration reached 60 ms. At this point exposure duration was raised or lowered according to response accuracy; a step down occurred following six consecutive correct responses and a step up occurred following an error. (Although refresh rate of the monitor was actually 16.74 ms and exposure durations were necessarily multiples of this, for simplicity they are presented as multiples of 20 ms). As

an additional reliability check, estimates of SOA_{90} were also derived using the Probit procedure of SPSS.

This study derived estimates of SOA_{90} rather than $SOA_{97.5}$ (the previously defined level error-free performance for IT). Because these two values will be scaled equivalent, the current study reports values of SOA_{90} and hereafter these are referred to as SOA_{LINES} , to distinguish them from estimates of IT derived from the FAST task (IT_{FAST}).

5.3.2 Results

Two estimates of SOA_{LINES} and the average SOA_{LINES} across the two sessions were derived for each subject from the traditional IT task (see Table 5.7). The second SOA_{LINES} estimates derived for two of the elderly adults were extreme (380 ms and 410 ms, respectively) and markedly skewed the distribution. These two cases represented marked increases from the initial estimates of 275 ms and 160 ms, respectively and the individuals concerned reported some confusion over IT task requirements at the second testing session. Because it is likely that the second estimates were measured unreliably for these two participants, averages were not calculated for these individuals; instead, performance was based on the single estimates.

Table 5.7 Mean estimates of SOA_{LINES} for young and elderly adults across two session.

	SOA_{LINES} (1)	SOA_{LINES} (2)	Average from two estimates
ELDERLY	147.7 (49.6)	129.0 (44.5)	143.9 (50.7)
YOUNG	89.9 (19.7)	80.2 (12.6)	84.9 (14.9)

(SD in parentheses)

Performance on the IT task was examined using a repeated measures analysis of variance on the variable group (between subjects: young or elderly) and session (within

subjects: first or second estimate) for estimates of SOA_{LINES} . As expected, a significant main effect was found for group ($F(1,28)=21.51$; $p<0.01$), indicating that elderly adults were slower than the young. Consistent with Experiment 4, the session main effect was significant ($F(1,28)=4.61$; $p<0.05$) but the group x session interaction was not ($p>0.05$), indicating that SOA_{LINES} reduced across sessions in both groups and the magnitude of the improvement was equivalent across groups⁵. The first and second SOA_{LINES} estimates were strongly correlated among both the elderly ($r=.75$; $p<0.01$) and the young ($r=.68$; $p<0.01$).

As was done previously in Experiments 1 and 4, the first and second estimates of SOA_{LINES} derived using the Wetherill and Levitt were compared to those derived from Probit. Estimates were highly correlated in both the young ($r=.97$, $p<0.01$) and elderly ($r=.91$, $p<0.01$) groups. Absolute estimates were compared in a repeated measures analysis of variance with one between subjects variable (age group: young or elderly) and one within subjects variable (estimation procedure: Probit or Wetherill & Levitt). Means and results of the analysis are presented in Appendix Q. Briefly, neither the procedure nor the group x procedure interaction were significant suggesting that estimates were measured reliably.

The mean number of correct responses produced in the two administrations of the FAST task combined across parameter manipulations are presented in Table 5.8.

Performance under the various parameter manipulations is presented in Table 5.9.

Table 5.8 Mean number of correct responses (out of 80) for first and second sessions for FAST data combined across stimulus sequences.

	SESSION 1	SESSION 2
YOUNG	56.9 (6.65)	59.8 (5.02)
ELDERLY	55.2 (6.9)	53.6 (8.0)

(SD in parentheses)

⁵ Anova table is presented in Appendix P(ii) - see reverse of pg 181.

Table 5.9 Mean number of correct responses (out of 40, combined across sessions) produced on the FAST task by onset probability and flash duration .

	Flash duration 50 ms		Flash duration 40ms	
	0.6	0.55	0.6	0.55
YOUNG	32.9 (3.2)	25.8 (3.5)	31.3 (4.0)	25.5 (2.6)
ELDERLY	29.9 (3.8)	24.4 (3.4)	29.0 (5.0)	25.6 (4.3)

(SD in parentheses)

FAST Performance was examined using a repeated measures analysis of variance for three within subjects variables: session (two levels), flash duration (50 ms and 40 ms) and onset probability ($p=0.6$ and $p=0.55$) and one between subjects variable: group (young versus elderly). A significant main effect was found for group, revealing, as expected, lower accuracy scores among elderly adults ($F(1,30)= 3.10$; $p<0.05$)⁶. Neither session nor duration main effects were significant ($p>0.05$). A significant main effect was found for onset probability ($F(1,30)=87.2$; $p<0.01$) revealing poorer performance when onset probability was equal to 0.55. None of the two-way or three-way interactions was statistically significant ($p>0.05$, in all cases). (See Appendix R for complete Anova table).

Despite there being no change in FAST scores across sessions and a strong correlation being found between the first and second FAST test among elderly adults ($r=.73$; $p<0.01$), there was no relationship between the two FAST estimates among young adults ($r=-0.14$; $p>0.05$). FAST performance was not correlated with SOA_{LINES} among the elderly ($r=.09$; $p>0.05$) or the young ($r=.01$; $p>0.05$). None of the participants was able to identify particular strategies that they had used during the task.

Following Formula 2, estimates of IT_{FAST} were derived from FAST scores.

Because neither session nor duration main effects were significant, data were combined across both variables. To estimate IT_{FAST} , exposure duration was assumed to be 45 ms (the

⁶ Because elderly adults were expected to produce lower FAST scores a directional hypothesis was proposed for the main effect of group and a 1-tailed test of significance used. The F ratio was converted to a t value (following Hays, W.L. (1963). Statistics for Psychologists. New York: Holt, Rinehart & Winston. p 375).

average of 40 ms and 50 ms) and estimates were derived for the two onset probability conditions separately. IT_{FAST} estimates could not be determined where response accuracy was less than the onset probability or where it was greater than the probability associated with registering all twenty flashes. Under these constraints, IT_{FAST} estimates could be derived for only 8 of the 16 young and 10 of the 16 elderly adults when onset probability was 0.6; for $p=0.55$, IT_{FAST} estimates were derived for 13 young and 10 elderly adults. Five of the estimates obtained (four from young subjects and one from an elderly subject) were extreme (above 300 ms) and have been omitted from analyses.

Although differences between IT_{FAST} scores were in the expected direction (see Table 5.10), they were not statistically significant ($p>0.05$, in all cases). The magnitude of estimates of IT_{FAST} estimates and those derived from traditional procedures were similar among young subjects. Among the elderly, however, IT_{FAST} estimates were shorter than estimates of SOA_{LINES} derived using traditional procedures.

Table 5.10 Estimates of IT_{FAST} for young and elderly adults derived from FAST task for onset probability of 0.6 and 0.55, separately.

	IT_{FAST} ($p=0.6$)	IT_{FAST} ($p=0.55$)
YOUNG	82.7 (33.2)	73.3 (49.4)
ELDERLY	112.7 (64.7)	104.7 (49.4)

(SD in parentheses).

When group estimates of IT_{FAST} were derived from group mean FAST accuracy scores (rather than from individual performance profiles), values of 52 ms and 97 ms were found for young and elderly adults, respectively, for onset probability=0.60; values of 62 ms and 93 ms were found for onset probability=0.55. Again, although the order of magnitude of the estimates of IT_{FAST} is smaller in magnitude than from the traditional task, the direction of the difference is consistent with a decline in speed of processing with age.

The individual IT_{FAST} estimates derived from the FAST task where onset probability was 0.6 was moderately correlated with the second traditional SOA_{LINES} estimate in the elderly group ($r=.61$; $p<0.05$; $n=10$) but, as a result of the small sample size, did not reach statistical significance in the young ($r=.54$; $p>0.05$; $n=7$). Among the young, the IT_{FAST} estimate derived from the FAST task where onset probability was 0.55 was negatively correlated with the first ($r=-.73$; $p<0.05$; $n=10$) and the second ($r=-.57$; $p<0.05$; $n=10$) estimates of SOA_{LINES} .

5.3.3 Discussion

The finding that elderly adults produced lower accuracy scores on the FAST task is consistent with the well-documented slower speed of processing found with age. The finding suggests that the nonsignificant difference found between the FAST measures from young and elderly adults in Experiment 4 was a result of a ceiling effect for accuracy on the version of the task employed in that study. FAST accuracy scores remained stable across two sessions which were between one and three weeks apart, suggesting that they were relatively immune to practice effects. In the elderly group a positive correlation found between the two estimates ($r=.73$) is consistent with this interpretation. In the young, however, the finding that the two measures were not related raises concern about the reliability of the measure. One young subject who performed at below chance level on the first task and at 75% accuracy level on the second reported that she had not fully understood the nature of the task in the first session. When her data were eliminated from analysis, the correlation between the two estimates remained nonsignificant ($r=-0.11$ $p>0.05$), suggesting that the finding was not simply the result of the extreme variation in performance produced by this subject.

Estimates of SOA_{LINES} derived using the traditional lines discrimination task showed a decline in speed of processing with age. SOA_{LINES} estimates were reliable in both subgroups examined in the current study. These findings are consistent with the findings of Experiment 4.

The attempt to derive estimates of IT_{FAST} from the FAST task was not successful. Estimates could not be derived where performance accuracy was greater than that theoretically derived for registering all of the flashes presented (clearly, one cannot be accurate if one identifies more flashes than were actually there) or when it was lower than that associated with the onset probability of the light (this occurred for 14 of the 32 participants for onset probability of 0.60 and 9 of the 32 participants for onset probability of 0.55). Because the task was not adaptive - parameters did not change in response to individual performance - ceiling and floor effects for accuracy were found in both young and elderly samples. The interrelationship between various estimates of IT derived from the FAST task and estimates of SOA_{LINES} derived from the traditional task were conflicting with both positive and negative correlations being found.

Because SOA_{LINES} in this experiment in fact represents SOA_{90} rather than SOA for error-free performance as is the case with IT_{FAST} , one would expect SOA_{LINES} to be shorter than IT_{FAST} . The fact that this was not the case is further evidence that reliable estimates of IT cannot be derived from the FAST task. The finding that estimates of IT_{FAST} derived for elderly adults were shorter than estimates of SOA_{LINES} derived from the traditional task may be the result of the lower emphasis placed on visual acuity processes by the former. Alternatively, as discussed in Chapter 3, IT may be particularly sensitive to focussed attention; the role of attention in IT performance is considered further in Experiment 6.

In conclusion, although both FAST and IT appear to differentiate between young and elderly adults, FAST was found to be less reliable. In addition, estimates of IT_{FAST} could not be derived from the FAST task following Formula 2 for a number of the participants in the current study, either because of ceiling or floor effects for accuracy or because estimates were inflated, probably as a result of spurious errors on the task. It is unlikely then that the FAST task can provide performance indices that are more reliable than those associated with the traditional IT task. FAST is not useful either as an alternative to IT or for determining the exposure duration required in future attempts to measure internal noise using a backward masking procedure. The task is not considered further in this thesis.

5.4 Experiment 6

This study tested the prediction that indices of attentional resources would make an independent contribution to the prediction of fluid ability in elderly adults after speed had been controlled. Experiment 4 found that speed assessed by DSS accounted in part for age-related decline in fluid ability. When age, noise and speed of processing were considered in a multiple regression equation, 45% of the variance in fluid ability (PM) was accounted for, with DSS contributing most - but with 55% of variance remaining not accounted for by these variables. Experiment 2 suggested that age-related differences in attention occur independently of generalised slowing. Stankov's (1988) model holds that age-related change in fluid ability are the result of changes in search, concentration and flexibility. Because the search index is an index of speed of processing, his model implicates both speed and attention.

In Experiment 4 estimates of IT and DSS were not found to be highly correlated and multiple regression suggested that IT did not make a unique contribution to the prediction of cognitive performance over and above that made by DSS. This finding suggests that IT, in fact, provides a less effective index of speed of processing than DSS. It is possible, however, that this may have been the result of the impact of strategy use during the IT task. As reviewed in Chapter 3, the presence of strategy users has been found to reduce IT-IQ correlations. The LED display IT task utilised in Experiment 4 appeared to be particularly prone to strategy use, presumably as a result of the less effective mask used (the mask was longer than the target but not wider or brighter). In the current study the relationship between IT and cognitive performance was reconsidered, IT being presented on a computer monitor with the lightening mask used in Experiment 1. This mask seems to be relatively immune to strategy effects (Evans & Nettelbeck, 1993).

This study examined the impact of attentional variables on IT performance. Work reviewed in Chapter 2 was consistent with the view that ageing is associated with a reduction in processing resources. In Chapter 3, it was suggested that estimates of IT can be inflated by the presence of spurious errors at long exposure durations. This finding emphasises the role of maintaining attention to the task. The effect of varying the

foreperiod in an IT task has been examined in both intellectually handicapped adults and children (Nettelbeck & McLean, 1984; Anderson, 1989). Although IT was lengthened by this manipulation, it was not found to account for group differences examined. This issue has been examined with respect to age-related differences in IT in the current study.

The current study also examined IT performance under conditions which made high demands on processing resources. Evidence for the view that decline with age in cognitive performance is the result of a reduction in processing resources was considered in Chapter 2. A dual-task paradigm was chosen to examine this issue. A recently published study by Egan and Deary (1992) has used a dual-task IT procedure to examine the use of task strategies during IT performance. In the current study, the random number generation (RNG) task piloted in Experiment 4 was used as the dual-task. This task involves producing a random sequence using the numbers between one and ten, inclusive. Subjects say numbers aloud at a rate of approximately one per second and a randomisation index is derived from the relative frequency with which number pairs are produced. Experiment 4 showed that the index does not show age-related differences for baseline performance and it has been argued that it is susceptible to attentional deployment, randomisation being poorer under attention demanding conditions and skill acquisition (Evans & Graham, 1980). On these grounds, it was predicted that elderly adults would be relatively more impaired than young adults by the dual-task manipulation. In other words, it was predicted that age-related differences in randomisation would be found and that age-related differences in IT would be accentuated during the dual-task procedure. In addition, it was predicted that the dual-task randomisation scores and estimates of IT would make unique contributions to the prediction of fluid ability (PM), over and above those made by single-task IT and DSS.

In Experiment 4 estimates of noise and IT were found to be confounded, long estimates of IT leading to a low level of difficulty, and thus low estimates of noise, on the noise task. Further, it was suggested that the variable discriminability task used to measure noise might be particularly susceptible to visual acuity effects. One suggestion revived recently by Levy (1992), but which had already been addressed in the current study, is that

response variability measured simply in terms of the number of errors produced during the IT task provides an index of individual performance. This technique has been utilised previously by both Longstreth et al. (1986) and Larson and Saccuzzo (1989). In the current study, it is assumed that moment-to-moment variability in performance will be reflected in the number of errors produced when the IT discrimination task is presented at a duration associated with 80 % accuracy for each individual. Clearly, while this measure simply provides a possible validation of estimates of SOA_{80} derived, it can also be thought of as reflecting the level of noise (or unreliability) in the system. On this basis, it was predicted that elderly adults would produce lower validation scores and further, that this index would make a unique contribution to the prediction of fluid abilities in the elderly.

In summary, this study measured speed using DSS and a standard IT task; attentional indices were derived from two IT tasks - one of which varied the intertrial interval during stimulus presentation, the other being a dual-task. Noise, as previously operationally defined in terms of procedures recommended by Vickers et al. (1972), was not measured directly in this study; rather performance variability was derived from a task that also provided a means for validating estimates of IT. Fluid ability was assessed using Raven's PM and the hypothesis that indices of speed, attention and variability would make unique contributions to the prediction of PM was tested using multiple regression analysis.

5.4.1 Method

(i) Subjects

Participants were 20 young adults (5 male and 15 female) aged between 17 and 26 years (mean=18.9, SD=2.7) and 32 elderly adults (11 male and 21 female) aged between 61 and 84 years (mean=70.2, SD=6.5). Young subjects were first year students of Occupational Therapy and attended the University of South Australia. The elderly were community-dwelling adults recruited through a senior citizen's club and ARPA; they were paid \$5-00 for their participation.

Elderly adults were found to have marginally higher WAIS-R vocabulary scores than the young ($t(50)=1.83$, $p<0.05$). Means were 45.8 (SD=4.8) for the young and 50.0 (SD=8.8) for the elderly suggesting that groups were near-equivalent with respect to crystallised ability. All participants reported themselves to be in either good or very good health. All reported free of ocular pathology and had visual acuity of at least 6/9 assessed using the Snellen chart.

ii) Apparatus and procedure

Testing took place in two 30-40 minute sessions held between one and four weeks apart. In the first session the random number generation task (RNG), the vocabulary and DSS subtests of the WAIS-R and two IT tasks were administered. One IT task involved a constant and the other a variable intertrial interval. That is, in the former the IT task was presented according to standard procedures with the interval between successive trials set at 2000 ms. In the latter the IT task was presented and the interval between successive trials was varied randomly across five levels. The order of presentation of the two IT tasks was balanced. In the second session participants completed an IT task and the RNG task concurrently (the dual-task manipulation), Raven's PM and an IT validation task.

The three versions of the IT task were presented on an EGA monitor controlled by an IBM compatible computer. The target and masking stimuli, were identical to those used in Experiments 1 and 5; that is, the target stimulus consisted of two vertical lines, one 35 mm and the other 25 mm in length, joined across the top by a line 15 mm in length. The masking stimulus was composed of the lightning bolts described by Evans and Nettelbeck (1993). This mask was used in an attempt to reduce the use of apparent motion and brightness cues which reduce the effectiveness of the mask.

In the standard and the dual-task the intertrial interval was set at 2000 ms. In the variable intertrial interval IT task (IT_v), five intertrial intervals (5000 ms, 3500 ms, 2000 ms, 1000 ms and 800 ms) were varied randomly across trials. In all three tasks, subjects indicated which of the two target lines was the shorter on a two-switch response pad.

For each IT task, exposure duration commenced at 300 ms and then varied in steps of 20 ms according to response accuracy (although the actual refresh rate of the monitor was 16.74 ms, for simplicity values are reported as multiples of 20 ms). Following Wetherill and Levitt (1965), the procedure, commencing either after three out of any six trials were errors or when exposure duration reached 60 ms, determined the exposure duration associated with the 80% accuracy level. A reduction in exposure duration followed three correct responses in a row at a particular level while an increase occurred following one error. The exposure duration associated with 80% accuracy (SOA_{80}) was derived by averaging across the eight durations at which a reversal in the direction of the exposure duration sequence occurred. The 80% level, requiring fewer trials to reach an estimate than 90% level, was used to reduce the impact of fatigue on repeated estimates of IT. Subjects completed 30 practice trials, ten at an exposure duration of 300 ms and 20 at 150 ms for each IT task. Criterion for inclusion in the sample was the achievement of 100% accuracy on the trials exposed for 300 ms.

As a reliability check, estimates of SOA_{80} derived from the Probit procedure of SPSS were compared to those derived following the Wetherill and Levitt (1965) method. Although the IT tasks involved determining SOA_{80} rather than $SOA_{97.5}$, the operationally defined level for error-free performance, these two values will be scaled equivalent of one another. For ease of presentation, the estimate of SOA_{80} derived from the standard IT task, the variable intertrial interval task and the dual-task will be referred to as IT, IT_V and IT_D , respectively.

The RNG task was identical to that administered in Experiment 4; subjects were required to say the numbers from one to ten inclusive, aloud in random order, at a rate of one per second. Baseline performance for the RNG task was determined for each individual in the first session. This involved producing 100 random numbers. During the dual-task subjects were required to complete the RNG and an IT task at the same time. The experimenter recorded the numbers produced, the RNG task was terminated when the IT task was completed. The randomisation index was derived following the formula given in Appendix L.

The IT validation task involved the presentation of fifty trials where the target and masking stimuli were identical to those used in the IT task and the exposure duration was held constant at the level previously determined using the Wetherill and Levitt (1965) procedure to be that required for the production of 80% accuracy on the standard IT task; (as a result of the refresh rate of the monitor, this value was rounded to the nearest 20 ms). The discriminability level of the task and the intertrial interval (2000 ms) remained constant. The task was preceded by 20 practice trials at an exposure duration equal to the 80% level for each individual. The response required was identical to that of the standard IT task - that is, the side of the stimulus on which the shorter line occurred was indicated using a button-press response. The number of correct responses made out of 50 was recorded.

5.4.2 Results

Table 5.11 presents the means and standard deviations for the various tests examined. DSS reflects the number of substitutions completed in 90 seconds. PM and validation are raw scores (the number of correct responses out of 60 and 50, respectively). The three estimates of IT represent the exposure duration (ms) required to reach 80% accuracy. RNG_{BASE} is the baseline randomisation index and RNG_{DUAL} is the dual task randomisation index, scores ranging from 0 to 1 with a high score reflecting poor attentional deployment. Six elderly adults did not complete the validation task; one elderly adult did not complete the dual-task.

As predicted, an unrelated samples t-test revealed that elderly adults had lower PM scores than the young ($t(49)=7.99$; $p<0.01$; one-tailed), consistent with Experiment 4 and other work which has found a decline in fluid ability with age. The finding that elderly adults produced fewer digit-symbol substitutions than the young on DSS ($t(50)=10.4$; $p<0.01$; one-tailed) was also consistent with Experiment 4. Contrary to expectations, there was no difference between number of correct responses produced by young and elderly adults on the validation task ($p>0.05$).

Table 5.11 Descriptive statistics for young and elderly adults.

VARIABLE	YOUNG	ELDERLY	Significant Difference as predicted
DSS (no. completed in 90s)	71.7 (6.6)	44.2 (10.6)	*
PM (raw scores)	49.3 (4.8)	31.6 (9.1)	*
RNG _{BASE}	0.315 (0.04)	0.328 (0.06)	n.s
RNG _{DUAL}	0.339 (.05)	0.359 (0.07)	not tested.
IT (ms)	76.9 (26.7)	96.8 (29.8)	*
IT _v (ms)	94.6 (27.4)	126.2 (41.2)	*
IT _D (ms)	116.6 (39.0)	146.4 (62.5)	*
VALIDATION (number correct/50)	40.5 (8.2)	38.8 (7.3)	n.s.

(SD in parentheses).

* $p < 0.05$, one-tailed

(Means for RNG_{DUAL} are based on $n=9$ elderly and $n=18$ young)

The impact of the variable intertrial interval of IT performance was examined using a two-way repeated measures analysis of variance on the variables group (between subjects: young or elderly) and condition (within subjects: constant or variable intertrial interval). Consistent with expectations, significant main effects were found for both group ($F(1,50)=9.98$; $p < 0.01$) and condition ($F(1,50)=25.9$; $p < 0.01$), indicating that longer ITs were found among the elderly and on the variable intertrial interval task. The group by

condition interaction was not significant ($p > 0.05$) indicating that the attentional manipulation had a similar impact in both young and elderly adults (decline in IT associated with the variable intertrial interval was 23% for the young and 30% for the elderly). (Complete Anova table is presented in Appendix S)

The effect of the dual-task manipulation on IT was examined using a two-way repeated measures analysis of variance on the variables group (between subjects: young or elderly) and condition (within subjects: single or dual task IT). Significant main effects were found for group ($F(1,49) = 6.59$; $p < 0.05$) and condition ($F(1,49) = 31.6$; $p < 0.01$), indicating that longer estimates of IT were found among elderly adults and under dual-task conditions. Contrary to expectations, the group x condition interaction was not significant ($p > 0.05$), the decline associated with dual-task performance being equivalent across groups (52% and 51% for young and elderly adults, respectively). (Complete Anova table is presented in Appendix T)

An unrelated samples t-test showed that, as would be expected, there was no difference between the groups on the randomisation index for the RNG task ($p > 0.05$) during baseline measurement (RNG_{BASE}). During the dual task, most of the elderly adults slowed the rate at which they presented the random numbers; indeed, only nine of the 31 elderly adults who completed the dual-task were able to produce the 100 numbers required to compute the randomisation index in the time it took to complete the IT task. A number of the elderly subjects gave verbal commentaries during the dual-task indicating the difficulty they were having completing both tasks concurrently. Clearly, whereas some subjects were completing the dual-task according to instructions, others completed the IT task at the expense of not completing the RNG task. As a result, the dual-task RNG scores of elderly adults have not been examined further and this feature of performance may account for the nonsignificant group x condition interaction reported when the standard and dual-task IT scores were compared.

All but two of the young subjects successfully completed the RNG task under dual-task conditions (RNG_{DUAL}). The randomisation indices produced during the baseline and during the IT task were compared in the young subjects using a related samples t-test. As

would be expected, performance declined during the dual-task ($t(17)=1.98$; $p<0.05$; one-tailed).

Among both young and elderly adults, IT was positively correlated with IT_V ($r=.46$, $p<0.05$; $r=.56$; $p<0.01$, for young and elderly groups, respectively). Positive correlations were also found between IT_V and IT_D in the young ($r=.45$, $p<0.05$) and elderly groups ($r=.50$, $p<0.01$). These measures thus shared variance but, given that the correlations were only moderate, also measured different aspects of performance. A composite IT score was derived from the sum of standardised IT, IT_V and IT_D estimates. This index was negatively correlated with DSS ($r=-.40$, $p<0.05$) among elderly adults. The validity of the estimation procedure used during the IT task was examined by comparing values of SOA_{80} derived from both the Wetherill and Levitt procedure and the Probit procedure. As expected, estimates were highly correlated in both young ($r=.98$, $p<0.01$) and elderly ($r=.96$, $p<0.01$) adults. The absolute value of estimates were compared using a two-way repeated measures analysis of variance with one between subjects variable (group: young or elderly) and one within subjects variable (procedure: Wetherill & Levitt or Probit). Means and results of this analysis are included in Appendix U. Briefly, a significant main effect was found for estimation procedure ($F(1,49)=6.76$, $p<0.05$), indicating that Wetherill and Levitt estimates were shorter than those from Probit. The group x procedure interaction was not significant ($p>0.05$).

Consistent with expectations, among elderly adults increasing age was associated with declining performance on the PM test ($r=-.51$; $p<0.01$). The prediction that indices of speed, variability and attention would make independent contributions to the prediction of PM in the elderly was examined using a standard multiple regression analysis.⁷ Age, DSS, IT, IT_V and validation scores were entered as independent variables with PM as the dependent variable. (IT_D was not included because the dual-task manipulation had been unsuccessful). Table 5.12 presents simple correlations between variables, standardised regression coefficients (β), R and R². The analysis indicates that all five variables make unique contributions to the prediction of PM, the combination accounting for 65.6% of the variance in PM scores.

⁷ Variables were entered as a block.

Table 5.12 Standard multiple regression of speed, age and attentional indices on PM

<u>Variables</u>	AGE	IT	IT _v	VAL _a	PM	β
DSS	-.48**	-.26	-.32	.17	.62**	.37*
AGE		.47**	.24	.29	-.51**	-.34 _b
IT			.56**	.57**	-.24	-.46*
IT _v				.27	.03	.37*
VAL					.28	.48*
						R ² = .66
						R = .81

* $p < 0.05$

a. VAL = IT validation score

b. $p = 0.06$

As can be seen, IT, IT_v and validation score all have smaller simple correlations with PM than their associated standardised regression coefficients. This finding implies the presence of a suppressor variable; that is, one that enhances the importance of other independent variable by virtue of the fact that it suppresses irrelevant variance in either the dependent or independent variables⁸. To determine which variable was the suppressor in this experiment, IT IT_v and validation score were removed from the equation one at a time and the effect on other variables noted (results of these regression analyses are included in Appendix V). When IT was removed from the equation the standardised regression coefficients associated with age, DSS, IT_v and validation were similar to the simple correlations. This was not found when either IT_v or validation score were removed from the equation, suggesting that IT was the suppressor variable (in other words, IT was heavily weighted, because it suppressed irrelevant variance in IT_v and validation scores). Thus,

⁸ Tabachnik and Fidell (1983, p116) provide an example of a suppressor variable: of two paper-and-pencil tests (vocabulary; listing dance partners) given to predict belly-dancing performance, only one (ability to list dance partners) is correlated with the dependent variable (belly-dancing). When both independent variables are entered into the multiple regression, variance due to ability in taking any paper-and-pencil test is partialled out by the nonpredicting variable (vocabulary test), so that the combined independent variables enhance the prediction achieved by the single genuine predictor variable by virtue of the fact that irrelevant variance has been partialled out or "suppressed" by the inclusion of the nonpredicting 'suppressor' variable.

elements common to the backward masking procedure but irrelevant to the prediction of PM were responsible for the effect.

5.4.3 Discussion

The findings of this study with respect to speed of processing were consistent with those of Experiment 4. Elderly adults were slower on both paper-and-pencil and psychophysical indices of performance. Manipulating the intertrial interval of the IT task reduced performance in both groups but no evidence was found to suggest that the elderly were relatively more disadvantaged by such a manipulation; (estimates of IT reduced by 23% and 30% in the young and elderly, respectively). This suggests that a decline in the ability to maintain attention to the task is not responsible for age-related decline in IT.

Concerning the measurement of IT under dual-task conditions, it was clear that the majority of the elderly adults were unable to complete both tasks successfully. The response of the elderly participants to the increasing demand for processing resources was to reduce the speed of RNG number production to such an extent that they were unable to produce the 100 numbers required to compute the randomisation index during the time taken to complete the IT task. Although this finding means that the attempt to derive indices of attentional resources from the tasks was unsuccessful, it is clearly consistent with the suggestion that the elderly have less resources available for processing. The fact that the majority of elderly adults did not successfully complete the two tasks means that the expected decrement in the IT performance of these subjects compared to the young was not found. Clearly, the dual-task manipulation did not work.

The current study did not measure noise directly but did derive an index of performance variability from a task that was assumed to be less subject to confounding with IT, by virtue of the fact that it did not vary the discriminability level of the lines discrimination task. In Experiment 4 it was suggested that the variable discriminability task may be particularly sensitive to visual acuity. The current task examined the number of correct responses attained by individuals for a preset level of accuracy. IT and the validation index derived were positively correlated, suggesting that long estimates of IT

were associated with higher accuracy on the validation task. This finding is consistent with the negative correlations found between IT and noise indices derived in Experiment 4 and suggests that the current task was just as subject to confounding during measurement as the variable discriminability task. Results suggest then that it is unlikely that an index of variability can be derived independently of speed of processing using a backward masking procedure. This issue is considered further in the general discussion in Chapter 6.

The relationship between age, speed, attention, variability and cognitive performance was examined to determine whether, as predicted, these variables made unique contributions to the prediction of PM by DSS. Despite the finding that no group differences were found for either IT_v or IT validation, these indices were thought to reflect attention (ability to maintain preparation and variability, respectively) and both were included as predictors of PM, following Stankov's (1988) finding that both speed and attention make unique contributions to the prediction of fluid ability in the elderly.

Contrary to Experiment 4 and the strong version of the slowing hypothesis, DSS, IT, IT_v , validation and age all made a unique contribution to the prediction of PM. This finding is consistent with the work of Nettelbeck and Rabbitt (1992) which showed that IT did account for a significant proportion of the variance in IQ in an elderly sample. However, findings of the current study were somewhat more equivocal, because simple correlations revealed no significant relationship between IT and PM.

Because IT was acting as a suppressor variable, it is likely that its weighting was increased simply because it partialled out variance in the IT_v and validation tasks that was irrelevant to the prediction of fluid ability. Elements common to backward masking tasks and irrelevant to the prediction of PM were responsible for masking the unique contributions of these two variables in the simple correlation analysis. In other words, when data from a number of backward masking procedures were considered together, variance that had previously obscured the relationship between these indices and PM was taken up and all were found to make a unique contribution to prediction. Although this additional variance might intuitively be attributed to features such as visual acuity or strategy use, making a more decisive statement regarding its source would require further

studies. Interpreting the unique contribution made by IT_v , for example, is constrained by the fact that it is not clear with what index one is dealing if variance shared by IT is controlled for in the variable intertrial interval task, though presumably it reflects some attentional process. Results suggest then that aspects of speed and attention are required to account for changes in fluid ability with age. Because attention has been measured in the current study using backward masking measures which are based on speed of processing, it is difficult to determine whether or not these constructs simply reflect different types of speed.

There was some support for the view that IT and DSS were measuring a common process in the current study, in the significant negative correlation found between the composite IT measure and DSS ($r = -.40$). Clearly, however, the amount of variance shared is small (16%). This relationship may, in part, be due to the contribution made by the attention demanding IT_v and IT_D tasks, because the correlation between the standard IT task and DSS, though in the expected direction, was not statistically significant. This finding suggests that there may be different aspects to "speed". One aspect (measured by IT) may reflect perceptual and encoding processes and it may be dependent on sensory acuity. IT_v and validation, although sharing variance with IT, may also reflect the operation of attention as a control process that maintains concentration and monitors performance. DSS reflects more complex, intentional processes and is more resource intensive.

In summary then, the current study has suggested that psychophysical indices make a contribution to the prediction of cognitive performance, in addition to that made by DSS. Unlike the findings of Nettelbeck and Rabbitt (1992), however, the current study was less conclusive, suggesting that this relationship is only evident when variance common to backward masking procedures but irrelevant to the prediction of PM is controlled statistically. Clearly, the finding is consistent with the weak version of the slowing hypothesis which considers that multiple independent deficits may operate on different subsystems within the processing system of elderly individuals. Although the dual-task manipulation was unsuccessful, findings from the variable intertrial interval IT task suggest

that the ability to maintain preparation or concentrate on the task was not responsible for age differences in IT. Consistent with the work of Stankov who has implicated both speed (search) and attentional variables (flexibility and concentration) in his account of the age-fluid ability relationship, this study found evidence that two variables thought to reflect concentration (performance variability measured in the validation task; and ability to hold preparation measured in the variable intertrial interval IT task) made unique contributions to the prediction of PM over and above the contributions made by DSS and age. Certainly, the finding that age made a significant contribution to the prediction of fluid ability suggests that the age-PM relationship cannot be accounted for simply in terms of speed of processing.

CHAPTER SIX

GENERAL DISCUSSION

6.1 Introduction

This chapter presents a discussion of the empirical findings presented in Chapters 3, 4 and 5. The studies presented have been concerned to account for age-related differences in cognitive performance, particularly fluid ability and, in order to do this, they have involved operationalising speed of processing and internal noise. A number of the statements made concerning findings have been qualified on the basis of various procedural difficulties. Within this context then, this discussion gives consideration to the following issues: (i) methodological concerns which constrain the interpretation of noise and speed as they have been operationalised within this thesis - including issues of curve-fitting and psychophysical scaling in IT measurement, and the independence of noise and speed as measured using backward masking procedures; (ii) the relationship between DSS and IT and the notion of speed as a unitary construct; and (iii) accounting for change in cognitive performance among elderly adults.

6.2 Methodological issues

6.2.1 Review of methodologies used to estimate IT

Before examining methodological concerns which constrain interpretation of noise and speed as they have been operationalised within this thesis, the methodologies used to estimate IT are reconsidered. The only difference across studies involved the mode of presentation. Experiments 1, 5 and 6 presented the IT task on an EGA monitor attached to an IBM compatible computer. The refresh scan rate of the screen was 16.74 ms. In Experiment 4 the task was presented on a LED display, in an attempt to increase the precision with which the exposure duration of the target stimulus was controlled. However, all experiments followed a staircase procedure to estimate IT, using the peak-

through averaging procedure of Wetherill and Levitt (1965). As a reliability check, data were also examined using the maximum likelihood estimates of the Probit procedure. In Experiment 6, the exposure duration associated with the 80% accuracy level was estimated, and in the other three experiments, the 90% level was determined. The 80% level, requiring fewer trials than the 90% level, was used in Experiment 6 to reduce the impact of fatigue on repeated estimates of IT for elderly adults. In all studies the exposure duration of the target was controlled by superimposing a masking stimulus with target offset occurring at mask onset so as to maximise the energy level of the target stimulus and thereby reduce the impact of sensory decline on performance among elderly adults. Two estimates of IT were determined for participants in experiments 4 and 5 as a reliability check; in Experiments 1 and 6 one estimate was obtained for each individual. Table 6.1 summarises procedural details and the number of IT data sets available from the four experiments which have been reexamined to address methodological concerns⁹.

Table 6.1 IT data sets available for reanalysis across four experiments

	NUMBER	PROCEDURAL DETAILS
EXPERIMENT 1	36	Staircase(90%); VIDEO 36 single estimates
EXPERIMENT 4	93	Staircase(90%); LED 42 repeated measures & 9 single estimates
EXPERIMENT 5	62	Staircase(90%); VIDEO 30 repeated measures & 2 single estimates
EXPERIMENT 6	51	Staircase(80%); VIDEO 51 single estimates

⁹ The six data sets previously excluded from analysis in Experiments 4 & 5 were also excluded here. Due to irretrievable disk error, three data sets from Experiment 4 were not available for reanalysis.

6.2.2 Logarithmic transformations

Levy (1992) recently drew attention to the issue of psychophysical scaling in IT measurement. He has argued that a better fit for the psychometric function is obtained if response accuracy is plotted against the natural logarithm of time rather than against time per se. Evidence for this assertion came from his reanalysis of data from Nettelbeck and Young (1989) and Smith (1986). This argument is based on the idea that the scale used in IT measurement does not represent equal intervals; that is, the psychological effect underlying a particular difference between levels of performance at one end of the scale is not necessarily the same as that underlying a difference of the same magnitude at the other end.

The issue of the psychological scale underlying IT estimates and the need to determine the most appropriate scale for the abscissa of the psychometric function is relevant to the interpretation of the empirical work presented in this thesis, because group means for young and elderly adults have been found to be disparate. For example, the issue of whether the difference between two elderly adults with ITs of 150 ms and 170 ms, respectively, is functionally the same as a difference between two young adults with ITs of 60 ms and 80 ms remains an empirical question. Clearly, if metric differences are found, this feature will have to be incorporated into a discussion of the explanatory power of IT as a predictor of age-related changes in cognitive ability.

Psychophysical scaling was addressed by comparing the goodness-of-fit for functions obtained when accuracy was plotted against, first, exposure duration and, second, natural logarithm transformations of duration. Data from experiments 1, 4, 5 and 6 as specified in Table 6.1 were examined. The Probit procedure of SPSS was used to determine i) the intercept of the psychometric function, and ii) the exposure durations associated with the 80% and 90% accuracy levels.

Goodness-of-fit chi-square values and the associated degrees-of-freedom were obtained for each data set by applying the Probit procedure. This fitted a curve through both exposure duration and logarithm-transformed values of exposure duration for each set of raw data available for young and elderly adults in each experiment. To determine

whether a better fit was obtained for duration or log-transformed duration, the chi-square values and degrees of freedom obtained from the Probit analysis applied to individual data sets were summed across individuals and the associated probability was determined. Table 6.2 presents the sum of the chi-square values, the total degrees of freedom and the associated probability level for each study.

Table 6.2 Summary of goodness-of-fit analyses for curves fitted through (1) duration and (2) log-transformed values of duration

	DURATION		LOG-DURATION	
	χ^2	DF	χ^2	DF
EXPERIMENT 1 young elderly	60.6 47.1	61 70	61.3 49.4	61 70
EXPERIMENT 2 young elderly	267.0 730.0	291 641	264.3 733.7	290 636
EXPERIMENT 5 young elderly	98.1 134.7	88 162	98.9 131.9	88 162
EXPERIMENT 6 young elderly	44.0 124.8	54 124	42.9 127.6	51 126

Note: $p > 0.05$, in every instance.

As can be seen from Table 6.2, all of the functions were well fitted by the Probit procedure and fitting the curves through duration and logarithm-transformed values of duration produced virtually identical goodness-of-fit parameters. This analysis provides no support for Levy's suggestion that log-transformed values of time provide a better fit for IT data. This finding is strengthened by the fact that the outcome applied across a very wide range of IT values and it suggests that IT estimates derived from young and elderly adults are not subject to metric differences and thus have been compared appropriately in the empirical work presented in this thesis.

6.2.3 Probit versus Wetherill & Levitt estimates

The absolute values of stimulus-onset-asynchrony (SOA) derived from IT tasks were critical to the procedures followed in this thesis, because any unreliability associated with the estimation of IT will have a multiplicative effect on estimates of noise when IT is used to determine the exposure duration for the noise task. Across studies, the Wetherill and Levitt (1965) procedure was used to derive IT estimates for both the 80% and the 90% accuracy levels. One advantage of the former is that IT estimation involves fewer trials, so that individual differences in fatigue, concentration span and motivation are likely to have less impact - an advantage for studying ageing. To verify procedures used when estimating IT, estimates derived using the peak-trough averaging technique of Wetherill and Levitt were compared to those derived using maximum-likelihood estimates with the Probit curve-fitting procedure of SPSS. The former does not rely on specific assumptions regarding the shape of the psychometric function. However, the two techniques are expected to provide similar estimates of IT, to the extent that performance on the IT task is well described by the cumulative normal ogive. The previous analysis of chi-square goodness-of-fit parameters suggests that the IT data collected in this thesis were, indeed, well described by this function.

Analyses presented in Chapters 3 and 5 showed that although estimates of SOA derived using the two procedures were highly correlated, in Experiments 1, 4 and 6, Wetherill and Levitt estimates were shorter than those derived from Probit. No difference was found for Experiment 5. Clearly, although absolute values of IT are dependent upon the curve-fitting procedure used in their measurement, the finding that mean absolute values were within 20 ms of one another suggests that, where video presentation of IT stimuli is used, both procedures will result in similar estimates of IT, given the refresh rate of video monitors. In other words, where video presentation of stimuli is used, the multiplicative effect of unreliability in IT on noise estimation will be similar when Probit and Wetherill and Levitt estimates are used. Although this analysis verifies the procedure used in the empirical work presented, it is clear that video presentation of stimuli in the noise task will increase unreliability associated with data. An LED display was used in

Experiment 4 in an attempt to avoid this problem. However, this form of presentation was associated with methodological problems also. Thus, Experiment 4 produced a high number of individuals who were able to use apparent motion and brightness cues to reduce the effectiveness of the backward mask. Additionally, a number of data sets obtained were not well-fitted by the cumulative normal ogive. In other words, these data sets were not consistent with those expected on theoretical grounds. It is clear that although the 243 IT data sets examined across studies in this thesis were *generally* well fitted by the maximum likelihood estimates procedure adopted by the Probit procedure of SPSS, there was a subgroup of individuals for whom data were not fitted by the cumulative normal ogive. Experiment 4, which used the LED display to present stimuli, seemed to produce a disproportionate number of such cases. However, the results of group comparisons of IT and noise presented in Experiment 4 were not the consequence of the unreliable cases, because group differences remained when these data sets were eliminated.

6.2.4 Determining whether psychometric functions have a zero intercept.

In Experiment 4 estimates of the exposure duration required to reach 97.5% accuracy on the IT task were extrapolated from the 90% level by using normal probability tables. This procedure assumes that data are well-fitted by the cumulative normal ogive and that chance responding accuracy occurs at an exposure duration of zero. Although analysis of IT data presented in Experiment 1 was consistent with this interpretation, Levy (1992) has argued that the existence of the zero intercept for the psychometric function obtained from the IT task has not been empirically demonstrated. Data collected in the studies presented in Chapters 3 and 5 were therefore examined together, to determine whether intercept values did indeed depart from zero.

Intercept values were obtained for IT data obtained in Experiments 1, 4, 5 and 6 using the Probit procedure of SPSS. Although for Experiments 4 and 5 analyses were confined to initial estimates (see Table 6.1), findings were unchanged if functions for the second IT estimates were also included. As can be seen from Table 6.3, the intercepts of

the psychometric functions were markedly similar for both young and elderly adults and all between 3 and 5 ms.

Table 6.3 Mean intercepts (ms) for psychometric functions, for young and elderly adults in Experiments 1, 4, 5 and 6.

	YOUNG	ELDERLY
EXPERIMENT 1	3.72 (1.24)	3.47 (1.53)
EXPERIMENT 4	4.82 (1.38)	4.01 (2.19)
EXPERIMENT 5	3.25 (1.80)	3.94 (1.20)
EXPERIMENT 6	3.43 (1.18)	3.52 (1.68)

(SD in parentheses)

Unrelated samples t-tests conducted on the intercept values for each experiment separately revealed no significant differences between the young and elderly groups for this parameter across experiments ($p > 0.05$, in all cases). It is possible that the absolute threshold value represented by the intercept reflects very early sensory components with the decision-making process, although the effect is remarkably small. Most importantly, the finding that there was no difference between young and elderly adults on this parameter suggests that, if there is some contribution from sensory factors, this is equivalent across a wide range of ages and that group differences in IT are valid. Clearly, the difference found between mean ITs from young and elderly participants is appropriately interpreted as reflecting differences in the speed of information processing, rather than simply reflecting age differences on sensory factors.

Intercept values were then examined to determine whether they were significantly different from zero for young and elderly groups separately, across studies. In Experiment 1, intercept values for both young adults ($t(17) = 12.74$, $p < 0.05$; two-tailed) and elderly adults ($t(17) = 9.59$, $p < 0.05$; two-tailed) were significantly different to zero. Similar

findings were obtained for Experiment 4 (young: $t(19)=15.6$; $p<0.05$, two-tailed; elderly: $t(33)=10.7$, $p<0.05$, two-tailed), Experiment 5 (young: $t(15)=7.23$; $p<0.05$, two-tailed; elderly: $t(15)=12.6$; $p<0.05$, two-tailed), and Experiment 6 (young: $t(18)=12.7$; $p<0.05$, two-tailed; elderly: $t(31)=11.9$, $p<0.05$, two-tailed). The mean intercept exposure duration obtained across all subjects in these experiments was 3.79 ms - a small absolute value but, nonetheless, a reliable finding, given the numbers, range of procedures and range of ages involved.

An assumption of IT work has been that performance reflects the upper portion of the cumulative normal ogive, with chance performance associated with zero exposure duration. Clearly, where the absolute threshold at which performance rises above chance is greater than zero, estimation of IT by extrapolation from standard normal probability tables is inappropriate. Although evidence examined in this thesis is consistent with the notion that the intercept of the psychometric function is above zero, the absolute magnitude of the estimate (3.79 ms) is not considered to be of practical significance, particularly given the level of accuracy associated with measurement; video monitor refresh rates, for example, are of the order of 16 to 20 ms. Certainly the mean value obtained here is lower than those reported by Levy (1992) in his reanalysis of data for university students (from Nettelbeck, 1987) and children (from Nettelbeck & Young, 1989) where intercept values were found to be 12 ms and 40 ms, respectively.

6.2.5 The independence of noise and IT

Chapters 3 and 5 presented a series of empirical studies in which indices of internal noise and IT were examined in young and elderly adults. A number of different procedures have been used to derive estimates of both IT and noise across the studies. Two modes have been used to present the stimuli for the IT task. In Experiments 1, 5 and 6 the task was presented on the video monitor of an IBM compatible computer, whereas in Experiment 4 a LED display was used. One limitation of the first mode of presentation is that stimulus exposure durations are necessarily multiples of the refresh scanning rate of the video monitor. With a LED display, exposure duration can be controlled more

precisely (to within 1 ms). However, the number of subjects who reported that they used a strategy based on apparent movement in Experiment 4 suggests that the effectiveness of the mask available with the LED display was reduced, compared to the other experiments. Because the exposure duration on which estimates of noise were based has been derived from IT tasks, any reduction in the accuracy with which IT is estimated will have a multiplicative effect on estimation of noise. Evidence from the comparison of Wetherill and Levitt estimates with those from Probit was consistent with the conclusion that accurate absolute values of IT cannot be derived and obtained values are dependent on the curve-fitting procedure used in estimation. Clearly, where IT is used in subsequent estimates of noise, this issue must constrain the interpretation of results

The theoretical rationale upon which the measurements of internal noise and IT were based was presented in Chapter 3. It was suggested that these parameters could be measured independently using the backward masking procedure, given certain assumptions. Early work measuring IT and noise was consistent with the view that these indices are independent. Data collected in the current studies have therefore been examined, to determine whether this can be verified with samples of young and elderly adults. This issue is now considered here in some depth, because the validity of the operationalisation of these constructs limits the confidence with which assertions concerning the link between these indices and cognitive ageing can be made.

Internal noise has been measured using a number of different procedures. In Experiments 1 and 4 noise was measured as the standard deviation of the psychometric function obtained when response accuracy was plotted against objective stimulus difference and exposure duration was held constant either at 100 ms or at the exposure duration required for each individual to reach 97.5% accuracy on the lines discrimination task used to measure IT. Experiment 1 used the staircase procedure and Experiment 4 the method of constant stimuli to present stimuli. In Experiment 6 noise was not measured directly but an index of performance variability was derived from the number of correct responses obtained when discriminial difference and exposure duration were held constant at a level previously associated with 80% accuracy on the lines discrimination task. The

independence of IT and internal noise as operationally defined for Experiments 1 and 4 was determined by examining the correlation coefficients obtained between these two indices from these two experiments. Table 6.4 summarises this analysis.

Table 6.4 Correlations between estimates of IT and noise from young and elderly adults in Experiments 1 (staircase method) and 4 (method of constant stimuli).

STUDY	NOISE MEASURE	YOUNG	ELDERLY
EXPERIMENT 1	Variable discriminability, staircase, duration = 100 ms	-.23	-.21
	Variable discriminability, staircase, duration = IT	.12	.67**
EXPERIMENT 4	Variable discriminability MCS; duration = IT	.23	-.32*

* $p < 0.05$; ** $p < 0.01$; two-tailed

As can be seen from Table 6.4, IT and noise were found to be independent indices of performance among the young participants. Among the elderly, however, the statistically significant negative correlation obtained for Experiment 4 suggests that to some extent estimates of noise and IT were confounded during measurement, long ITs being associated with smaller noise estimates.

Although the correlation between IT and noise was significantly positive in Experiment 1, contrary to Experiment 4, this finding can be reconciled by considering the procedural shortcomings that were identified during Experiment 1. The adaptive procedure used in Experiment 1 commenced at a low level of discriminability and discriminability level increased with each error on the task. Estimates of noise were derived from the psychometric curve and the number of points available for curve-fitting varied across individuals, depending on how difficult each individual found the task to be. Among elderly adults if initial estimates of IT were inflated for some individuals, possibly as a result of momentary inattention during the task, the noise task would be relatively easy,

because of the long exposure duration on the task. If the task was relatively easy, the adaptive procedure would vary around a lower level of discriminability, reducing the number of points available for curve-fitting. For other elderly adults where initial estimates of IT were not inflated, the noise task would be relatively difficult, the adaptive procedure would vary around a higher level of discriminability and, as a result, more data points would be available for fitting the psychometric curve from which estimates of noise were derived. It is suggested that estimates of noise may be inflated where less data points are used in curve-fitting. In other words, long estimates of IT led to fewer data points being available for curve-fitting and this led to inflated estimates of noise. Thus, the finding that long ITs were associated with high estimates of noise is consistent with the findings of Experiment 4 that noise and IT are confounded during measurement.

Smith (1986) has suggested that IT and noise are scaled equivalents. Because IT is derived from the slope of the psychometric function, increasing response errors result in lower slopes, higher standard deviations and longer IT estimates. Up to a certain threshold, a poor signal-to-noise ratio will result in long estimates of IT and high estimates of noise. However, if estimates of IT are too generous in some cases, possibly as a result of momentary inattention during the task, then noise estimates will be low and less likely to be influenced by inattention, because exposure is long. Evidence was found in Experiments 1 and 4 to suggest that noise and IT were confounded; and in different ways. It is possible that this was the result of a number of elderly adults for whom IT was overestimated, possibly as a result of inattention, and a number whose IT was underestimated, possibly as a result of utilising apparent movement and brightness cues that reduced the effectiveness of the backward mask. In other words, unreliability associated with initial estimates of IT have had a multiplicative effect on the reliability of estimates of noise.

Data examined in this thesis suggest that the likelihood of deriving an index of noise which is independent of IT (particularly with respect to the contribution made by sensory acuity, momentary inattention and strategy use to both) is low. It is clear then that noise and IT, as measured using the backward masking procedure, are inextricably linked.

Noise, as currently operationalised, therefore has no explanatory power beyond that offered by the notion of processing speed, because a construct that cannot be extracted from others during measurement has limited practical significance, despite theoretical arguments to the contrary. On this basis then rate of processing is the more useful construct for discussing changes among the elderly in the resources available for processing.

The finding that noise and speed cannot be measured independently using backward masking procedures is consistent with Salthouse's finding (1980), that on a discrimination task the function obtained when exposure duration is held constant and discriminability varied is virtually identical to that obtained when discriminability is held constant and exposure duration varied. He suggested that a decline with age in signal-to-noise ratio was responsible for both functions. Both IT and internal noise are concerned with the fidelity of the information processing system, and Smith (1986), and more recently Levy (1992), have argued that IT itself is the best index of noise or moment-to-moment processing variability.

Work by Raz and his colleagues has similarly blurred the distinction between speed and the fidelity of the information processing system. Raz et al. (1983) found that high aptitude young adults required shorter interstimulus intervals for correct identification on a tone recognition task. They interpreted this finding in terms of increased information processing efficiency, expressed as a higher signal to noise ratio. Similarly, Raz, Willerman and Yama (1987) have argued that high IQ subjects are capable of faster feature extraction and therefore have higher sensory representation of stimuli. Because the resolution of their information processing systems is high, they have less need for external signal redundancy.

These studies, and Smith's (1986) suggestion that IT and noise are scaled equivalents, are consistent with a recently published paper in which White (1993) argues against the tenability of the early theoretical rationale of IT. Because his argument is concerned with the validity of assumptions upon which the operationalisations of speed and noise examined in this thesis are based, his argument is considered in some detail. The

empirical work presented in this thesis was completed before the publication of White's critique and findings are certainly consistent with the model he proposes.

6.2.6 Locating the IT delay: a sensory versus post-sensory model.

IT was originally developed within the context of the accumulator model of psychophysical discrimination and one assumption made was that data accumulation occurs by a process of sequential sampling. White (1993), however, has examined the assumptions upon which the interpretation of IT has been based, particularly with respect to the existence of the sampling mechanism. White distinguishes between IT as it was originally defined (that is, as the time required for one sample of stimulus information) and IT as it is measured (that is, as the SOA required to produce near-perfect discrimination performance on a two-choice task). He suggests that the belief that these two formulations are equivalent is flawed, because the assumptions underlying IT, as it was originally conceived, are not well-established.

White argues against the commonly accepted assumption that the IT delay is cognitive rather than sensory in origin. He defines sensory processing as "explicable in terms of neurophysiological processes at the level of the sense organs or within the first few relay centres within the central nervous system." (White, 1993, p186). "Post-sensory processing" is White's term to refer to processing that takes place beyond this level and which has typically been referred to as cognitive. White argues that the IT delay is sensory, because there is a lack of empirical support for the two specific assumptions upon which the post-sensory model is based. These are (i) that a perceptual sampling period exists, and (ii) that the target stimulus is available for processing for the entire duration of the SOA period in a backward masking task.

In the original formulation of the IT rationale, it was assumed that stimulus information could only be registered if it was available at the start of the sampling period. The existence of the sampling period was based on the existence of the psychological moment. According to Vickers and Smith (1986, p610), "...evidence for the discrimination process is provided by a series of discrete samples of sensory information, with each

sample or observation taking a small constant amount of time..." White (1993), however, suggests that a number of different types of perceptual moment have been proposed in the literature, not all of which are consistent with the IT formulation; and, more importantly, he argues that the existence of the perceptual moment has not been empirically demonstrated. As a consequence, he suggests that the specific model which equates IT and the sampling period should be abandoned.

Recent studies utilising electrophysiological techniques are consistent with the notion that IT reflects the time taken for sampling in the initial stages of information processing (Colet, Piera & Pueyo, 1993; Zhang, Caryl & Deary, 1989a,b). A more general theoretical model of IT argues that it reflects the general efficiency of the information processing system rather than some specific characteristic of the sampling mechanism (Brand & Deary, 1982; Deary, Caryl, Egan & Wight, 1989; Nettelbeck & Young, 1989). White, however, argues that this general model of IT still locates the delay at the post-sensory level, because this model is based on the notion of the unrestricted availability of the target stimulus during the period of stimulus-onset-asynchrony.

Vickers et al. (1972) argued that, because IT is based on response accuracy rather than RT, the procedure eliminates nondecisional factors associated with sensory and motor delays. Although White acknowledges that the IT procedure eliminates the motor delay, he is sceptical of its ability to eliminate sensory delay. The basis of his argument concerns the nature of the masking process which occurs in the backward masking task. Although White suggests that the notion that the mask limits the visual persistence of the target stimulus is uncontroversial, he argues that the assumption of unrestricted availability of the target is challenged by current theories of backward masking.

White has argued that the original formulation of the IT procedure was based on the interruption theory of backward masking. This theory assumes that a masking stimulus will overwrite or erase the representation of a target stimulus which is stored in the sensory buffer. The mask will halt processing of the stimulus information and the effect is independent of the form of the mask. The duration for which the target is available for further processing is thus controlled by and assumed to be equal to the SOA period. White,

however, argues that the integration theory of masking has higher explanatory power. According to this theory, masking effects are the result of "lack of fine temporal discrimination at the level of sensory processing." (White, 1993, p197). In the integration conceptualisation, a target and masking stimulus may be treated as though they occur simultaneously and an amount of stimulus degradation may occur depending upon specific features of the mask such as its energy level and structure (White, 1993, p195). The reasonably high level of support afforded to this model in the literature has lead White to conclude that IT, as measured in the backward masking procedure, reflects a delay in sensory rather than post-sensory processing.

It should be noted that White does not consider the distinction between sensory and post-sensory to be the same as the distinction between peripheral and central processes. Indeed, he points out that a great deal of sensory analysis and elaboration will take place centrally. His argument then should not be seen as an attempt to deny that IT involves components of central processing; rather it draws attention to the likelihood that sensory processes, incorporating both peripheral and central aspects, are confounded in IT as it is currently measured. Additionally, his argument questions the existence of the sampling period, a notion upon which the original formulation of IT was based.

Noise as operationally defined in section 3.2.3 was based on particular assumptions concerning stimulus representation and the process of psychophysical decision making. White's view, which increases the emphasis placed on sensory processes and questions the existence of the sampling period, is not consistent with the view that IT and internal noise, as operationalised by Vickers et al. (1972), represent independent parameters of perceptual performance. The results from the current studies, demonstrating that IT and noise were inextricably linked and, indeed, confounded during measurement, are clearly consistent with the model that White proposes.

If this reasoning is correct then noise cannot be considered to add anything to the prediction of cognitive performance among the elderly, once speed assessed using backward masking procedures has been considered. Clearly this argument suggests that Salthouse's generalised slowing hypothesis will be sufficient, without invoking the

additional noise construct, to account for age-related change. Findings of Experiment 4 were consistent with this view. Findings of Experiment 6, however, suggest that a backward masking task that assessed performance variability did make a contribution to the prediction of fluid ability beyond that made by speed assessed using DSS. This outcome therefore suggests that "speed" is not a unitary construct. The implications of this argument are considered further in the following section.

6.3 The nature of speed and its relationship to cognitive ability

The previous discussion has focussed on methodological issues concerning the operationalisation of speed and noise using the backward masking procedure. This was necessary because such factors constrain interpretation of the relationships between various speed measures and between speed of processing indices and age-related changes in cognitive ability that were found in this thesis. Consideration is now given to the nature of these relationships, because the aim of the empirical work was to determine whether speed decline was sufficient to account for decline with age in cognitive ability.

Findings relevant to the hypothesis that slower processing speed is responsible for age-related decline in cognitive ability were presented in Experiments 4 and 6. In both studies, support for Salthouse's generalised slowing account for cognitive ageing was found in the interrelationships between age, fluid ability (PM) and speed assessed using the DSS. In both studies PM score was predicted by DSS, and, the age-PM correlation was reduced after controlling statistically for DSS. In Experiment 4 the finding that age did not make a unique contribution to the prediction of PM over and above that made by DSS suggested that the age-PM relationship was mediated by speed of processing assessed using DSS. In Experiment 6, however, age was found to contribute to PM when DSS and various backward masking variables were considered. This was contrary to Experiment 4 but consistent with the argument that factors in addition to speed of processing contribute to decline with age in fluid ability.

Findings regarding IT were more equivocal than those regarding DSS. In Experiment 4 it was suggested that IT made no significant contribution to the prediction of

PM score once speed assessed by DSS was considered. This finding may reflect commonality between IT and DSS; but may also have been associated with the unreliability inherent in estimating IT using the LED display. Experiment 6 used a more reliable version of the IT task and in addition, examined performance on two tests that were assumed to reflect ability to attend to the task. These were a variable intertrial interval IT task and an IT validation task where subjects completed 50 trials with a constant exposure duration to test the accuracy of previously derived estimates of the SOA associated with 80% accuracy. Consistent with the weak version of the slowing hypothesis, these two variables and IT, DSS and age all made unique contributions to the predication of PM (fluid ability) among elderly adults. During discussion of Experiment 6 it was argued that IT was acting as a suppressor variable, so that the unique contribution made by the backward masking variables was only evident when variance common to the tasks and irrelevant to the prediction of PM had been controlled statistically. Although consistent with Nettelbeck and Rabbitt's (1992) finding that RT, IT and Coding (an index similar to DSS) all contributed significantly and reliably to the prediction of spatial-fluid abilities in a sample of elderly adults, the findings of Experiment 6 were less conclusive. Further studies are needed to elucidate the unique contribution made by backward masking variables to the prediction of cognitive performance and, in particular, to determine the nature of the constructs with which one is dealing when, for example, irrelevant variance due to backward masking procedure is partialled out of a backward masking, attention demanding task.

IT provides a useful index of speed to the extent that it does make a unique contribution to the prediction of PM. Nettelbeck and Rabbitt's (1992) finding that RT, IT and Coding, though sharing variance, all made unique contributions to the prediction of PM, was interpreted as evidence for the fact that speed is not a unitary construct. Evidence concerning the amount of common variance shared by DSS and IT among elderly adults in the current studies was equivocal. Although in Experiment 1 a correlation of $r = -.47$, ($p < 0.05$) was found between these two indices, nonsignificant negative correlations were found in Experiments 4 and 6 ($r = -.26$; $p > 0.05$, in both cases). Consistent with Experiment

1, a composite IT score derived from estimates obtained on a variable intertrial interval task, a dual-task and the standard IT task in Experiment 6 was negatively correlated with DSS ($r = -.40$; $p < 0.05$). However, this correlation appeared to be due to the contribution of the two, nonstandard, attention demanding tasks. The finding that IT and DSS shared little common variance, although not consistent with Nettelbeck and Rabbitt's finding regarding the interrelationship between speed measures, is still consistent with their view that speed of processing is not a unidimensional construct.

Clearly, the findings of Experiment 6 revealed that deficits were found in a number of different performance parameters which were derived from tests of speed of processing. Although both IT_v and validation scores were assumed to reflect attentional processes, both were derived from backward masking, speed-based tests and so may reflect different aspects of speed rather than attention *per se*. Although the type of speed being tapped in each task administered is not unequivocally clear, they do appear to be differentiated, because each made a unique contribution to the predication of fluid ability. Most plausibly, backward masking variables reflect perceptual or input processes. Following White (1993), backward masking tasks reflect sensory processes, incorporating both peripheral and central processes. The IT task presumably reflects sensory acuity and input processes. In addition to this, the IT_v and IT validation tasks used in Experiment 6 appear to be tapping aspects of attention (particularly concentration) once irrelevant variance has been partialled out by IT. These two variables may reflect aspects of concentration that are more dependent on the operation of attention as a control process that monitors various input channels. DSS appears to reflect more complex, intentional processing.

These findings are also consistent with the work of Roberts and Stankov (1994) who administered a series of time-based tests to 179 subjects and examined the structure of speed found using factor analytic procedures. Evidence was found for a general factor that was defined by a number of broader speed factors. Such work is not consistent with the strong version of the slowing hypothesis, because it suggests that deficits are occurring across a number of subsystems within the information processing system. Support for the weak version of the slowing hypothesis was also found in the current work in Experiment

4, where incidental recall was predicted by general ability (PM) but not speed of processing; and in Experiment 2 where age x complexity effects in visual search functions were not removed by log-transformations of data.

As discussed in Chapter 2, the pattern of change in intelligence during adulthood has been described successfully by recourse to broad ability factors which show different age trajectories. Similarly, it would be expected that, because speed is not a unitary construct, different factors may also show different age trajectories and be differentially related to cognitive abilities. This argument is similar to that presented by Cerella, DiCara, Williams and Bowles (1986), who argued that changes with age in intellectual functioning should mirror changes in information processing variables. These workers summarised three levels of information processing deficit found with age : automatic linguistic functions showing minimal decline; perceptual-encoding functions showing a moderate decline; and, intentional processes showing a severe decline. Measures of abstract reasoning, verbal ability, CRT, primary memory scanning and lexical decoding rates were examined in young and elderly adults. Whereas correlations between verbal IQ and rate of lexical operations remained when age was partialled out, no correlation remained between abstract reasoning and parameters of CRT after controlling for age. Although Cerella et al. found support only for information processing correlates of verbal intelligence, further examination of the relationship between various types of speed decline and decline in cognitive abilities appears to be warranted.

In Chapter 1 it was suggested that, where redundancy of information or information processing structures is involved, more noise can be tolerated in the system. This view suggests that the impact of general decline in speed of processing on various information processing subsystems will depend on their resource requirements. This view is consistent with the differential decline found with age on a range of cognitive measures and with the weak version of the slowing hypothesis.

Where attention operates as a control process to monitor various input channels, redundancy in certain information processing structures would result in a freeing up of such resources, allowing some individuals to compensate for increasing variability in

subsystems that would otherwise show the effects of CNS decline. The issue of whether attention or rate of processing is the more fundamental construct and, indeed, whether both constructs are necessary requirements of any model which attempts to account for age-related changes in performance is still open and remains worthy of further study.

6.4 Summary and conclusions

The working hypothesis of this thesis was that structural changes to the CNS occurring with age result in an increase in the level of noise in the information processing system. It has been argued that the well-documented decline in speed of processing and selective attention found with age may occur in response to increasing noise. In other words, speed decline occurs to compensate for an increase in variability and the likelihood of error occurring in the information processing system. The empirical basis of this argument was examined in Chapter 2. Evidence was consistent with the view that, although noise has been used to account parsimoniously for a range of age-related changes including aspects of both speed and attention, recent empirical studies have not attempted to measure noise directly in young and elderly adults.

In Chapter 2, speed decline with age in RT, backward masking studies and paper-and-pencil indices of performance were reviewed and findings were consistent with the view that (i) the absolute magnitude of decline depends on the nature of the task administered; (ii) there is increased heterogeneity in performance with age; (iii) the decline is the result of central rather than peripheral changes - factors such as practice, motivation and health status, although contributing to the decline, are not responsible for it. The slowing hypothesis contends that the main behavioural manifestation of ageing is a slowing across all information processing systems and that recourse to differences in the amount rather than the type of processing involved in particular tasks is sufficient to account for age-related deficits found in performance. Researchers differ with respect to whether they accept the strong or the weak version of the slowing hypothesis. The former postulates the existence of a single generalised deficit affecting the timing of all variables, while the latter suggests that multiple independent factors have a differential effect on subsystems within

the information processing system. Although evidence reviewed in Chapter 2 was consistent with the view that slowing in rate of response is the primary behavioural manifestation of ageing, a number of studies reviewed were consistent with the weak version of the slowing hypothesis.

It was argued that decline with age in certain cognitive skills is a consequence of slowing. Evidence consistent with this view was found in (i) the decline occurring in both speed and aspects of cognitive functioning with age; (ii) correlations reported between aspects of timed-performance and intellectual functioning across the life-span; and (iii) studies reporting a reduction in the amount of variance shared by age and cognitive ability when speed of processing is controlled statistically.

The argument upon which this thesis was based was that cognitive performance, speed of processing and noise might be examined from a reductionist perspective: noise is assumed to cause speed decline and speed, in turn, is assumed to be responsible for reductions in cognitive performance. Following examination of the literature it was suggested that noise may be related to both speed and attention, and further that noise can be measured independently of speed using a backward masking procedure. In other words, noise and speed are not synonymous. Following the weak version of the slowing hypothesis it was considered likely that speed is not a unitary construct and that different tests would make independent contributions to the prediction of fluid ability in the elderly. In addition, it was suggested that recourse to attentional resources reflecting some selective mechanism or control processes responsible for monitoring channels may also be useful in explaining why certain cognitive abilities appear to be relatively immune to the effects of ageing. Where there is increased redundancy associated with processing structures, the impact of noise and thus speed may be reduced.

The empirical work presented was concerned with testing the prediction that indices of noise, speed and attention predict fluid ability. In order to do this studies were concerned with operationalising speed of processing and noise, using a backward masking procedure. This procedure was adopted because it avoids certain interpretive difficulties associated with RT data - particularly speed-accuracy tradeoffs. Cognitive performance

was measured using Raven's PM, a unidimensional test of abstract reasoning, because there is strong evidence for age-related decline in this ability. Speed and noise were operationalised using procedures proposed by Vickers, Nettelbeck and Willson (1972). In addition, aspects of attention were examined within a backward masking procedure and using visual search tasks.

The five main issues addressed by the empirical work were (i) comparing speed of processing in young and elderly adults within a backward masking procedure; (ii) determining whether speed and noise can be measured independently using a backward masking procedure; (iii) examining the relationship between cognitive performance and noise and speed indices; (iv) considering the role of attentional variables in performance; and, (v) using a visual search procedure to provide convergent support for the noise hypothesis, test the strong version of the slowing hypothesis and to link notions of noise and selective attention.

Attempts to measure levels of internal noise in young and elderly adults were made in Experiments 1 and 4. Noise was estimated from the standard deviation of the psychometric function relating objective stimulus difference to response accuracy on a fixed exposure duration, variable discriminability task. When the exposure duration of this task was held constant across individuals (Experiment 1), ceiling effects for accuracy were found in the elderly.

In Experiments 1 and 4, noise was also measured when the exposure duration of the task was set at a level previously estimated from an IT task to be associated with error-free performance. With respect to group differences, findings were equivocal. Higher estimates of noise found among young adults in Experiment 1 were most plausibly attributed to procedural shortcomings. Specifically, the adaptive procedure employed to estimate IT and noise appeared to be susceptible to curve-fitting problems associated with the number of points derived from the adaptive procedure which had commenced at a low level of discriminability. A group difference was found in noise estimates determined using the method of constant stimuli, with higher estimates evident among the elderly in Experiment 4. This group difference appeared to be the result of a larger spread of scores

in the elderly sample, consistent with the existence of individual differences in rate of CNS decline with age. Although group differences were consistent with the noise hypothesis, the validity of estimates derived for individuals was questioned, because there was evidence of some confounding of IT and noise estimates.

In Experiment 6, noise was not measured directly; but an index of performance variability assumed to reflect ability to concentrate of the task was derived from the number of correct responses produced on a constant discriminability, constant exposure duration task where exposure duration was set at a level previously associated with 80% accuracy on the IT task. Although the accuracy levels achieved by young and elderly adults were 81% and 77.6%, respectively, this difference was not statistically significant. Evidence suggested that this validation score was confounded with estimates of IT, with higher accuracy being associated with long ITs.

Evidence was found to suggest that IT and noise are inextricably linked and are confounded during measurement. Findings were thus consistent with Smith's (1986) suggestion that IT provides the best index of moment-to-moment variability in performance. In addition, findings were consistent with White's (1993) view that the IT delay reflects aspects of both sensory and post-sensory processes and with Nettelbeck and Young's (1989) view that IT reflects the general efficiency of the information processing system, rather than some specific characteristic of the sampling mechanism proposed in the accumulator model discussed by Vickers, Nettelbeck and Willson (1972). It is unlikely then that estimates of noise and speed can be measured independently within a backward masking procedure. Indeed, both constructs are concerned with the fidelity of the information processing system and, despite attempts to reduce speed decline to the impact of noise, it is not clear that differentiating the two adds anything to the level of explanation.

Experiments 4 and 5 examining test-retest reliability and the impact of strategy use on IT performance were consistent with the view that speed of processing can be measured reliably in elderly adults using the backward masking procedure. An attempt was made to derive an estimate of IT to be used in a subsequent noise task using an expanded judgement procedure in Experiment 5. Although group differences found in the number of correct

responses produced on this task were consistent with age-related slowing, reliable estimates of IT could not be derived from the task.

Experiment 6 found that ability to maintain preparation was not responsible for age differences in IT performance and that, consistent with the view that ageing is associated with a reduction in processing resources, elderly adults were poorer than the young in a dual-task. There was some support in Experiments 4 and 6 for concluding that the speed dimension tapped by IT is different to that assessed by DSS. Following Smith (1986), it is likely that IT taps moment to moment variability in processing and that, despite the attempt to explain decline in speed in terms of an increase in internal noise in Chapter 2, these two aspects of performance, assessed by DSS and IT respectively, are not strongly related. This finding is consistent with the view that speed of information processing is not a unitary construct. Indeed, findings of Experiment 6 suggested that there may be different forms of speed. It was suggested that these might reflect input or encoding processes, concentration and more complex, intentional processes.

The relationship between speed differences and fluid ability was examined in Experiments 4 and 6. In Experiment 4, no evidence was found to suggest that IT made a significant contribution to the prediction of PM once speed assessed by DSS had been considered. It was suggested that this result may have been due to the impact of strategy users in this study, because the LED display used appeared to be particularly prone to the adoption of cues based on apparent movement which reduce the effectiveness of the backward masking procedure and thus increase unreliability of IT estimates. Experiment 6 which examined IT performance using a mask that reduces such strategy use found evidence for the view that two backward masking procedures assumed to reflect concentration made significant contributions to the prediction of PM. However, interpretation of this finding was constrained by the fact that the unique contribution made by these variables was only evident when IT acted as a suppressor variable, partialling out variance unrelated to PM. The findings with respect to backward masking variables suggests that features common to backward masking procedures but irrelevant to their relationship with cognitive ability may have reduced the simple correlations between these

indices and PM. Further studies would be required to determine the source of this irrelevant variance and to decide with what indices one is dealing if variance common to the backward masking procedure is controlled for in such tasks. In this thesis it has been suggested that they reflect aspects of attention.

Experiments 2 and 3 examined age-related changes in parameters of visual search performance. Decline in target recognition processes found with age were consistent with the noise hypothesis. An attempt to relate recognition performance parameters to indices of noise derived in Experiment 1, however, was unsuccessful. The finding that age x condition interactions remained when data were subject to logarithm transformations was not consistent with the strong version of the slowing hypothesis. This manipulation tests whether group effects reflect complexity and are simply the result of scaling differences (proportionate change being the same across groups). The finding that transformed data maintained group x condition interactions suggests that processes in addition to generalised slowing are responsible for group differences; internal noise and selective attention have been implicated in the literature, although distinguishing empirically between the two is problematical.

To summarise with respect to the five aims of the empirical work outlined earlier, it was found that:

- (i) Speed of processing could be measured reliably using the backward masking procedure; evidence suggested that future attempts to measure IT should avoid use of the LED display, using instead video or, where possible, tachistoscopic stimulus presentation using the lightening mask of Evans and Nettelbeck (1993).
- (ii) Noise and IT are not independent indices of performance. Reduced signal-to-noise ratio can account for performance on both measure as they have been operationalised, because this results in increasing numbers of errors, steeper slopes and longer IT estimates

on a forced two-choice task. Evidence was found to suggest that unreliability in initial IT estimates had a multiplicative effect on noise estimates; that is, the tasks were confounded.

(iii) Although strong support was found for a link between speed and cognitive performance in elderly adults using a paper-and pencil index of speed (DSS), findings regarding the contribution of backward masking variables were more equivocal. Findings were, however, consistent with the view that "speed" is not a unitary construct.

(iv) Whereas performance on backward masking tasks is undoubtedly affected by the ability to maintain attention to the task, no evidence was found to suggest that there is an age-related decline in this ability. Despite this, it was argued that concentration reflects one aspect of speed of processing which does predict fluid ability when variance due to IT is partialled out.

(v) Visual search performance with confusable and nonconfusable target-distracter combinations provided some support for the weak version of the slowing hypothesis and the view that the impact of noise is mediated by the level of redundancy, either in the stimulus or in the structures associated with processing.

The empirical work presented in this thesis has examined a unidimensional index of cognitive performance (Raven's PM) and a restricted range of speed measures. This work has not supported the strong version of the slowing hypothesis and has provided some qualified support for recent arguments against the unitary nature of speed as this influences cognitive ageing. Future studies will need to address the implications of a multidimensional view of speed for accounts of cognitive performance across a wide range of domains.

From a theoretical perspective, further examination of the contribution of backward masking variables is of interest, because it suggests that aspects of speed not assessed by DSS, and possibly related to concentration, contribute to the prediction of fluid abilities.

From a practical perspective, however, given the resource-intensive nature of data collection using backward masking procedures and various methodological concerns which constrain interpretation, the paper-and-pencil DSS test has priority as a quick index of speed of processing when a single measure is preferred for examining the relationship between age and cognitive performance. This proposition is consistent with Salthouse's (1985b) suggestion.

In Chapter 1 it was suggested that the distinction between internal noise, speed of processing and attentional resources might not remain after closer scrutiny. This thesis found evidence consistent with the view that, because both noise and speed are concerned with the fidelity of the processing system and its capacity for resolution, distinguishing empirically between the two is problematical. Indeed, the level of explanation is not clearly increased by attempting to reduce speed decline to noise. Regardless of theoretical arguments, the noise index has no value if it cannot be extricated from other performance parameters.

Both attentional capacity explanations and the generalised slowing hypothesis are concerned with some reduction in the resources available for processing. It was suggested that the notion of redundancy in information or structures may, in part, account for differential decline across various tasks. Although this thesis has not compared these explanations based on speed and attention directly, it is clear that the differential decline of cognitive abilities with age, and the finding that speed is not a unidimensional construct, are consistent with a model in which both speed and attention are seen to be determinants of performance. This argument is consistent with the model of Stankov (1988) where speed, attentional flexibility and concentration are used to predict fluid ability among the elderly. The link between rate of information transmission and attention (conceptualised as a control process that monitors various input channels) is thus worthy of further empirical study.

In conclusion then, the findings of this thesis are consistent with the weak version of the slowing hypothesis. Support was found for the suggestion that speed predicts cognitive decline with age and that, despite procedural difficulties, various backward

masking procedures make a unique contribution to the prediction of cognitive ability. The unique contribution of the backward masking variables appears to be based on aspects of attention, particularly concentration. Although it was argued that speed and noise cannot be measured independently, the distinction between resource limitations conceptualised in terms of speed and attention (conceptualised as a control process that monitors various input channels) remains worthy of further empirical study.

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APPENDIX A

Analysis of Variance Table: Comparison of Mean SOA₉₀ (ms) derived using Probit or Wetherill & Levitt procedures for young and elderly adults (Experiment 1)

Between-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	85603.89	34	2517.76		
GROUP	4769.39	1	4769.39	1.89	.178

Within-Subject Effect 'PROCEDURE'.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	3250.44	34	95.60		
PROCEDURE	747.56	1	747.56	7.82	.008
GROUP BY PROCEDURE	32.00	1	32.00	.33	.567

APPENDIX B

An examination of the mean discriminial difference required by young and elderly adults to achieve 80 % accuracy on the NOISErr task

	Mean	Standard deviation
young n=18	3.63	1.98
elderly n=18	6.09	5.47

Note: Discriminal difference between lines is expressed in terms of number of pixels where 1 pixel is 0.35 mm

t-tests for independent samples revealed a significant difference ($t(34)=1.79$; $p<0.05$; one tailed) between young and elderly adults

APPENDIX C

Analysis of Variance Table: Comparison of vocabulary scores for three age groups (Experiment 2)

Oneway Analysis of Variance

Source of Variation	SS	DF	MS	F	Sig of F
Between Groups	2.5598	2	1.2799	.3026	.7405
Within Groups	181.8750	43	4.2297		
Total	184.4348	45			

APPENDIX D

Analysis of Variance Table: Comparison of Mean RT by array-size (3, 6 or 9 letters) and distracter type (confusable vs nonconfusable). across three age groups. (Experiment 2).

Between-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	2545201.53	43	59190.73		
AGE GROUP	1881928.00	2	940964.00	15.90	>.001

Within-Subject Effect 'CONFUSABILITY'.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	294770.60	43	6855.13		
CONFUSABILITY	1709959.82	1	1709959.8	249.44	> .001
GROUP BY CONFUS	163784.14	2	81892.07	11.95	>.001

Within-Subject Effect 'ARRAY'.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	329896.79	86	3836.01		
ARRAY	1446772.65	2	723386.33	188.58	> .001
GROUP BY ARRAY	113480.37	4	28370.09	7.40	>.001

Within-Subject Effect 'CONFUSABILITY BY ARRAY'.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	373509.80	86	4343.14		
CONFUS BY ARRAY	596998.71	2	298499.36	68.73	>.001
GROUP BY CONFUS BY ARRAY	73585.85	4	18396.46	4.24	.004

APPENDIX E

Analysis of Variance Table: Comparison of mean RT for young and elderly adults with confusable target-distracter combinationsBetween-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	2043760.43	43	47529.31		
GROUP	1512480.39	2	756240.19	15.91	>.001

Within-Subject Effect 'ARRAY SIZE'.

Univariate F-tests with (1,43) D. F.

Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
1897109.6	342506.4	1897109.6	7965.3	238.2	>.001

GROUP BY ARRAY

Univariate F-tests with (2,43) D. F.

Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
176480.280	342506.3	88240.1	7965.3	11.1	>.001

Analysis of Variance Table: Comparison of mean RT for young and elderly adults with nonconfusable target-distracter combinationsBetween-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	796211.70	43	18516.55		
GROUP	533231.75	2	266615.88	14.40	>.001

Within-Subject Effect 'ARRAY'.

Univariate F-tests with (1,43) D. F.

Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
101800.0	56309.0	101800.0	1309.5	77.7	>.001

GROUP BY ARRAY

Univariate F-tests with (2,43) D. F.

Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
2709.2	56309.0	1354.6	1309.5	1.03	.364

Appendix F

Analysis of Variance Table for log-transformed values of RT for young and elderly adults across array size for confusable target-distracter combinations

Between-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	3.03	43	.07		
GROUP	2.11	2	1.06	14.97	>.001

Within-Subject Effect 'ARRAY SIZE'

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.57	86	.01		
ARRAY	2.93	2	1.46	221.50	>.001
GROUP BY ARRAY	.10	4	.02	3.69	.008

APPENDIX G

Analysis of Variance Table: Comparison of error rates in young and elderly adults for visual search with confusable and nonconfusable target-distracter combinations

Between-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	863.36	43	20.08		
GROUP	135.22	2	67.61	3.37	.044

Within-Subject Effect "DISTRACTER TYPE"

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	213.34	43	4.96		
TYPE	34.78	1	34.78	7.01	.011
GROUP BY TYPE	1.85	2	.92	.19	.831

APPENDIX H

Analysis of Variance Table: Comparison of selective attention and visual search conditions for three age groups

<u>Between-Subjects Effects.</u>					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	2520933.53	43	58626.36		
GROUP	2854761.09	2	1427380.5	24.4	>.001
<u>Within-Subject Effect 'TRIAL'</u>					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	463136.76	43	10770.62		
TRIAL	421122.22	1	421122.22	39.1	>.001
GROUP BY TRIAL	98461.98	2	49230.99	4.57	.016
<u>Within-Subject Effect 'DISTRACT'</u>					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	795589.32	43	18502.08		
DISTRACT	2174045.98	1	2174046.0	117.5	>.001
GROUP BY DISTRACT	465669.99	2	232834.99	12.58	>.001
<u>Within-Subject Effect 'TRIAL BY DISTRACT'</u>					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	180063.98	43	4187.53		
TRIAL BY DISTRACT	53128.22	1	53128.22	12.9	>.001
GROUP BY TR BY DIST	59444.54	2	29722.27	7.10	.002

Analysis of Variance Table: Comparison of selective attention and visual search conditions for three age groups(log-transformed data).

<u>Between-Subjects Effects.</u>					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	3.61	43	.08		
GROUP	4.51	2	2.25	26.8	>.001
<u>Within-Subject Effect 'DISTRACTOR TYPE'</u>					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.71	43	.02		
DISTRACTOR	3.01	1	3.01	181.5	>.001
GROUP BY DISTR	.31	2	.15	9.24	>.001
<u>Within-Subject Effect 'TRIAL'</u>					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.69	43	.02		
TRIAL	.86	1	.86	53.3	>.001
GROUP BY TRIAL	.24	2	.12	7.37	.002
<u>Within-Subject Effect 'DISTRACTOR BY TRIAL'</u>					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.19	43	.00		
DIST BY TRIAL	.07	1	.07	17.23	>.001
GROUP BY DIST BY TR	.11	2	.06	13.01	>.001

APPENDIX I

Raw Data for Visual Search Task (Experiment 3)Reaction Times for Varying Array Sizes

Subject ID	Array Size						
	AS1	AS2	AS3	AS4	AS5	AS6	AS9
1	500	507	555	622	705	686	847
2	406	428	452	462	492	516	569
3	487	616	664	606	689	835	896
4	401	429	475	425	485	455	538
5	407	396	386	449	424	430	431
6	407	429	468	498	634	641	748
7	425	405	431	500	477	563	607
8	592	591	547	580	654	721	783
9	484	481	532	563	592	645	733
10	418	481	456	546	587	605	817
11	477	459	482	555	531	603	639
12	427	436	468	502	583	634	722
13	453	494	545	606	652	688	789
14	526	560	542	718	681	899	925
15	451	449	454	542	550	607	641
16	473	463	536	561	612	706	829
17	453	474	448	473	546	597	656
18	532	591	582	685	705	847	953

APPENDIX J

The FAST task

The task presents a series of randomly flashing lights and the subject's task is to judge which is the more frequent. The flashes represent a series of Bernoulli trials (l,l,l,r,r,l,r,l,r...). The probability that the right light will be lit is given by p and the probability that the left light will be lit is given by q where $p+q=1$. In the case where the right light is the more frequent ($p>q$), the probability that the subject will make a correct response is given by the binomial probability of encountering a majority of right flashes plus half the probability of encountering an equal number of right flashes and left flashes. The binomial probability (b) may be determined from the following formula:

$$b(n,k;p) = \frac{n!}{k!(n-k)!} \cdot p^k q^{n-k}$$

where b = binomial probability level
 k = the number of "successes" -eg right flashes
 p = probability of right light
 q = probability of left light

APPENDIX K

Questions asked to determine whether or not subjects used apparent movement and brightness cues during the IT task (Experiment 4)

- (1) How did you decide which line was the shorter ?
- (2) Was there anything you did which made your job of deciding which line was the shorter easier ?
- (3) Did you notice any change in the lines as you were looking at them ?

APPENDIX L

Scoring scheme for the Random Number Generation task (Experiments 4 and 6).

During the task subjects are asked to produce a random sequence of 100 numbers. In such a sequence, each number from 1 to 10 would be expected to follow each other number only once. Responses are tallied in a 10 x 10 matrix. The nth response is cross-tabulated with the (n+1)th response for each of the 100 responses. (Note: the 100th response is cross-tabulated with the first). The random number generation score (RNG) reflects the disproportion of sequence pairs within cells adjusted by the disproportion of marginal frequencies according to the formula below:

$$\text{RNG} = [\sum(f_{ij}) \cdot \log(f_{ij})] / [\sum(f_i) \cdot \log(f_i)]$$

APPENDIX M

Analysis of Variance Table: Comparison of estimates of IT across sessions for young and elderly adults (Experiment 4)

Between-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	182273.33	43	4238.91		
GROUP	21817.16	1	21817.16	5.15	.028

Within-Subject Effect. 'SESS'

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	38551.09	43	896.54		
SESS	19609.53	1	19609.53	21.87	>.001
GROUP BY SESS	1817.53	1	1817.53	2.03	.162

APPENDIX N

Analysis of Variance Table: Comparison of Mean SOA90 (ms) derived using Probit or
Vetherill & Levitt procedures for young and elderly adults (Experiment 4)

Between-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	355631.58	82	4336.97		
GROUP	8560.20	1	8560.20	1.97	.164

Within-Subject Effect 'PROC'

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	68432.19	2	834.54		
PROC	5709.59	1	5709.59	6.84	.011
GROUP BY PROC	305.30	1	305.30	37	.547

APPENDIX O

Analysis of Variance Table: Comparison of DSS scores obtained by young and elderly adults with recall entered as a covariate

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	4997.37	53	94.29		
REGRESSION	86.33	1	.92	.343	
GROUP	5183.43	1	5183.43	54.97	>.001

Regression analysis for WITHIN+RESIDUAL error term

Dependent variable .. DSS

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
RECALL	.58992	.09157	.617	.957	.343

Analysis of Variance Table: Comparison of IT scores obtained by young and elderly adults with noise entered as a covariate

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	103864.51	45	2308.10		
REGRESSION	6065.29	1	6065.29	2.63	.112
GROUP	13676.33	1	13676.33	5.93	.019

Regression analysis for WITHIN+RESIDUAL error term

Dependent variable .. IT

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
NOISE	-23.05308	-.23185	14.221	-1.621	.112

Analysis of Variance Table: Comparison of DSS scores obtained by young and elderly adults with noise entered as a covariate

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	4600.52	45	102.23		
REGRESSION	48.21	1	48.21	.47	.496
GROUP	4683.20	1	4683.20	45.81	>.001

Regression analysis for WITHIN+RESIDUAL error term

Dependent variable .. DSS

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
NOISE	-2.05519	-.07205	2.993	-.687	.496

APPENDIX P

Multiple Regression (Experiment 4)

Equation Number 1 Dependent Variable..Raven's PM
 Block Number 1. Method: Enter

Variable(s) Entered on Step Number

- 1.. RECALL
- 2.. DSS
- 3.. NOISE
- 4.. IT
- 5.. AGE

Multiple R .69923
 R Square .48892
 Adjusted R Square .37277
 Standard Error 7.20698

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
AGE	-.252444	.303380	-.153886	-.832	.4143
DSS	.470505	.175570	.495215	2.680	.0137
AVIT	-.009546	.029336	-.055503	-.325	.7479
NOISSD	2.091510	2.559314	.132804	.817	.4226
RECALL	.781554	.638437	.197086	1.224	.2338
(Constant)	25.827303	26.440327		.977	.3393

APPENDIX Pii

Analysis of Variance Table: Comparison of estimates of IT across sessions for young and elderly adults (Experiment 5)

Between-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	45715.93	28	1632.71		
GROUP	35120.47	1	35120.47	21.51	.001

Within-Subject Effect "SESSION"

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	7390.72	28	263.95		
SESSION	1218.01	1	1218.01	4.61	.040
GROUP BY SESSION	4.21	1	4.21	.02	.900

APPENDIX Q

Analysis of Variance Table: Comparison of estimates of SOA90 (ms) derived for young and elderly adults using Probit and Wetherill and Levitt procedures

Between-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	749263.19	179	4185.83		
GROUP	57690.92	1	57690.92	13.78	>.001

Within-Subject Effect 'PROCEDURE'.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	80595.30	179	450.25		
PROC	5342.59	1	5342.59	11.87	.001
GROUP BY PROC	.23	1	23	.00	.982

Mean Values of Estimates of SOA90

	Probit	Wetherill & Levitt
Elderly	111.9 (86.6)	104.2 (47.3)
Young	61.7 (46.7)	78.8 (27.3)

(SD in parentheses)

APPENDIX R

Analysis of Variance Table: Comparison of number of correct responses obtained by young and elderly adults on the FAST task across 2 sessions, 2 flash durations and 2 probability levels

Between-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	483.12	30	16.10		
GROUP	49.88	1	49.88	3.10	.089

Within-Subject Effect 'SESSION'.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	214.71	30	7.16		
SESSION	.88	1	.88	.12	.728
GROUP BY SESS	4.79	1	4.79	.67	.420

Within-Subject Effect 'DURATION'

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	79.30	30	2.64		
DURATION	3.29	1	3.29	1.24	.274
GROUP BY DUR	4.79	1	4.79	1.81	.189

Within-Subject Effect 'PROBABILITY'.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	152.59	30	5.09		
PROB	443.63	1	443.63	87.22	>.001
GROUP BY PROB	10.16	1	10.16	2.00	.168

Within-Subject Effect 'SESSION BY DURATION'.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	88.59	30	2.95		
SESS BY DUR	3.29	1	3.29	1.11	.300
GROUP BY SESS BY DUR	.00	1	.00	.00	.971

Within-Subject Effect 'SESSION BY PROBABILITY'.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	86.93	30	2.90		
SESS BY PROB	8.63	1	8.63	2.98	.095
GROUP BY SESS BY PROB	.32	1	.32	.11	.743

Within-Subject Effect 'DUR BY PROB'

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	119.09	30	3.97		
DUR BY PROB	5.94	1	5.94	1.50	.231
GROUP BY DUR BY PROB	2.85	1	2.85	.72	.404

Within-Subject Effect 'SESS BY DUR BY PROB'

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	58.99	30	1.97		
SESS BY DUR BY PROB	.19	1	.19	.10	.757
GROUP BY SESS BY DUR BY PROB	.19	1	.19	.10	.757

APPENDIX S

Analysis of Variance Table: Comparison of IT (ms) under constant and variable intertrial intervalsBetween-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	81634.34	50	1632.69		
GROUP	16297.78	1	16297.78	9.98	.003

Within-Subject Effect 'ITI'

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	26294.85	50	525.90		
ITI	13637.27	1	13637.27	25.93	> .001
GROUP BY ITI	838.80	1	838.80	1.59	.212

APPENDIX T

Analysis of Variance Table: Comparison of IT (ms) under single or dual task procedureBetween-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	112468.31	49	2295.27		
GROUP	15136.33	1	15136.33	6.59	.013

Within-Subject Effect 'DUAL'

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	74560.66	49	1521.65		
DUAL	48117.59	1	48117.59	31.62	>.001
GROUP BY DUAL	568.69	1	568.69	.37	.544

APPENDIX U

Analysis of Variance Table: Comparison of estimates of SOA80 (ms) derived using Probit and Wetherill & Levitt procedures for young and elderly adults (Experiment 6)

Mean Values of Estimates of SOA90

	PROBIT	W & L
YOUNG	79.5 (29.5)	76.9 (26.7)
ELDERLY	105.5 (44.5)	96.8 (29.8)

(SD in parentheses)

Between-Subjects Effects.

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	112911.50	49	2304.32		
GROUP	12307.33	1	12307.33	5.34	.025

Within-Subject Effect 'PROCEDURE'

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	5102.19	49	104.13		
PROC	703.89	1	703.89	6.76	.012
GROUP BY PROC	247.65	1	247.65	2.38	.129

APPENDIX V

Experiment 6: Multiple regression analyses to determine suppressor variable.

Equation Number 1 Dependent Variable.. Raven's PM

Variable(s) Entered on Step Number

- 1.. ITv
- 2.. AGE
- 3.. VALIDATION
- 4.. DSS

Multiple R .75165
R Square .56498
Adjusted R Square .48212
Standard Error 6.54974

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
AGE	-.587371	.248479	-.429566	-2.364	.0278
VALIDATION	.341518	.214558	.272726	1.592	.1264
DSS	.370129	.162281	.429524	2.281	.0331
ITv	.045196	.035816	.204577	1.262	.2208
(Constant)	37.561732	20.308801		1.850	.0785

Equation Number 2 Dependent Variable.. Raven's PMVariable(s) Entered on Step Number

1..	IT
2..	DSS
3..	AGE
4..	VALIDATION

Multiple R	.75466
R Square	.56950
Adjusted R Square	.48751
Standard Error	6.51562

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
AGE	-.538606	.251255	-.393902	-2.144	.0439
VALIDATION	.620687	.245257	.495662	2.531	.0194
DSS	.234685	.158470	.272345	1.481	.1535
IT	-.081601	.060327	-.267221	-1.353	.1906
(Constant)	42.869975	19.587705		2.189	.0401

Equation Number 3 Dependent Variable.. Raven's PMVariable(s) Entered on Step Number

1..	ITv
2..	AGE
3..	DSS
4..	IT

Multiple R	.73117
R Square	.53461
Adjusted R Square	.46301
Standard Error	6.66952

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
AGE	-.317745	.229799	-.232379	-1.383	.1785
DSS	.497731	.135921	.577603	3.662	.0011
IT	-.060347	.054301	-.197621	-1.111	.2766
ITv	.085519	.036851	.387095	2.321	.0284
(Constant)	27.029032	19.073550		1.417	.1683

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