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The effects of age, task complexity and task domain on dual task performance.

The Effects of Age, Task Complexity and Task Domain on Dual Task Performance

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Abstract

This thesis examined why there have been mixed findings in the literature as to whether older adults have a dual tasking deficit. We examined task complexity and task domain as important moderator variables of dual task costs in older adults. In addition, a number of methodological criticisms have been discussed (e.g. Somberg & Salthouse, 1982); therefore, methodological issues that have clouded the interpretation of previous research findings are also evaluated.

The first experiment used the traditional dual task paradigm to investigate whether disproportionate dual task costs would be observed for episodic and semantic memory retrieval. The results highlighted the potential problems of task trade-offs inherent in the dual task methodology and led to the development of the n-back procedure that was used in subsequent experiments. In chapter 3 disproportionate dual task costs were observed for episodic but not semantic memory retrieval. However, the magnitude of the age effect for episodic memory retrieval was minimised when favourable retrieval conditions were given (cued recall versus recognition).

Chapters 4 and 5 further examined the costs of dual tasking when relatively automatic processing is required. Much like semantic memory retrieval the costs of dual tasking were age invariant in both the language and mental arithmetic domains. Two further experiments examined the contribution of controlled rather than automatic processing on dual task performance in the visuospatial domain. There was some suggestion that in such domains, which are less reliant on the accumulation of knowledge, older adults are particularly impaired.

In the final experimental chapter, we carried out a meta-analysis to consider further task domain as a moderator variable of dual task costs in older adults. The results of the meta-analysis were in agreement with the experimental evidence presented in this thesis.

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This thesis is dedicated to my family for their endless support and encouragement.

AUTHOR'S DECLARATION

I declare that the work in this dissertation was carried out in accordance with the Regulations of the University of Bristol. The work is original except where indicated by special reference in the text and no part of the dissertation has been submitted for any other degree.

Any views expressed in the dissertation are those of the author and in no way represent those of the University of Bristol.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

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1. General Introduction

In this thesis we examine age differences in dual task performance. There has been considerable interest in older adults' performance on dual tasks but there have been mixed findings in the literature. In order to explain these discrepancies, we address concerns with previous research by attempting to answer three main questions. Firstly, do older adults have a specific deficit in dual tasking over and above the problems they have on tasks when they are performed alone? Secondly, since a variety of tasks and combination of tasks have been examined, can this account for the mixed pattern of results? Particularly, dual tasks have varied in complexity and difficulty and have been examined across a variety of domains. Finally, can methodological variations between studies account for why older adults are only sometimes found to have problems in dual tasking?

In this chapter we argue that older adults' poorer performance with some cognitive abilities, such as dual task performance cannot be accounted for by a general age related decline in cognitive performance. A brief account will first be given of executive functions such as task co-ordination, which are thought to be particularly impaired in normal ageing. A review of the literature concerned with age differences in dual task performance is then given. A brief account of older adults' performance in everyday activities is presented in order to highlight that this research, as well as being of great theoretical interest, is also of practical importance. Before reviewing the behavioural evidence, theoretical models proposed to account for age differences in dual task performance are outlined. Since dual task performance has been considered on a variety of tasks this may account for the mixed pattern of results. Therefore, we review the literature on dual task performance across a variety of task domains. Finally, methodological criticisms of previous research are discussed before outlining the research presented in this thesis.

1.1 Cognitive Ageing

1.1.1 Local versus Global Models of Cognitive Ageing

A great deal of research has been conducted on the effects of age on cognitive performance. Although age related differences in performance have been observed on a large number of cognitive variables, in some domains of cognition it is unclear whether older adults are more penalised than the young. It is undeniable that increased age is accompanied by a decline in processing speed, and this has been attributed to diffuse neuronal loss with increased age. However, it is arguable whether poor performance by older adults on a variety of tasks can be explained by speed of processing alone (e.g. Craik & Anderson, 1999). Certainly, evidence does point to diffuse neurophysiological changes with increased age but it has been suggested that along with these general changes, there are marked changes to particular regions of the brain such as the temporal and frontal lobes (e.g. DeSanti, De Leon, Mony & Volkow, 1995). Consequently, those functions that are subserved by these regions show greater decline in ageing. One such account proposes that increased age is accompanied by a marked change in the frontal lobes.

The frontal ageing hypothesis (e.g. Greenwood, 2000; West, 1996) has frequently been used to explain cognitive decline in ageing. This hypothesis suggests that what have been termed as executive functions, largely dependent on the frontal regions, decline in ageing. The focus of this thesis is on one aspect of executive functioning, i.e. dual task performance. Before examining the performance of older adults on dual tasks, a brief discussion will be given on the nature of executive processes and the two lines of evidence that suggest older adults have an executive deficit, i.e. behavioural and neurophysiological.

1.1.2 Executive Functioning in Older Adults

Executive processes refer to those higher cognitive functions that either control or monitor other ongoing activities. Typically executive functions involve processes such as goal selection, planning, decision-making, task switching and multi-tasking. Anatomically executive processes are thought to be carried out by the frontal lobes, particularly the pre-frontal region. Lesion studies have provided the bulk of evidence that executive functions are carried out by the frontal lobes. For instance, Daigneault, Braun, & Whitaker (1992) reviewed the neuropsychological literature and reported that frontal lobe patients perform more poorly on tests of planning (e.g. the self ordered pointing task), self regulation of behaviour (e.g. perseverative errors on the Wisconsin Card Sorting Test), maintenance of behavioural set (e.g. the Stroop Test) and spontaneity (e.g. verbal fluency). There are a number of other reviews and in depth discussions on lesion studies of frontal lobe functioning (e.g. Reitan & Wolfson, 1994; Stuss & Benson, 1984).

As well as lesion studies contributing to a greater understanding of executive/frontal lobe function, a number of neuro-imaging studies on normal individuals have been carried out. In this thesis we were concerned with one aspect of executive functioning, namely dual task performance. A number of studies have investigated the neural basis of dual tasking. For example, Bunge, Klingberg, Jacobsen, & Gabrieli (2000) gathered functional magnetic imaging data while participants carried out a sentence reading and short-term memory tasks either separately or concurrently. In the dual task conditions there was activation particularly in the frontal region. An earlier study by Esposito, Kirkby, Van Horn, Ellmore, & Berman (1999) found similar results. They investigated dual task performance using functional magnetic resonance imaging (fMRI). When the two tasks were performed concurrently there was activation to the pre-frontal cortex. There was no such activation when the tasks were performed alone which led the investigators to conclude the pre-frontal cortex was involved in dual task co-ordination.

The study of executive processing in older adults is of particular interest because it has been suggested that there are similarities in the behavioural problems exhibited by frontal lobe patients and older adults (West, 1996). We will now consider evidence that suggests older adults might have an executive deficit. The neurophysiological evidence presented suggests that although there is a general decline in the integrity of the brain in old age, this is particularly marked in the frontal lobe region. The behavioural evidence demonstrates that age related cognitive decline mirrors that of frontal lobe patients.

Neurophysiological

During the process of normal ageing it has been found that there is a significant age-related neuronal loss in the pre-frontal cortex of 17%, compared to the occipital and temporal lobes where 1% change is observed, occurring between the ages of 20 and 80 years of age (Haug, Barmwater, Eggers, Fischer, Kuhl & Sass, 1983). Ivy, MacLeod, Petit, & Markus (1992) also reported that the most striking atrophy of tissue loss was in the frontal lobe region, and they reported a 50% loss in neuronal density across the lifespan. Another study by DeSanti et al. (1995) used positron emission tomography (PET) scans to demonstrate age related metabolic reductions in the frontal and temporal lobe, with the greatest reduction in the frontal lobes. Certainly, these data provide some evidence that the integrity of the frontal lobe region is particularly compromised in ageing. Therefore, similarities in the cognitive profile of older adults and patients with lesions to the frontal region might be expected.

Behavioural

Daigneault et al. (1992) investigated the frontal dysfunction model of cognitive ageing by requiring younger and older adults to carry out a battery of six tests that had been previously validated as good indicators of pre-frontal function. Younger and older adults carried out the Self Ordered Pointing Task, the Wisconsin Card Sorting Test, Porteus Maze Test, controlled Oral Word Association Test, Design Fluency and the Stroop Test. The authors examined perseverative and non-perseverative performance separately. For perseverative errors age differences were found on all measures except word association and the Stroop Test. An examination of non-perseverative errors found age differences on all measures except word association and design fluency. The authors concluded that older adults have particular difficulty in the "...regulation of behaviour based on plans, abstract concepts, experimenter feedback, and ones one's own responses, regardless of external interference" (Daigneault et al., 1992, pp. 110 –111).

Mittenberg, Seidenberg, O' Leary, & DiGiulio (1989) gave a battery of neuropsychological tests to participants ranging from 20 to 75 years of age. Participants were administered a range of verbal and non-verbal tests. Three of the four strongest relationships were between age and frontal lobe measures (discrimination of word and image recency and non-verbal fluency). The authors concluded that frontal dysfunction best characterises the decline of cognitive function in ageing.

However, more recent studies have given mixed results. Robbins et al. (1997) had participants carry out a variety of cognitive tests that make up the Cambridge neuropsychological test battery (CANTAB) and a battery of tests constructed by Burgess & Shallice (1996). The results were far from convincing, as there was poor intercorrelation between the frontal/executive measures. A factor analysis revealed that a number of the executive tests from the two batteries loaded on the same factor which cross-validated those tests. However, other tests of executive function such as verbal fluency and the cognitive estimate tests loaded separately and were related to general measures of intelligence such as the National Adult Reading Test (NART). Furthermore, there was no evidence that those tests thought to reflect frontal lobe functioning were particularly sensitive to ageing.

The above gives some indication that older adults may have an executive deficit but what is needed is a greater understanding of what the components of executive functioning are, and which in particular are difficult for older adults. In this section we briefly described the frontal lobe deficit model of cognitive ageing and we will return to this later in section 1.2.2 when we consider possible mechanisms that underlie older adults' poorer performance in dual task activities. In summary, there is some indication that older adults have a frontal lobe deficit and executive functioning such as dual task performance may be more penalised than cognitive skills supported by other brain regions.

1.2 Dual Task Performance in Older Adults

As well as being of considerable theoretical interest, a greater understanding of age differences in dual task performances is of practical importance. A brief description of the problems older adults encounter in everyday activities when required to combine two tasks will first be given. In the previous section we proposed that older adults have an executive deficit. In order to set the scene an account will then be given of other theoretical models that have been proposed to account for older adults' dual tasking deficit, before moving on the behavioural evidence. Finally, methodological considerations are discussed as these may explain why there are discrepancies in the literature as to whether or not older adults do have a dual tasking deficit.

1.2.1 Dual Task Performance in Everyday Activities

An insight into the factors that affect dual task performance is invaluable in understanding the problems that older adults encounter in a modern society where tasks are increasing in complexity. There are a number of activities that older adults have been reported to have difficulties in everyday life. For instance, older adults have been reported to have difficulties in dual tasking when driving, working in complex environments in the workplace and also when using computer packages that require multi-tasking (McDowd, Vervcruyssen, & Birren, 1991).

Tun & Wingfield (1995) developed a divided attention questionnaire to investigate whether older adults find combining two tasks problematic. Examples of activities listed in the questionnaire were: 'talking and watching television', 'driving and talking' and 'driving while listening to music'. Older adults reported that most of the task combinations were difficult, and had become more difficult over time. The authors further investigated self-perception of divided attention ability by dividing the items in the questionnaire into three scales on a conceptual basis. They also confirmed the groupings by carrying out a confirmatory factor analysis. Task domain was found to be an important moderator variable, such that activities that involved monitoring of novel information became increasingly difficult with advanced age. The two scales that were based on routine and speech processing showed little change with increased age. This is consistent with the literature that suggests older adults have an executive deficit and particularly have problems with novel activities.

Tun & Wingfield (1995) found that one of the activities that older adults reported as being particularly difficult under conditions of divided attention was driving. Experimental studies have gone further and examined which conditions affect driving performance in older adults. Ponds, Brouwer, & Vanwolffelaar (1988) had younger, middle aged and older age groups of participants perform a dual task experiment involving two continuous performance tasks. The first was a compensatory tracking task, which was used to simulate the everyday activity of car driving. The secondary task was a self-paced visual choice reaction time task, which was used to simulate the information intake from road signs and signals. Participants were required drive in a straight line while continually being pushed out of course by a simulated side wind. The secondary task involved the counting of dots in a rectangular display on the computer screen. It was found that older adults' dual task performance was particularly impaired compared to either the middle or younger age group. The authors concluded that older adults found dual tasking particularly problematic because of less efficient control processes. Since the dual task was paced there would be less time for these processes to carry out the necessary operations in the given time (a speed of processing account of cognitive ageing will be discussed in section 1.2.2). An alternative account may be that older adults have more difficulty combining two motor programmes and the competition for the same processing operations demanded by the two tasks is problematic for older adults.

One study investigated the influence of both cognitive and motor factors on dual task performance (Crook, West, & Larrabee, 1993). The authors used a driving reaction time task to investigate age differences in dual task performance. The primary task involved the presentation of traffic lights, a brake and an accelerator pedal on the computer screen. Participants were instructed to move their hand from the accelerator to the brake pedal when a red light appeared and back to the accelerator when the green light appeared. The secondary task involved monitoring weather and traffic reports for later recall. Age differences in dual task performance were found on both the primary and secondary tasks. Of particular interest was that the authors were able to examine the influence of both cognitive and psychomotor factors on performance. On the driving reaction time task a measure of lift time and travel times were taken. Lift time was the time of onset of the red light until the finger was lifted off the accelerator and represented central attentional processes. Travel time was the time the finger was lifted until the alternate pedal was pressed and represented psychomotor speed. An analysis of both these measures revealed a greater age effect on cognitive rather than psychomotor factors.

Korteling (1994) reported no age differences in dual task performance when the subtasks were familiar. Using a driving simulator, younger and older adults performed a car steering task concurrently with a car following task. The steering task involved maintaining the position of the car in a particular lane in the presence of simulated wind gusts. In the car following task participants were required to adjust the speed of the vehicle so as to keep a particular distance from the lead car. In the familiar condition speed of the vehicle was adjusted by a normal pedal push. In the novel condition the speed of the vehicle was adjusted with reverse pedal polarity. Generally, there was age invariance, except when the dual task involved the modification of an over-learned activity. In the reverse pedal polarity condition older adults would have to devote considerable attention in the acquisition of the new skill and at the same time inhibit automatic responses. This cognitive effort resulted in a greater performance decrement for older adults in the steering task.

The authors argued against the notion of the slowing – complexity hypothesis (see section 1.2.2) because the magnitude of the age difference was not proportional to the complexity of the task (complexity as indexed by younger adults' mean performance).

One alternative explanation is that there is a decrease in the efficiency of inhibitory processes with increased age (Hasher & Zacks, 1988). Under this view when tasks have to be carried out concurrently, it is necessary to inhibit the processing of one task while the other is being carried out. Older adults are likely to do less well as interference from competing tasks arises. Furthermore, inhibitory processes are thought to be carried out by the frontal lobes. For example, Sweeney, Rosano, Berman, & Luna (2001) suggest that changes to the frontal striatal systems are responsible for the reduced efficiency of executive functions with increased age (especially inhibitory control). We will see later under the section on cognitive models how it may be better to think of older adults' problems in terms of an executive deficit.

The above studies provide a good illustration of how everyday activities can be examined in the laboratory. Tun & Wingfield (1995) found that older adults reported that they found concurrent processing particularly problematic while driving. Subsequent experimental studies were then able to investigate what task characteristics may moderate task performance. Clearly interference between tasks could arise simply because of motor problems such as structural incompatibility. Korteling (1994) were able to investigate the effects of motor and cognitive factors independently. This study found that inefficient control mechanisms were largely responsible for older adults' poorer dual task performance. Before an examination of further experimental studies, a review is carried out of current models of divided attention.

1.2.2 Models of Age Differences in Divided Attention

Craik (1977, p. 391) suggested that "...one of the clearest results in experimental psychology of ageing is the finding that older adults are more penalised when they must divide their attention." However, more recent research has given a mixed pattern of results and there is great variability in the size of the age effect in dual task studies. Before an examination of the experimental evidence, an account of possible mechanisms underlying older adults' dual task deficits will be outlined and where necessary elaborated on in the experimental evidence sections.

The Slowing Complexity Hypothesis

The slowing complexity hypothesis proposes that all age effects can be explained by generalised slowing. The original work carried out by Birren (1964) found that the absolute difference between response time between the young and the old became larger as the processing demands of the task increased when the stimulus input and response output remain constant. It was proposed that this slowing was due to the generalised decline in central processing speed with increased age. Therefore, under this view older adults' response times on both single and dual tasks are a linear function of younger adults' response times. A number of meta-analyses have been carried out which have considered a variety of tasks differing in difficulty and complexity (e.g. Cerella, 1985). The slope of the linear function plotted from younger and older adults' reaction times is typically found to be approximately 1.5.

In this framework a dual task is just a more complex single task needing no additional processing operations. In fact, McDowd & Craik (1988) carried out a study to investigate the effects of ageing and task difficulty on dual task performance. If a divided attention manipulation is just one of several ways of increasing task difficulty, when we plot mean reaction times of the younger adults against mean response times of the older adults, the resulting functions should be the same as that of a similar function plotted for single tasks of varying degrees of complexity. McDowd & Craik (1988) found that the functions were the same and thus supporting an account based on generalised slowing.

There is no doubt that the slowing complexity hypothesis can account for a great deal of the dual task ageing data but as stated this thesis is concerned with the situations were older adults have a disproportionate deficit. The slowing complexity hypothesis predicts that older adults' response times will be proportionally slower than younger adults' but studies have found disproportionate deficits. These will be discussed in detail in the experimental evidence section. It should also be noted that the slowing complexity hypothesis is descriptive in nature and provides no explanation about why older adults are more disadvantaged with increased single or dual task complexity (Kramer, Larish, & Strayer, 1995).

Unitary Resource Deficit Model

Another account suggests that increased age is accompanied by a reduction in central processing capacity. The unitary resource theory has been proposed to account for age differences in dual task performance (e.g. Craik, 1977). This account suggests that dual task performance is mediated by the availability of a limited capacity processing resource, and this resource declines with increase age. Therefore, if two attentional demanding tasks are performed concurrently, there is a greater likelihood that older adults' capacity will be exhausted and this will lead to poorer performance on either or both of the component tasks. This capacity interference may only be small or absent in younger adults. Although the idea of a reduction in processing resources with increased age has been an influential theory, it has been argued that such a theory lacks predictive and explanatory power (Navon, 1984) much like the speed of processing account.

Multiple Resource Deficit Model

A more commonly held view is that rather than being a single resource commodity that is being tapped by processing demand, there are a number of independent resource pools. Wickens, Mountford, & Schreiner (1980) suggest that the different resource pools could be a function of modalities of stimulus inputs, different internal codes (visual versus verbal), and different response modes (manual versus verbal). Greater interference from competing activities is likely to occur when they call on resources from the same pool. Older adults may find task combinations particularly problematic if the component tasks share the same modality or perhaps the same domain. In these circumstances there is greater chance of interference as the tasks tap the same processing mechanisms. Although the idea of a number of independent resource pools is appealing, we could continue to describe independent modules to account for specific cases of dual task interference (Navon, 1984; Tun & Wingfield, 1993).

Cerebral Distance Principle

In a similar vein, Kinsbourne (1980) proposed the functional cerebral distance principle to account for age differences in performance. According to this model different cerebral areas are responsible for the performance of different tasks, and dual task interference results from 'cross talk' between these areas. In other words, the closer the areas being tapped by the component tasks the greater the dual task interference. In old age it is proposed that cortical thinning results in poorer selective inhibition and therefore older adults find it more difficult preventing interference from tasks that are close in functional distance. Hiscock & Kinsbourne (1978) suggest that their account of the costs of dividing attention is compatible with a resource account. Having to avoid interference or cross talk between tasks results in less cognitive resource to perform the tasks themselves.

Specific Deficit in Executive Control

How do we know tasks are in competition for a processing resource? We could assume that all cases of dual task interference result from capacity limitation and this would lead to a circular argument (Allport, 1980). In fact, Neumann (1987, p. 362) suggests that there are "...no obvious neurophysiological grounds for the assumption that dual task performance is limited by the hardware properties of the brain." Meyer & Kieras (1997) do not adopt the assumption of limited resources in their analysis of dual task performance, but stress the strategies that are mediated by executive processes that allow effective dual task performance.

Another way to conceptualise dual task performance and older adults' deficit is in terms of a specific deficit in executive control. We have already discussed executive processes; older adults may have problems in managing and controlling multiple tasks, and it is these operations that are particularly impaired in ageing. In fact, Guttentag (1989) reviewed the literature on the dual task paradigm and suggested an alternative account to the resources deficit model. The author suggests that a performance decrement that results from dividing attention between two tasks can be explained entirely in terms of a cost of concurrence. Simply, older adults may be less able to manage the competition between tasks. This is compatible with the idea that older adults suffer a deficit in the central executive component of working memory.

Baddeley & Hitch (1974) refer to the working memory as the temporary storage and processing of goal relevant information. Working memory is thought to include domain specific short-term stores referred to as the articulatory loop and visual spatial scratchpad. The central executive component of the working memory model is responsible for the co-ordination of the two slave systems. Baddeley (1986) suggested that the central executive resembles the supervisory attentional system described by

Norman & Shallice (1980). This system is responsible for high order processing involved in decision making, planning and in novel situations where the constant monitoring of performance is required.

Baddeley, Logie, Bressi, Della Sala, & Spinnler (1986) investigated dual task performance of patients with dementia of the Alzheimer's type and matched older adults. In this study participants were required to carry out a tracking task with a variety of secondary tasks. However, there was no evidence that healthy older adults were impaired in dual tasking. There was a marked decline in dual task performance in patients with dementia of the Alzheimer's type, which suggested a central executive deficit. A follow up study confirmed a central executive deficit in Alzheimer's disease by testing the same participants and demonstrating a marked decline in dual task performance with disease progression (Baddeley, Bressi, Della Sala, Logie, & Spinnler, 1991). This research contradicts our hypothesis that older adults have an executive deficit, and dual task performance is impaired in normal ageing.

Other studies have argued that the central executive is compromised in normal ageing. Random generation is thought to be carried out by the central executive and is a good indicator of the capacity of this system. Random generation is a novel task where the participant is required to avoid stereotypical responses. The participants must monitor and devise a strategy so as to avoid sequences such as "...a,b,c" and the like. In two experiments, Van der Linden, Beerten, & Pesenti (1998) investigated age differences in random generation and the capacity of the central executive system. In the first experiment participants were required to generate random strings of letters at different response rates. Older adults produced more stereotypical responses even at the slowest rate condition. A further experiment investigated the mechanisms underlying older adults' poorer performance. Participants were required to generate letters at the same time as sorting cards into one, two, four or eight categories. Age differences were found on all measures of randomness, especially as difficulty of the sorting task increased. The authors concluded that there was a reduction in central executive resources with ageing and a reduction in inhibitory control. In contrast to the work carried out by Baddeley and colleagues this work points to a central executive deficit in normal ageing. The different pattern of results might be due to the different procedures used to assess the functioning of the central executive system and therefore further work is warranted.

Computational Models of Dual Task Performance

It may then be more appropriate to think of older adults' deficit in terms of specific problems in executive control. Meyer, Glass, Mueller, Seymour, & Kieras (2001) outline some difficulties with current theories of cognitive ageing and advocated the use of computational theories. They used the Executive Process Interactive Control (EPIC) theory to model age differences in dual task performance, using the psychological refractory period (PRP) procedure. They argued for the analysis and investigation of executive processes and task strategies in the pursuit of a clearer understanding multi-task performance.

In the psychological refractory period procedure participants are presented with two stimuli (S1 and S2). The presentation of S1 and S2 is separated by what has been termed the stimulus onset asynchrony (SOA). The participant is required to make a response to both stimuli but S1 is emphasised. The reaction time and accuracy are then analysed as a function of SOA. The psychological refractory period effect is reflected in the difference between S2 reaction time at the longest and shortest SOAs. Shorter SOAs usually lead to greater S2 reaction times and this effect has been interpreted as interference caused by limited processing capacity preventing concurrent processing

(Pashler, 1994).

The architecture of the EPIC model comprises a cognitive processor that encompasses a production rule interpreter and working memory. The working memory system is connected to modality specific sensors and processors, and motor processes and effectors. Task performance is modelled by programming the production rule interpreter with rules that allow the working memory system to make decisions and produce the appropriate responses to the stimuli (see Meyer & Kieras, 1997). Meyer et al. (2001) having obtained quantitative results using the PRP procedure identified two models to account for younger and older adults' dual task performance. The models demonstrated that both older and younger adults are faced with a limited capacity system to deal with perceptual and motor processes. To deal with such limitations it is necessary to adopt scheduling strategies to cope with concurrent task demands. The fit of the models to the reaction times gathered using the psychological refractory time procedure were very similar for both age groups. This indicates that both age groups handle concurrent processing in a qualitatively similar way. The authors suggest that their conclusions differ from the majority of the dual tasking ageing literature in that they use the more reliable psychological refractory period procedure. They argue that in the traditional dual task paradigm there is little experimental control over the interference between the two tasks from trial to trial and therefore making it difficult to determine which aspects of the tasks are causing the dual task interference. The interference may be the result of either stimulus presentation times, central processing aspects of the task or output mechanisms. However, this procedure restricts the analysis to all but simple reaction time dual tasks.

1.2.3 Age Differences in Simultaneous Processing

Early research on age differences in simultaneous processing gives some indication that older adults have problems in task co-ordination. McDowd et al. (1991) reviewed the literature on age differences in simultaneous processing and found that when processes were required to be carried out in an overlapping manner, older adults were more penalised than the younger adults. For instance, one study by Singleton (1955) found older adults' response time to be the greatest in a choice reaction time task. In this task there were two lights arranged horizontally with a lever underneath. The lever was situated in a grove in the shape of an arrow. When a light appeared participants were required to move the lever up the central shaft of the arrow and down either arrow head which was situated beneath the two lights and then return to the start position. It was found that older adults' response times were the highest overall. Of particular interest was that older adults' time at the start point was particularly high. The authors concluded that older adults were unable to carry out this movement when they were making a decision. However, younger adults were able to start the movement while deciding to which light to respond.

Rabbitt & Rogers (1965) reached similar conclusions; again, participants were required to carry out a choice reaction time task. There were two lights arranged horizontally with two response keys underneath. There was also a third response key placed alongside and after each response to the particular light participants were required to return their hand to this response key. For younger adults the response time to the light and the response time to the start key were equivalent. However for the older adults the response time to the light was the greatest. The authors concluded that for younger adults the processes involved in the motor movement and those involved in the choice could be carried out simultaneously as the response times for the choice plus movement and the movement alone were equivalent. However, for older adults the response times for the choice plus movement was the greatest. This seemed to suggest that older adults carried out this task in a serial manner.

1.2.4 Early Research on Age Differences in Dual Task Performance

Early research indicates that older adults find it problematic to carry out simultaneous processing in the context of a single task but does this hold in tasks were there are two different activities? Again, early research seemed to reveal similar results (see McDowd et al., 1991, for a review). For instance, Broadbent & Heron (1962) had participants carry out a digit cancellation task concurrently with an auditory monitoring task. In the digit cancellation task participants were required to cross out target letters on a sheet of letters. Also they were required to listen to a series of letters and were required to respond when a letter was repeated. Younger adults were able to maintain their accuracy on both tasks. However, older adults' performance was unaffected on the cancellation task but was poor on the monitoring task. Older adults found it difficult to switch between tasks so tended to concentrate on the cancellation task at the expense of the monitoring task. Older adults may find it more difficult to allocate resources effectively between the tasks, whereas younger adults find it easy to develop strategies to enable them to perform concurrent tasks.

Early work on dual task performance invariably demonstrated that older adults were more penalised than the young. Often put forward is the reduced attentional capacity account of normal ageing to explain older adults' poorer performance (e.g. Craik, 1977; see section 1.2.2). Wright (1981) examined the reduced processing capacity theory of ageing in more detail by examining older adults' dual task performance at different levels of difficulty. Digit span and verbal reasoning tasks were used in this study. Difficulty was manipulated in the digit span task by increasing the number of items to be held in memory. In the reasoning task, difficulty was manipulated by increasing the number of operations to complete a solution. The results demonstrate that older adults were poorer at dual tasking, particularly as task demands increased.

More recent research has questioned the idea that older adults have a dual tasking deficit. Somberg & Salthouse (1982) were the first to bring attention to methodological problems in dual task studies. They point to single task performance differences as a possible confound. The age difference in dual task performance may therefore be the result of differences in the component tasks. This is a common problem in cognitive ageing research as baseline differences in performance are usually found (Perfect & Maylor, 2000). In the divided attention literature one solution is to analyse proportional differences in performance (dual task cost analysis). The issue of baseline differences in performance is outlined in the methodological issues section 1.3.1.

Somberg & Salthouse (1982) were the first to examine dual task costs in older adults as a function of single task performance. They found strong evidence that older adults' performance on dual tasks was comparable to the performance of the young. Two experiments were carried out to eliminate the possible confounding effect of baseline differences in performance. In the first experiment, participants were required to make two manual responses to the presence or absence of a target in two visually presented arrays. Somberg & Salthouse controlled for the effects of baseline differences in participants' performance by manipulating single task characteristics according to each participant's competency. That is, stimulus durations were manipulated to equate the performance of all participants. This manipulation resulted in the absence of any age difference in dual task performance. However, it is questionable whether this method of eliminating the influence of baseline differences in performance is valid as it could be argued that the nature of the task changed with this type of manipulation. Similarly, if we were to equate task performance by giving older adults more practice it is arguable whether this is a sound method of equating performance as extensive practice might make performance more automatic and therefore produce findings that are difficult to interpret.

Somberg & Salthouse (1982) carried out a further experiment to see whether their finding would generalise to tasks where the dependent measure was response time rather than accuracy. In this experiment younger and older adults performed a manual reaction time task concurrently with a repetitive keying task. Obviously with reaction time tasks, the manipulation used in their first experiment is difficult and so the investigators controlled for baseline differences in performance statistically. This was achieved by transforming the raw reaction time data into a measure of dual task costs. In other words, the absolute difference between dual task and single task reaction time was divided by the single task reaction time score (a fuller discussion of controlling for baseline difference in performance will be given in the methodological issues section 1.3.1). They found that the significant age x condition (dual versus single) interaction was removed when the dual task costs analysis was carried out. Thus Somberg & Salthouse (1982) argued that there was no particular problem in dual task performance for the elderly; their poorer performance under dual task conditions is entirely in line with their poorer performance in the single task condition.

1.2.5 Age Differences in Dual Task Performance for Implicit Memory

With the introduction of more sophisticated methods of accessing dual task performance came the idea that older adults may not in fact have a deficit in dual tasking over and above the problems they already encounter on single tasks. A number of studies on the effect of age and divided attention on performance on implicit memory tasks has revealed similar results. Implicit memory refers to memory processes that draw on the effects of the prior exposure of stimuli without deliberate recollection. In other words, implicit memory refers to effects on performance caused by previous exposure to items even though you are not trying to consciously recollect those items.

Isingrini, Vazou, & Leroy (1995) carried out a study on the effects of age and divided attention on an implicit memory category exemplar generation task and an explicit memory cued recall task. The aim was to investigate a possible dissociation between the processes that mediate performance on the implicit and explicit memory tasks. The procedure involved an initial study phase where category exemplars were presented visually and participants were required to rate each item on how pleasant they found the meaning of the word on a five-point scale. A priming phase followed with category names being presented and participants required to write as many category exemplars belonging to the particular category. Half of the categories tested appeared on the study list and half of the categories were new. Cued recall was the final stage where category names from the original list were presented and participants were required to respond with the category exemplar that had been presented in the study list. In the dual task condition a consonant monitoring task was used at study. Participants were required to listen to a series of letters and respond vocally every time a consonant was heard. The data demonstrated that for cued recall, performance was particularly impaired by age and division of attention. However, there was no age or division of attention effect in the category exemplar generation task. This finding is consistent with the majority of research that has found no effects of age and divided attention for both conceptual and perceptual implicit memory tasks.

Clarys, Isingrini, & Haerty (2000) investigated the effects of age and divided attention on word stem (conceptual) and word-fragment (perceptual) implicit memory tasks. In this study it was found that dividing attention at study reduced the effect of repetition priming on the word stem completion task but not the word fragment completion task. This demonstrated that the processes involved in the two tasks are distinct. The results of this study suggested that automatic processes and controlled processes are involved in implicit memory. Word fragment completion tasks primarily involved data driven processes and word stem completion tasks require conceptual processing. What was somewhat surprising was that older adults did not perform differently on the two measures. The authors suggested that the data were inconsistent with a reduced attentional resource account of cognitive ageing since the more demanding word stem completion task did not bring about an age effect.

The two-process theory of memory (e.g. Jacoby & Dallas, 1981) suggests that two factors contribute to performance on memory tasks that is, effortful retrieval processes and a familiarity component. Familiarity seems to be an important influence on both conceptual and perceptual implicit memory performance and it has been suggested that the processes involved are spared with normal ageing. Since these processes may be carried out in a relatively automatic manner, interference from a competing task is likely to be minimal for both younger and older adults. We will turn to the effortful retrieval component of memory processing when we consider the influence of contextual information on memory performance in sections 1.2.6 (episodic memory) and 1.2.8 (semantic memory).

1.2.6 Age Differences in Dual Task Performance for Episodic Memory

The studies discussed earlier suggest that older adults find dual tasking no more problematic than younger adults. However, the tasks used in these studies were either relatively simple data driven tasks or tasks that may rely on automatic processing. In fact, Craik & Watkins (1973) reported findings suggesting a three-way interaction between age, divided attention and task complexity. When tasks comprise demanding central processes, rather than peripheral sensory processes, age effects emerge. Kieley (1991, reported in Hartley, 1992) carried out a meta-analysis on the dual tasking ageing literature and suggested that a large memory component within a task influences the magnitude of the age effect. In section 1.2.5 we found that on implicit tests of memory there is no requirement to form new connections between memory representations but connections are in fact strengthened. It may be that it is the additional contextual processing that older adults find problematic and perhaps under divided attention conditions performance is particularly impaired.

Consider episodic memory where it is necessary to form new connections between the to be remembered items and the context that they appeared. It has been widely reported that older adults have problems with episodic memory (e.g. Burke & Mackay, 1997). Episodic memory refers to memory for specific events occurring in a particular place at a particular time. Older adults are found to perform poorly on a variety of tasks involving recall and recognition. Furthermore, this is the case for practically any stimuli (see Burke & Light, 1981 for review). The size of the age effect is partly dependent on the difficulty of the tasks. For instance, manipulating the familiarity of the material to be remembered, the presentation rate of the material or perhaps increasing the number of items to be recalled will increase the age effect. Consequently, dividing attention when episodic memory is involved is likely to be particularly problematic for older adults.

Turning to dual task studies, Park, Smith, Dudley, & Lafronza (1989) carried out a study on the effects of a concurrent task on both encoding and retrieval from episodic memory. In the first experiment, younger and older adults studied female proper names concurrently with a number monitoring task. In the number monitoring task participants heard two-digit numbers at regular intervals and were required to respond manually when they heard an odd digit. As well as a single task condition, there were three dual task conditions. The number-monitoring task was performed at either the study phase, free recall phase or both. Older adults were poorer at recall when attention was divided at encoding but not at retrieval. Poorer performance dividing attention at encoding may be due to a less demanding retrieval phase, where the lack of time constraints enabled participants to easily switch between tasks. Therefore, a second experiment was carried out where a paced cued recall task replaced the free recall task. Again an age effect was only found at encoding. This result was somewhat surprising given the evidence in the literature that older adults find both encoding and retrieval from episodic memory problematic (e.g. Craik, 1986). One problem with these data is that the authors failed to control for baseline differences in performance.

Nyberg, Nilsson, & Olofsson (1997) found somewhat different results when they investigated the effects of age and division of attention during both encoding and retrieval from episodic memory. In this study participants were required to study words presented orally before a paced free recall phase. A card sorting distracter task was presented either at encoding or retrieval or at both. In the card sorting task participants were simply required to sort a standard pack of playing cards into two piles determined by colour. The authors examined whether there were any age differences in dual task performance by carrying out a multiple regression analysis to investigate whether age predicted performance after adjusting for single task performance differences. Converting raw scores into both ratio and difference scores controlled for age differences in baseline performance. In both analyses there was no age difference in performance. However, these results should be treated with caution since the secondary task was relatively simple in nature and its presence caused little interference for both age groups.

More recent research has gone further in explaining the mechanisms underlying dual task performance when encoding and retrieval from episodic memory is involved. Anderson, Craik, & Naveh-Benjamin (1998) carried out four experiments to investigate the attentional demands of both encoding and retrieval in younger and older adults. Using the dual task paradigm, the effects of divided attention on performance of free recall, cued recall and recognition were investigated. The results from these studies showed that divided attention at encoding disrupted memory performance equally for the young and the old. However, dividing attention at retrieval had either little or no effect on performance. The analysis of the secondary task costs revealed that concurrent processing demands at encoding was more disruptive for older adults. When attention was divided at retrieval, memory performance was unaffected. For the secondary tasks there was an age related increase in secondary task costs. The data suggested that overall older adults find concurrent processing demands problematic at both encoding and retrieval.

Anderson et al. (1998) based on their data proposed a distinction between attentional control and attentional resources. In younger adults it was found that memory performance was modulated by task emphasis instruction at encoding but not at retrieval. However, there were secondary task costs for both encoding and retrieval. These data suggested that encoding processes consume attentional resources and are under attentional control. At retrieval, although the processes are out of attentional control, they still consume attentional resources. The effects of concurrent task on memory retrieval are considered further in chapters 2 and 3. An examination will be made of both episodic and semantic memory retrieval. In addition, we will consider the effects of age and concurrent processing demands on memory retrieval and the effects of manipulating the amount of self-initiated processes required by the task.

1.2.7 Age Differences in Dual Task Performance for Prospective Memory

The memory literature has also covered older adults' ability to carry out an intended action in the future rather than remembering past experiences. This has been termed prospective memory and is of great ecological importance. The life style of older adults has resulted in the increase in research in this area. For instance, prospective memory is particularly important for an individual who has health related needs such as remembering to take medication (Einstein, Smith, McDaniel, & Shaw, 1997). Prospective memory tasks usually occur in the presence of some background activity so in a sense there is a dual tasking requirement. There is evidence to suggest that older adults have particular problems with prospective memory when the attentional demands of the primary activity are high. Einstein et al. (1997) carried out a series of experiments to investigate the effects of increasing task demands on prospective memory performance. In one experiment participants were required to carry out a prospective memory task at two levels of difficulty. In the easy condition, the background activity was rating words on various dimensions. In the harder of the conditions as well as rating words participants heard a series of numbers that they had to monitor for a target. The prospective component of the task was embedded in the word-rating task. The prospective encoding phase comprised the appearance of a target word in yellow. The retrieval phase was prompted by the reappearance of the target word in the normal colour. Participants were required to respond manually on a computer keyboard when the word reappeared. It was found that age differences in performance only occurred in the more demanding condition. The authors concluded that in the easy version of the task, even though older adults had fewer processing resources, both the young and the older adults' capacity was not reached. It was only when the attentional demands increased that an age effect emerged.

An earlier study by Einstein, Richardson, Guynn, Cunfer, & McDaniel (1995) attempted to explain the discrepancies in the prospective memory literature with regard to time and event based prospective memory tasks. Much like the literature on the effects of age and divided attention on episodic memory, the degree of environmental support influences performance. As discussed earlier it seems that older adults have problems with memory retrieval when self-initiated processes are required. In one experiment, participants were required to perform a time based prospective memory task. Participants were required to carry out a continuous memory span task within which the prospective task was embedded. The memory span task involved memorising a series of words and at times a signal would indicate that recall was required. While carrying out this task participants were required to hit a response key at ten minute intervals (self initiated retrieval). In another experiment an event based prospective memory task was used where an action had to be performed when a particular word appeared (cue driven retrieval). The procedure was identical to the previous procedure except one of the words presented in the memory span task acted as a cue for a response. It was found that like retrospective memory tasks when self-initiated processes are required (the time based task) age differences were found. However, for the event based task the word cue facilitated older adults' performance and no age effect emerged. Therefore, although older adults may find effortful retrieval processes problematic they are as capable when they can capitalise on environmental cues.

1.2.8 Age Differences in Dual Task Performance for Semantic Memory

Important in the human memory literature is the distinction between episodic and semantic memory. The effects of age and divided attention on episodic memory where participants are required to use demanding encoding and retrieval operations in the face of competing processing demands have already been considered. We consider now semantic memory and ask the question whether age and concurrent processing impairs performance much like that observed on episodic memory tasks.

Semantic memory is concerned with the general knowledge of facts without necessarily knowing when or where the fact was learned. This memory is reasonably stable and either small or no age differences in performance have been observed. Tulving (1972) first described the distinction between semantic memory that is concerned with the knowledge of words and concepts, and episodic memory that is concerned with both content and the context in which the memory was learned. Typically, performance on tests of semantic memory that tap well learned information show age equivalence. This has been demonstrated on tests of general knowledge, vocabulary and semantic priming tasks (Burke & Mackay, 1997). A fuller discussion of semantic memory and ageing is given in chapter 2 were we consider the effects of age and divided attention on episodic and semantic memory retrieval.

There has been little work on the effects of a concurrent task on semantic memory. However, one study has examined semantic memory retrieval in the context of a dual task and found dual task costs to be age invariant. Perfect & Rabbitt (1993) were concerned with whether the resource deficit model of cognitive ageing could be extended to the retrieval of overlearned material. Discussed previously was the study investigating encoding and retrieval from episodic memory (Anderson et al., 1998). The authors concluded that memory retrieval makes greater attentional demands for older adults.

However, it is unclear whether retrieval in general is problematic for older adults or just episodic memory retrieval. In Perfect & Rabbitt's study, middle aged and older adults' performances were compared on a dual task involving category exemplar generation and a choice reaction time task. The results from this study found that retrieval of overlearned information from semantic memory is in fact resource demanding and is dependent on the familiarity of the information to be retrieved. However, there was no support for the resource deficit model of cognitive ageing as manipulating the familiarity of the 'to be retrieved' information affected both groups in the same way.

Since no study has compared dual task cost for both episodic and semantic memory retrieval in the same experiment we consider this in chapters 2 and 3.

1.2.9 Age Differences in Dual Task Performance for Language Processing

In the previous section we discussed semantic memory which is closely related to language abilities. Semantic memory contains information about words, their appearance, what they represent and how they are organised. Like semantic memory the information and the processes involved may be so well learned they are resilient to concurrent processing demands. However, there are a number of reasons why older adults may find language processing problematic and increasing the demands of a language-processing task by introducing a concurrent activity may prove to be particularly difficult for older adults.

Both speech perception and language comprehension may be problematic. Speech is carried out in a rapid manner and since speed of processing declines in ageing, older adults may be particularly penalised. Language comprehension may also be difficult for older adults since working memory is required for the temporary storage of the incoming information and the integration of this information into words, followed by the organisation of the words into sentence which we can understand (Tun & Wingfield, 1993). Working memory has been found to be impaired in normal ageing (e.g. Wright, 1981).

There is good reason to believe that older adults would find language processing tasks problematic but they may be able to compensate for any general declines in speed of processing or working memory capacity by using familiar overlearned processes. One study by Gick, Craik, & Morris (1988) used the working memory paradigm designed by Daneman & Carpenter (1980) to investigate age differences in dual task performance when language processing was involved. Participants were required to verify a series of sentences and also keep in mind the final word of each sentence. A serial recall test was given at the end of the sentence verification task. To examine age differences in performance of the sentence verification task with concurrent working memory load, verification times, errors and recall errors were examined. There were no age differences in verification times and surprisingly there were fewer verification errors in the divided attention condition. Overall, participants' recall errors were reduced when they were required to carry out a concurrent verification task but this did not interact with age. Divided attention was an effective manipulation of task difficulty but the effect was the same for both age groups. These results are consistent with other studies using the working memory paradigm to investigate age difference in performance when language processing is involved (Wright, 1981; Morris, Gick, & Craik, 1988).

Tun, Wingfield, Stine, & Mecsas (1992) investigated the effects of age and division of attention on rapid speech processing. In the single task condition it was found that when speech rates were increased, older adults were differentially affected when they were required to immediately recall a spoken passage. However, the further requirement to divide attention did not exaggerate the effect. The authors concluded that increasing the demands of the task (by varying speech rate) and increasing the demands by the requirement to divide attention are independent and do not necessarily bring about the same effect.

One theme of this thesis is the distinction between difficulty or complexity and domain effects. The review so far has identified task difficulty and task domain as possible moderator variables of dual task costs in older adults. Although difficulty may account for a great deal of the discrepancies in the literature with regard to age difference in dual task performance, domain is also an important moderator variable. Although language processing can be considered a complex activity, it is a domain that has special status among cognitive abilities (Tun & Wingfield, 1995). The processes involved may be so overlearned that they are largely automatic in nature. They may also be relatively independent of other processes so concurrent activities have little effect for the young or the old.

1.2.10 Training Studies of Dual Task Performance

In the previous section we outlined how familiarity has an impact on dual task performance. When tasks are highly familiar the presence of a concurrent activity has little effect on dual task performance. However, for novel or effortful dual tasks older adults are particularly impaired. The focus in this section is whether practice or training can compensate for this poorer performance. In earlier sections we have discussed how older adults benefit a great deal from environmental support. Environmental support through training may reduce or eliminate ageing effects. If practice is effective in compensating for older adults' poorer performance this has practical implications. We outlined how dual task skills are important in situations such as driving so this research seems particularly important because of its everyday applicability.

There are two issues in the dual tasking training literature that are particularly important in the current investigation. First, although older adults may have problems dual tasking this may just be because such activities are unfamiliar and perhaps the elderly could benefit from practice and training on such activities. Second, training studies could help answer whether dual tasks are nothing more than a complex single task. Kramer et al. (1995) suggest that if dual task specific training and transfer effects were demonstrated, we could conclude that dual tasking involves additional processing operations over and above those required for the component tasks.

McDowd (1986) investigated the effects of age and extended practice on dual task performance and found that practice did not remove the age effect. In this experiment younger and older adults performed two perceptual-motor tasks under both single and dual task conditions. After six one-hour sessions, absolute levels of performance improved for both groups. However, divided attention costs were higher for older adults across each of the six sessions. This suggested that the age difference in dual task performance was not caused by insufficient practice on the component tasks and practice led to equivalent improvements for both the young and the old. However, the conclusions were questionable, as both younger and older adults did not reach their asymptote therefore, with further practice the age effect might have disappeared.

Baron & Mattila (1989) argued that rather than older adults' poorer performance being due to a reduction in cognitive resources with increased age, poorer performance was a consequence of under use of cognitive resources. Therefore, it may be the case that if older adults are subjected to extensive practice their performance may improve and approach the levels of younger adults. Younger and older participants were given extended practice on a memory scanning task that involved the presentation of visually and auditory items either on their own or concurrently with a second visual and auditory list. There was a greater degree of slowing for older adults particularly when a dual task requirement was introduced. However, the age difference in performance was reduced after extensive training where time limits were placed on responding, and thus gave support for the disuse theory of ageing. However, the effect was not completely removed and thus provides evidence that older adults have particular problems in dual tasking. One concern with this study is that the effects were in terms of absolute levels of performance.

In the dual task literature two different training strategies have been employed. Kramer et al. (1995) examined the efficacy of both variable priority and fixed priority training on dual task performance for both younger and older adults. With variable priority training participants are required to continually shift their emphasis between tasks. In fixed priority training participants are instructed to concentrate on each task equally across trials. In Kramer et al.'s (1995) study younger and older adults were trained on a target cancellation task concurrently with a one dimensional pursuit tracking task. Each of these tasks were performed separately and together. After training, participants were transferred to a different version of the tracking and cancellation task and also to a monitoring and alphabet arithmetic task. As before, tasks were performed separately and together. It was found that, using the variable priority training, rate of learning and ability levels results from two factors. First, training led to the component tasks being performed in a more automatic manner. Second, training enabled the development of effective task co-ordination skills enabling the management of the component tasks. That is, training effects were larger in the dual task than the single task conditions and also when participants were required to use these dual task skills on a novel dual task there were considerable benefits. With respect to ageing, the investigators found mixed results but certainly under certain dual task conditions training can narrow or even eliminate age differences in dual task performance. The results were not congruent with an account suggesting that a dual task is nothing more than a more complex single task, as training benefits were larger for the dual task conditions. Furthermore, after the investigators carried out a complexity analysis much like that carried out by McDowd & Craik (1988) slopes and intercept were not the same (see section 1.2.2). The authors suggested that their results could be explained in terms of additional processing operations being involved in dual task co-ordination. They suggest that such management and co-ordination processes are the responsibility of the frontal lobes, which decline with age.

1.3 Methodological Issues

There has also been a great deal of methodological criticism with regard to the dual tasking literature (see Somberg & Salthouse, 1982; Salthouse, Fristoe, Lineweaver, & Coon, 1995). McDowd et al. (1991) bring attention to participant characteristics, task characteristics and data collection procedures as factors that should be considered closely in dual tasking studies. Previously, ageing research has identified educational background and crystallised intelligence as possible sources of covariation. It is necessary to report such information and include them as covariates in any analyses carried out. For instance, in this thesis we gather details of participants' years of education and National Adult Reading Test (NART) scores. Also, largely ignored is a fuller description of the task characteristics and how they influence performance. McDowd et al. finally encourage more details of data collection. For instance, was sufficient practice given to older adults so their performance was stable and they fully understood the task requirements?

1.3.1 Controlling for Baseline Differences in Performance

Manipulation of Task Parameters

The main methodological criticism lies in the methods used to control for baseline differences in performance. Older adults invariably perform more poorly on a variety of tasks and as a result these differences must be considered when we evaluate older adults' performance on dual tasks. To eliminate the potential confounding effect of baseline differences in performance, two approaches have been taken. A number of researchers have manipulated task parameters and equated single task performance. For instance, Baddeley (1996) required participants to carry out a tracking task concurrently with memory span task. The difficulty of the tracking task (speed of movement of target) and the length of the sequence of digits were adjusted to equate performance between groups when the tasks were performed alone. In a similar vein, Somberg & Salthouse (1982) directly controlled for baseline differences in performance by adjusting stimulus duration to equate the difficulty of the tasks. Another means of equating task performance between groups is by giving older adults extra practice on the single tasks until their performance matches that of the younger adults. Lipps-Birch (1978) used just such a procedure to investigate dual task performance difference between children and young adults. However, this procedure can be criticised as extra practice on the experimental task could make task performance more automatic and produce misleading results (Somberg & Salthouse, 1982). Although equating task performance is appealing it is often difficult or time consuming to determine the most reliable measure of single task performance. Also, if we alter the task parameter to equate performance it could be argued that age comparisons are unreliable as the nature of the task has changed.

Statistical Control for Baseline Differences in Performance

The second approach that is more often used to control for baseline differences in performance is statistical control. There have been two different metrics widely used to index dual task costs in the literature, that is absolute differences (dual task score minus single task score) and proportional differences ([dual task score minus single task score]/ single task score). It is arguable which method is more appropriate in the analysis of dual task performance and most researchers adopt a particular method without justification. In this research we were concerned with whether older adults have a disproportionate deficit in dual tasking. A significant age by condition interaction (single versus dual) gives some suggestion of a proportional age effect but since this interaction is based on the absolute differences in performance this is not necessarily the case (see Perfect & Rabbitt, 1993). Therefore, Somberg & Salthouse (1982) advocated the use of proportional difference scores to control for baseline differences in performance.

Previously we have mentioned that this research is concerned with whether older adults have a dual task deficit over and above the problems encounter on single tasks. If participants differ in their performance under single task conditions, it is likely they also differ in the proportion by which task difficulty increases by having to do a concurrent task. Participants who perform poorly in the single task conditions might be close to their performance limits, so in the more difficult dual task condition you would expect a greater impairment. Therefore, in order to control for baseline differences in performance proportional dual task costs are our focus. This is the most common metric used in the literature and it can be argued that it is the most valid method of controlling for baseline differences in performance.

A further theoretical justification for using proportional change scores rather than absolute differences in performance is related to earlier discussion on the slowing complexity hypothesis. In this thesis we were concerned with whether older adults have a specific deficit in dual tasking and it could be argued that an analysis of anything less than proportional differences could be accounted for by the generalised slowing model of ageing. In other words, the slowing complexity hypothesis predicts that older adults' response times will be proportionally slower than younger adults no matter under single or dual task conditions. For example, Somberg & Salthouse (1982; see section 1.2.4) found age differences in dual tasking when absolute differences in performance were analysed. However, the age effect was removed when proportional differences were considered. These results suggested that the slowing complexity hypothesis can account for age differences in dual task performance and a dual task is nothing for than a more complex single task. In this thesis we argue that the slowing complexity hypothesis and task difficulty accounts of age differences do not go far enough. If disproportionate differences are observed, other possible explanations for older adults' poorer performance must be pursued such as a specific deficit in executive control.

1.3.2 Task Characteristics

We observed in the experimental evidence section that there has been considerable variation in the types of tasks used in dual task comparisons (e.g. simple perceptual, memory and motor tasks). What is necessary is a systematic examination of dual task performance across a range of dual tasks. In this thesis we consider performance across a number of task domains in order to add to the database of findings on age differences in dual task performance. In chapter 3 we develop a new paradigm to examine age differences in dual task costs. This eliminates the problems of comparing results across studies where different paradigms have often been used. We will argue that although dual task performance is perhaps dependent on the difficulty of the component tasks, this is not the whole story and task domain is a critical factor.

1.3.3 The Problem of Task Trade-offs

Another problem with using the dual task paradigm is individual differences in task trade-offs. It is difficult to know what emphasis each individual places on the two tasks in the dual task activity. An age effect might or might not be observed simply because younger and older adults differ in the relative emphasis they place on each task. Salthouse et al. (1995) identified a number of solutions to the problem of individual differences in task trade-offs. It is not enough just to assume each participant performs the dual task in the same way. An elaborate way of dealing with this potential problem is to construct attentional operating characteristics for each subject. Norman & Bobrow (1975) were the first to introduce performance operating characteristics (POC). The emphasis participants place on each of the two tasks is manipulated by reward or instruction to produce a POC function. A POC function has an advantage over a single data point in that we are able to separate the effect of different resource allocation strategies and age differences in actual divided attention ability. Unfortunately, this type of analysis is time consuming and it is undesirable, as prolonged testing session will lead to fatigue. This may particularly influence older adults' performance.

In chapter 2 we minimise task trade off effects by emphasising one of the tasks. In addition we carry out a correlational analysis between tasks to investigate whether there are any age differences between performance of the primary and secondary tasks. In the remaining studies dual task performance is examined within the context of a single task. A new paradigm is developed that eliminates the potential problem of task trade off effect.

1.3.4 Alternatives to the Dual Task Paradigm

A number of other paradigms have been used to investigate older adults' ability to co-ordinate multiple tasks or processes. We have discussed early work on simultaneous processing and it was found that older adults have problems performing multiple processes in a parallel manner. More recent research has examined dual task performance in the context of a single task. For instance, in section 1.2.9 we described the working memory paradigm designed by Daneman & Carpenter (1980). This has been used to investigate age difference in dual task performance when language processing abilities are involved. In this procedure, participants are required to undertake a sentence verification task while concurrently keeping in mind a series of words. While verifying sentences participants are required to keep in mind the final word of the sentences for later recall.

In chapter two we use the dual task paradigm to investigate age differences in dual task performance. It will be shown that differences in task trade-offs makes interpretation of results problematic even though an attempt was made to minimise such problems. Furthermore, dual task interference could result from an overlap in the processes involved in making two separate responses to the component tasks. Therefore, in chapter 3 the n-back procedure is introduced in an attempt to minimise the potential problems of individual differences in trade-offs and to examine the more central aspects of dual task co-ordination. The n-back procedure involves

1.4 Overview

A series of experiments will be carried out to examine older adults' performance across a range of dual tasks. We begin by examining whether tasks that rely on more central processes such as memory result in substantial age differences in dual task performance.

Using the traditional dual task paradigm, in experiment 2.1 an investigation is carried to see whether older adults are poorer at dual tasking when memory retrieval is involved. Previously identified are two possible reasons for why disproportionate costs are only found in certain circumstances. We ask the question whether task difficulty or task domain moderates age differences in dual task performance. That is, we compare dual task performance for both episodic and semantic memory retrieval at different levels of difficulty. In experiment 3.1 we further examine the cost of dual tasking when episodic and semantic memory retrieval is involved. This study particularly addresses some of the methodological issues raised in experiment 2.1. In experiment 3.1 evidence is presented for domain differences in dual task effects. Obviously, age and domain differences in dual task performance may be specific to the tasks used in experiment 3.1. Therefore, experiment 3.2 was carried out to replicate these findings using a different set of dual tasks. In addition, we were concerned with the issue of familiarity and whether this mediates task performance. In this experiment recognition versions of the dual tasks are employed to investigate whether increasing environmental support reduces the age effect.

In experiment 4 and 5 we further examine age differences in dual task performance for tasks involving the retrieval of familiar over-learned material. The n – back procedure developed in experiment 3.1 was again used. Based on the data obtained in experiment 3.1 for semantic memory retrieval, we expected age invariance for dual tasks involving familiar material.

It has been argued that when dual tasks involve peripheral, sensory processing no or only small differences in performance are observed. However, when visuospatial tasks involve the interaction between peripheral sensory processing and high order cognitive processing such as attention and memory, the performance of older adults may be impaired. Since everyday activities such as driving involve visuospatial abilities and dual task performance, we were concerned with whether older adults find these situations problematic. In experiment 6.1 and 6.2 investigations of visual spatial dual task are carried out.

We conclude by carrying out a meta-analysis of dual task ageing studies to see whether the age effect is robust and whether on overall effect size best describes the data across studies. Furthermore, it was of interest to see whether the present data fit well with previous findings.

2. Using the Dual Task Paradigm to Investigate Age Differences in Retrieval from Episodic and Semantic Memory

2.1 Introduction

The focus of this chapter will be on the effects of concurrent processing demands on memory retrieval. This is an important line of inquiry as we are constantly encoding and retrieving information in the presence of competing activities. For instance, when we are attempting to remember which route to take while driving a car, we may be also attending to a traffic report on the radio. Furthermore, a large body of research has suggested that memory processes demand more cognitive effort for older adults (e.g. Rabinowitz, Craik, & Ackerman, 1982). Therefore, the introduction of a concurrent activity is likely to be more detrimental to older adults' memory retrieval performance. The present experiment was carried out to answer three questions. First, is domain an important moderator variable of dual task costs in older adults? This was achieved by examining both episodic and semantic memory retrieval. A number of authors (e.g. Tsang & Shaner, 1998) have suggested that it is only when the attention demands are high that older adults have problems in dual tasking. Therefore, the second question was: does increasing the difficulty of the secondary tasks lead to greater dual task costs for older adults? Finally, if older adults exhibit a dual task deficit would this remain after controlling for baseline differences in performance? In other words we were interested in whether task difficulty or task domain best explains disproportional dual task costs in older adults.

2.1.1 Episodic and Semantic Memory Retrieval in Older Adults

Memory retrieval has been identified as a major reason for poorer memory performance in older adults (Burke & Light, 1981). However, more recent research has gone further by examining this issue in more detail. For instance, although age related differences in memory retrieval have been observed on episodic memory tasks, the size of the age effect differs depending on the particular paradigm being used. Typically, older adults suffer the greatest impairment on tests of free recall compared to cued recall, and only small differences are found in recognition memory. This has been explained in terms of the environmental support hypothesis (Craik, 1986).

Craik (1986) describes the distinction between those tasks that rely primarily on self-initiated process (e.g. free recall) and those tasks that draw on environment cues to aid performance (e.g. recognition). It has been suggested that self-initiated processes are particularly effortful and resource demanding and since older adults are presumed to have fewer processing resources, tasks that require such processes are likely to be performed less well. Rabinowitz (1984) investigated recognition memory and described retrieval processes and familiarity as factors contributing to memory retrieval performance. The more familiar the material the less effortful retrieval processes are required. In addition, a number of authors have made the distinction between item memory and contextual memory. Age differences are typically found on measures of context memory compared to item memory (Newman, Allen, & Kaszniak, 2001). It has been suggested that familiarity and relatively automatic retrieval processes are involved in item memory. However, context memory uses effortful retrieval processes related to frontal lobe functioning (Cabeza, Anderson, Houle, Mangels, & Nyberg, 2000).

In a similar vein, semantic memory involves familiar material and since no recollection of a previous learning event is required, none or only minimal age differences in performance are expected on semantic memory retrieval tasks. Older adults' performance on the vocabulary and information subsets of the Wechsler Adult Intelligence Test (WAIS) and the National Adult Reading Test (NART) suggests that retrieval from semantic memory is less impaired compared to the retrieval of recently acquired information (e.g. Crawford, Deary, Starr, & Whalley, 2001; Kaufman, 2001). Such measures of performance have been used as indicators of crystallised intelligence which has been shown to remain stable across the life-span or even show slight improvement (e.g. Salthouse, Fristoe, & Rhee, 1996).

Another study that suggests that semantic memory processes are preserved in normal ageing was carried out by Light & Anderson (1983). They compared performance of older adults on memory for scripts. Scripts refer to a representation of stereotypical action sequence stored in long term memory. Participants were required to listen to a story about a character that performed a number of activities over a series of days. While listening they were also required to follow along with a written version of the story. In the recall phase participants were presented with an activity the character had carried out and asked to list as many things that had occurred in the activity. In the recognition phase participant were again presented with an activity that the character had carried out along with a list of items that did or did not appear in the activity. Participants were required to identify the items that did appear in the activity. Age differences in recall and recognition performance were observed. However, there was no evidence of age differences in the retrieval of semantic knowledge (stereotypical script information) to aid inferences made about action carried out in the stories. That is, both age groups produced recall intrusions that were typical of items produced in script generation. Also, both age groups made more false alarms for typical items. In terms of episodic memory as indexed by recall and recognition accuracy there were clear age effects. However, there was no evidence of age differences in use of semantic memory as typicality effects were similar for both groups.

A similar pattern occurs for word association that is regarded as a good measure of the organisation and availability of semantic memory. Burke & Mackay (1997) report that when word association responses are matched for verbal IQ and education, responses are similar for younger and older adults.

2.1.2 Dual Task Studies of Memory Retrieval

There is some suggestion that memory retrieval is particularly problematic for older adults, particularly episodic memory retrieval. Consequently, under conditions of divided attention we may expect to find disproportionate costs of dual tasking involving episodic memory retrieval for older adults. However, previous research on the effects of age and division of attention on episodic memory retrieval has produced mixed results. Macht & Buschke (1983) investigated the costs of dual tasking for free recall. Participants were required to perform a free recall task concurrently with a reaction time task to visual signals. The authors hypothesised that memory retrieval would require more cognitive effort for older adults. In that study both age groups were able to maintain their memory performance but older adults' secondary task costs were greater. These data are consistent with the idea that memory retrieval is resource demanding and older adults have fewer resources to deploy to the effortful retrieval processes.

A more recent study by Anderson et al. (1998) examined the effects of age and divided attention on encoding and retrieval in free recall, cued recall and recognition in more detail. The authors were particularly interested in the distinction between attentional resource and attentional control. For episodic memory encoding, typically performance is affected by concurrent task (e.g. Baddeley, 1984) and also secondary task performance is impaired (e.g. Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). These data suggest that encoding operations are effortful for both groups and require attentional resources. Evidence that encoding operations are also under cognitive control is based on task emphasis effects. When the memory task performance is emphasised performance falls in the secondary task and when participants are asked to emphasise the secondary task performance falls on the memory task. The pattern of results for episodic retrieval is somewhat different. Retrieval performance is largely unaffected by concurrent task and insensitive to task emphasis manipulations. However, performance on the secondary task is impaired so although retrieval seems to be relatively automatic, retrieval operations do draw on cognitive resources.

Anderson et al. (1998) found for both age groups cued recall performance and recognition retrieval performance was unaffected by divided attention manipulation. For free recall there was an age effect for absolute measures of performance but this was small compared to the age effect found at encoding. However, secondary-task reaction times were considerably slowed for the older adults at retrieval which suggests retrieval makes greater attentional resource demands for older adults. From these results, Anderson et al. (1998) concluded that retrieval is obligatory for all age groups. Despite this, retrieval still makes greater attentional demands for older adults, as indexed by a secondary task performance decrement. Retrieval may not be under attentional control but still requires cognitive resources.

However Anderson et al.'s (1998) conclusion that ".... retrieval makes greater demands on attentional resources for older than younger adults." (p. 419) is too generalised because they did not study retrieval from semantic memory. Perfect & Rabbitt (1993) investigated whether the resource deficit model could be extended to the retrieval of over-learned familiar material. We have already noted that the resource deficit model of ageing proposes that increased age is accompanied by a global reduction in processing resource. Furthermore, for episodic memory it has been observed that effortful retrieval processes consume attentional resource, and older adults are impaired due to insufficient capacity. Perfect & Rabbitt (1993) had participants carry out a category exemplar generation task alone or with an auditory reaction time task. The difficulty of the category exemplar generation task was manipulated by requiring participants to either generate frequent or less frequent category exemplars. The secondary task costs were found to be greater when less frequent category exemplars were used. This demonstrated that semantic retrieval was effortful but the costs were equivalent for both groups even when difficulty was increased. This led them to suggest that retrieval in general may not be difficult for older adults. Therefore, the findings of age invariance for both the easy and the difficult categories argued against the idea of task difficulty. So although the retrieval task was demanding there was no differential impairment. Thus, it may be the case that it is retrieval from episodic memory that is particularly difficult for older adults, rather than retrieval in general. However, Perfect & Rabbitt (1993) did not include an episodic retrieval condition, and hence, this hypothesis remains to be tested.

2.2 Experiment 2.1

2.2.1 Introduction

The first experiment in this thesis examined two kinds of memory retrieval task: an episodic paired-associate task and a semantic category-exemplar-generation task. The traditional dual task paradigm was used to investigate dual task performance. That is, error rates and response latency were taken on the retrieval tasks when they were performed alone and when they were performed concurrently with a secondary task. In addition to examining task domain (episodic versus semantic retrieval) we investigated the effect of increasing the demands of the dual task. Two secondary tasks were included to provide different levels of difficulty. Again, error rates and response times were taken when the secondary tasks were performed alone and concurrently with the retrieval tasks.

The inconsistencies in the literature with regard to whether older adults have particular problems in dual tasking are partially due to methodological weaknesses (e.g. Salthouse et al., 1995; Somberg & Salthouse, 1982). The potential problems of baseline differences in performance confounding any interpretation has already been outlined, and this will be addressed by carrying out a dual task costs analysis on the data. So, rather than the focus being on the absolute differences in performance we were primarily concerned with proportional differences, in memory tasks, and secondary tasks.

If task domain is the critical moderator variable, it is expected that age differences in dual task costs would be observed for the episodic paired associate task only, since deficits in episodic abilities have been consistently found. Semantic memory is relatively well preserved in old age and the effect of a concurrent task on retrieval performance and visa versa is likely to be less dramatic. If task difficulty is critical, which the majority of the literature suggests, there will be greater dual task costs in the high load conditions, and task domain will be irrelevant, other than perhaps a greater dual task cost for the harder retrieval task.

2.2.2 Method

Participants

Sixteen younger adults (range 18-29, mean age 20.5, SD 3.1 years) and sixteen older adults (range 62-81, mean age 74.1 years, SD 5.8 years) participated in the experiment.

The young volunteers were undergraduate students from the University of Bristol. The older adults were volunteers selected from a pool of older adults registered with the Experimental Psychology Department. On average the younger adults were better educated than the older adults (15.4 versus 12.9 years of education respectively, $t (29) = 3.4$, $p < 0.01$). Older adults scored more highly than younger adults on the National Adult Reading Test (raw scores of 42.1 and 37.6 respectively, $t (29) = 2.5$, $p < 0.05$). Both the National Adult Reading Test scores and years of education were entered as covariates in the main analyses.

Materials

Categories and category members were selected from the Connecticut norms for responses to category names (Marshall & Cofer, 1970). Results from a pilot study demonstrated that when category members were selected from the most frequent responses, the participants' performance was at ceiling level. Therefore, the two most frequent category members from a particular category were excluded from the selection of the stimulus lists. The next most frequent category exemplars from 20 categories were used to create 6 lists of 10 category – member pairs (e.g. Animal – Horse). The paired associates were constructed from high imagery (score equal to or greater than 300), high frequency words (greater than 100 occurrences per million), between four and seven letters in length, selected from the MRC Psycholinguistic Database (Coltheart, 1981). Six lists of 10 word-pairs (e.g. Fast – Staff) were constructed. Each list was produced so that as far as possible the mean word length, imagability and frequency were equivalent. The complete list of category – member pairs and word pairs are shown in Appendix A. Stimuli were presented on a 14-inch monitor in 36 point Arial font.

Procedure

Prior to the experimental session each participant received detailed instructions regarding the nature of the tasks (Appendix B). A pictorial representation of the primary (episodic paired associate or category exemplar generation) and secondary (mental arithmetic or digit monitoring) single tasks and the dual task (combinations of either of the primary and either of the secondary tasks) conditions accompanied the instructions (see figure 2.1 for example). Participants were required to demonstrate to the experimenter that they understood the instructions by talking through the printed examples.

In order to ensure that participants understood the requirements of the tasks, a practice session of one block was given for each single task and the dual tasks. In the experimental block there was one session of each of the primary tasks (episodic and semantic retrieval tasks), secondary tasks (digit monitoring and arithmetic tasks) and one session of each of the dual tasks. Each single and dual task session were presented in a counterbalanced order. Each of the six category – member pair lists and word pair lists were as far as possible assigned randomly to each condition.

An example of the procedure is shown in Figure 2.1. Displayed are the single and dual task episodic memory conditions.

Single Tasks

Mental arithmetic (Low Working Memory Load)

In the low working memory load task a series of five digits, between zero and three, appeared in the centre of the computer screen at 3 second intervals. The participants were required to keep a running total of the digits until a sixth digit appeared. The sixth digit was presented with a red background, which served as a prompt for a response.

The participant was required to decide whether the sixth digit was the same as their running total. A response was made on a pushbutton console. Responses were made with the left and right index fingers to buttons marked 'yes' or 'no'. The right hand button was marked 'yes' and the left 'no' for half the participants and the opposite for the other half of the participants. A further three sequences (4 blocks in total) of digits followed and again the participants were required to respond as quickly and as accurately as possible on the response console. Pilot work indicated that the demands of this task were low in comparison to the digit-monitoring task described below. Although participants had to perform mental addition they were only required to keep in mind a single digit (the current total) at any one time. However, in the digit-monitoring task (high load) participants were required to keep in mind five digits.

Digit Monitoring (High Working Memory Load)

In the high load condition, the task was identical to the low working memory load condition with two modifications. On this occasion the digits were between zero and nine. The participants on this task were required to keep in mind the sequence of five digits until the prompt. When the prompt appeared they were required to decide whether this digit had appeared in the previous sequence. The participants were required to respond as quickly and as accurately as possible on the response console. A further three sequences of digits followed and again participants were required to respond as quickly and as accurately as possible on the response console.

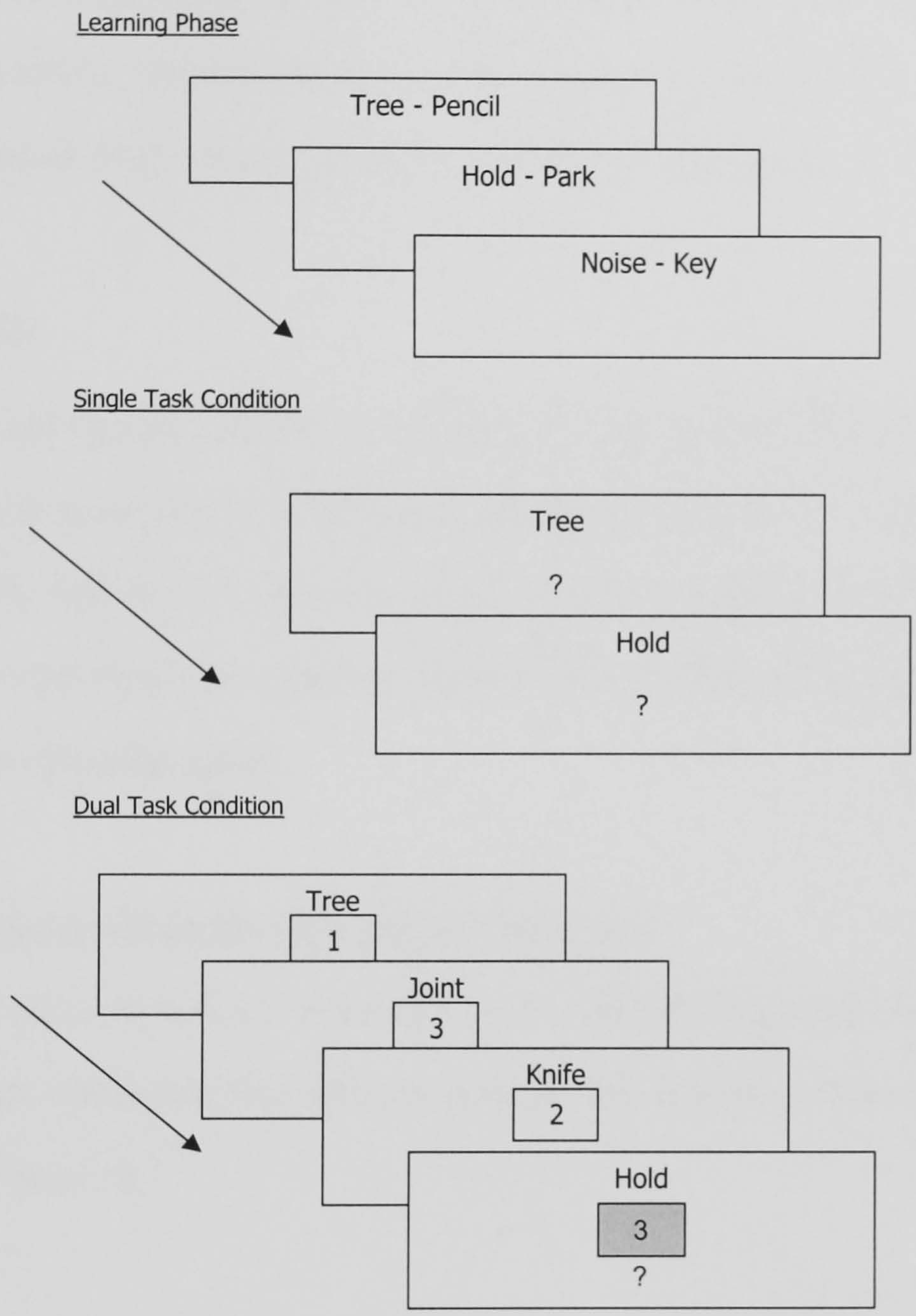
Semantic Memory Task

The semantic memory task consisted of the presentation of a category name and a category exemplar cue. The category name (e.g. Animal) appears on the computer screen with a partially completed category exemplar cue (e.g. H****), underneath. The first letter of the category exemplar was provided and asterisks replaced each of the missing letters. Participants were instructed to respond verbally with an appropriate category member as quickly and as accurately as possible with a maximum time limit of six seconds. Participants had to produce a category member that started with the specified letter and was exactly the correct length. Category cues were presented at six second intervals. No feedback was given and the final category member response made during the six second interval was recorded by a pushbutton operated by the experimenter. This final response was used in the analysis.

Episodic Memory Task

The procedure for the episodic task was identical to the semantic task, except that episodic retrieval cues were used instead of category retrieval cues. The episodic retrieval cues referred to a set of paired associates which were presented in an initial training phase. In the training phase the word pairs were re-presented for four trials or until participants were able to recall at least seven of the 10 words. The word pairs were re-presented in the same order. All participants reached criterion within four presentations of the word lists. In the learning phase the pairs of words were individually presented in the centre of the screen at seven second intervals. In the test phase the first word of each pair was presented on the screen with a question mark underneath. The participants were required to respond vocally as quickly and as accurately as possible with the second word of the pair.

Fig. 2.1 Example of the procedure – Episodic memory retrieval single and dual task conditions



Dual Tasks

The procedure for the dual task condition involved the simultaneous performance of the memory load tasks and the memory retrieval tasks. For example in the semantic memory task under low working memory load conditions a category name and category exemplar cue would be presented on the screen at regular intervals. The digits in the secondary working memory load task would be presented on the computer screen between the category name and category exemplar cues. Participants were required to respond orally with the appropriate category exemplar, while keeping a running total of the digits, and responding appropriately on the pushbutton console when required.

2.2.3 Results

Because the age groups differed in education and vocabulary ability, these measures were entered as covariates in all analyses. However, as neither covariate was significant in any analysis, they are not discussed further. Post-hoc analyses were conducted using the Bonferroni procedure (e.g. Seaman, Levin, & Serlin, 1991) with a significance level of $p<0.05$ unless otherwise stated.

<u>Analysis of Absolute Response Time and Error Rate Data</u>

The absolute response time and error data for no load, low load (mental arithmetic) and high load (digit monitoring) for both the episodic and semantic memory retrieval tasks are shown in Table 2.1.

Table 2.1 Mean (and SD) response latency (in msec) and errors for the episodic paired associate task, and the semantic category exemplar generation task, under no load, low load (mental arithmetic), or high load (digit monitoring) conditions

	Retrieval Task							
	Paired Associates				Category Exemplar Generation			
	Response latency		Errors /10		Response latency		Errors /10	
	M	SD	M	SD	M	SD	M	SD
Younger Adults								
No Load	2304	503	1.7	1.6	3000	529	3.8	1.2
Low Load	3005	628	3.2	1.8	3100	504	5.0	1.1
High Load	2793	348	3.6	1.5	3262	713	4.4	1.4
Older Adults								
No Load	3175	750	3.4	2.3	3280	580	3.5	1.8
Low Load	3395	359	6.1	2.0	3553	546	6.3	1.3
High Load	3514	675	6.0	2.1	3395	745	5.8	1.6

The first set of analyses was carried out on both the absolute response time and error rate data for memory retrieval. Memory retrieval response times were analysed in a 2 (Age Group) x 2 (Memory Task) x 3 (Working Memory Load: Mental Arithmetic versus Number Monitoring) analysis of variance. This analysis revealed that response times were generally slower for older adults ($F(1,27) = 19.49$, $p < 0.01$, $MSE = 556019$), were longer in the semantic task ($F(1,27) = 8.05$, $p < 0.01$, $MSE = 364741$) and were slowed by working memory load conditions ($F(1,54) = 6.57$, $p < 0.01$, $MSE = 323452$). Post hoc comparisons using the Bonferroni procedure indicated that there were significant differences between memory retrieval response times in both of the working memory load conditions compared to the no working memory load condition. Overall, there was no difference between the low and high working memory load response times. All interactions were not significant.

An equivalent analysis of variance was conducted on the error rate. This analysis showed that older adults produced more errors ($F(1,29) = 17.46$, $p < 0.01$, $MSE = 6.69$), error rates were greater in the semantic memory condition ($F(1,29) = 5.63$, $p < 0.05$, $MSE = 5.33$) and errors increased with working memory load ($F(2,58) = 63.2$, $p < 0.01$, $MSE = 1.28$). Post hoc comparisons using the Bonferroni procedure indicated that errors were greater in the working memory load conditions compared to the no working memory load condition. Overall, there was no difference between the error rates in the low and high working memory load conditions. The interaction between working memory load and age group ($F(2,58) = 6.59$, $p < 0.05$, $MSE = 1.28$) showed that the older adults were more penalised when retrieving from long term memory with a concurrent working memory load. In addition, the interaction between memory task and age group ($F(1,29) = 5.02$, $p < 0.05$, $MSE = 5.33$) demonstrated that overall the older adults' error rates were the greater in the episodic memory task compared to younger adults' error rates. All other interactions were not significant.

Table 2.2 Mean (and SD) response latency (in msec) and errors for the mental arithmetic, and the number monitoring task, under single task and presence of primary memory retrieval task conditions

	Secondary Task							
	Mental Arithmetic (low load)				Number Monitoring (high load)			
	Response latency		Errors /4		Response latency		Errors /4	
Memory Task	M	SD	M	SD	M	SD	M	SD
Younger Adults								
None	1173	271	0.44	0.51	1336	246	0.50	0.63
Episodic	1327	238	1.19	0.70	1607	221	1.19	0.75
Semantic	1470	279	0.75	0.68	1821	371	1.56	0.73
Older Adults								
None	1938	473	0.47	0.64	2109	378	0.33	0.62
Episodic	2685	1007	1.40	0.91	2397	938	1.80	0.77
Semantic	2392	487	1.60	0.63	2466	644	1.30	0.97

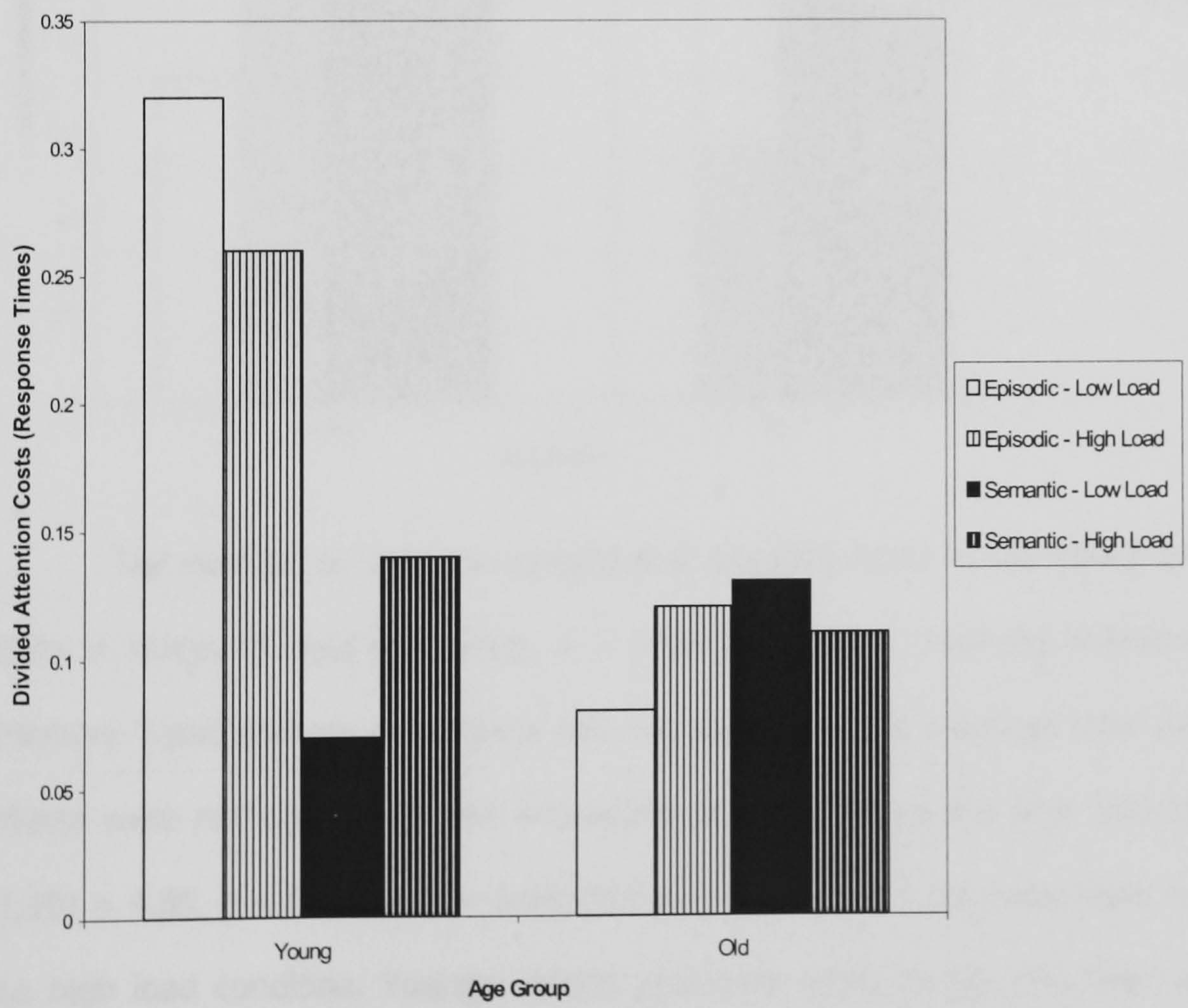
The absolute response time and error data for mental arithmetic and digit monitoring secondary tasks are shown in Table 2.2. In order to investigate the effects of the primary task on the two working memory load tasks a 2 (Age Group) x 2 (Secondary Task) x 3 (Memory Task) analysis of variance was conducted on secondary task response times. This analysis showed that response times were generally slower for older adults ($F(1,29) = 56.28$, $p < 0.01$, MSE = 632458), were longer in the number monitoring condition ($F(1,29) = 4.31$, $p < 0.05$, MSE= 169381) and slower when secondary tasks were performed concurrently with a memory retrieval task ($F(2, 58) = 10.82$, $p < 0.01$, MSE = 279806). The interaction between secondary task and age group was significant ($F(1,29) = 5.34$, $p < 0.05$, MSE = 169380). Post hoc comparisons using the Bonferroni procedure revealed no difference between secondary task response times for older adults. For younger adults, response times were slower in the high load condition. This somewhat surprising interaction and its relationship to older adults' poorer error rates is discussed in section 2.2.4. All other interactions were not significant.

An equivalent analysis of variance was conducted on the error rates for the secondary tasks. A 2 (Age Group) x 2 (Secondary Task) x 3 (Memory Task) analysis of variance was conducted on the error rates for secondary tasks. The main effects of age group and secondary task were not significant. There was a main effect of concurrent memory task that showed error rates were greater when there was a concurrent memory task compared to the single task condition ($F(2,58) = 27.47$, $p < 0.01$, $MSE = 0.63$). All two-way interactions were not significant. An interaction between secondary task, concurrent memory task and age group was found ($F(2,58) = 5.79$, $p < 0.01$, $MSE = 0.41$). An analysis of simple interaction effects indicated that the secondary task by concurrent memory task was only significant for the younger age group. An examination of Table 2.2 shows that the pattern of errors is unclear. In the low load mental arithmetic task for younger adults there was a difference in error rates between the full attention condition and the concurrent episodic retrieval condition. For older adults there was a difference between the full attention condition and both the concurrent episodic and semantic retrieval conditions. In the high load number monitoring task there were differences in error rates between the full attention condition and both of the concurrent retrieval conditions, for both age groups. The error rates are discussed further in section 2.2.4.

Dual Task Costs Analysis

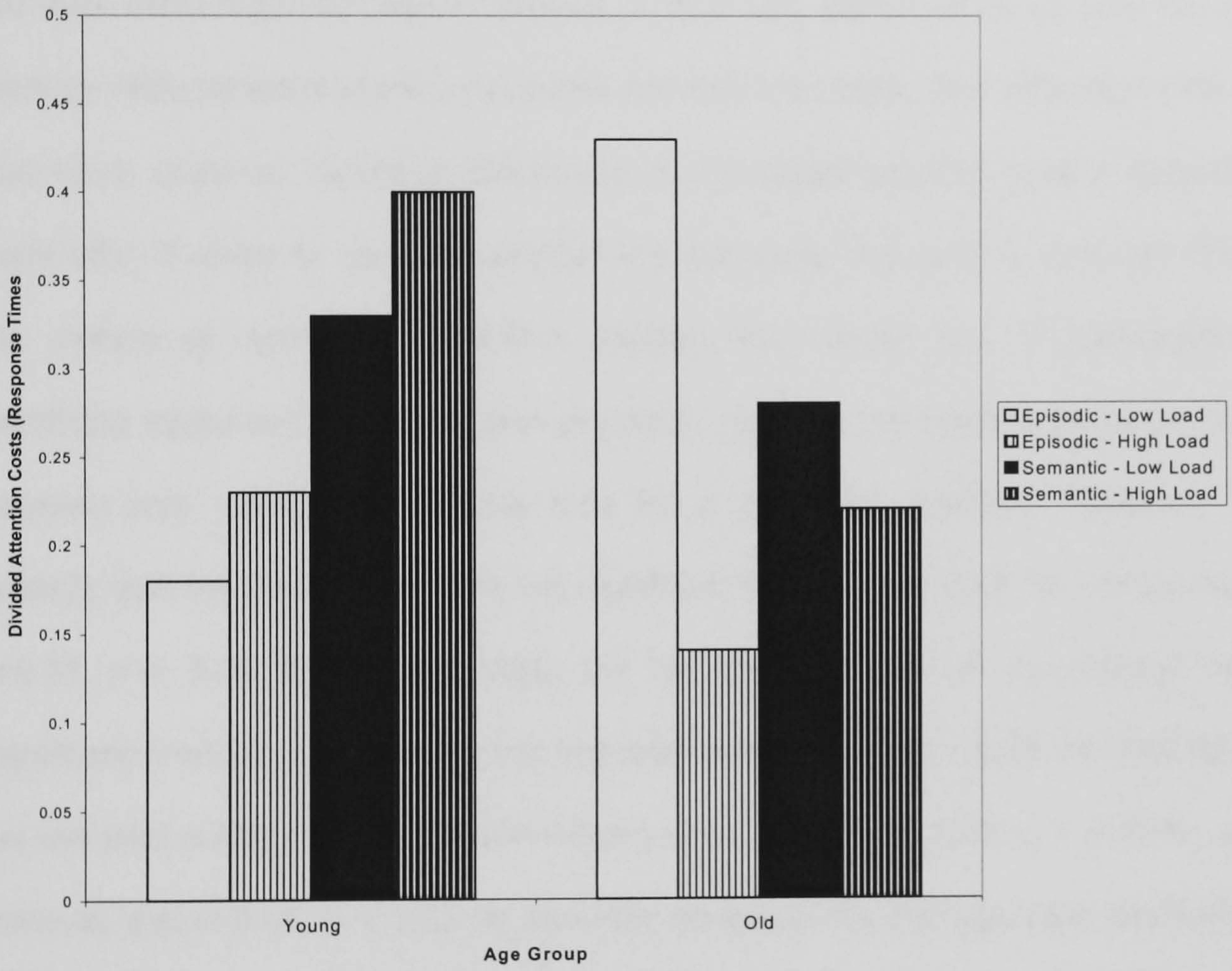
In order to control for baseline differences in memory retrieval and secondary task performance a dual task costs analysis was carried out on the response times and error rates, as advocated by Somberg & Salthouse (1982). The raw data were transformed into a dual task cost measure (i.e., (dual – single)/single). Figure 2.2 shows younger and older adults' performance for memory retrieval response time in terms of dual task costs. Figure 2.3 shows younger and older adults' performance on the secondary task for response time in terms of dual task costs. It should be noted the dual task costs analysis was not carried out on the error rate data for both the memory retrieval and secondary tasks. This was because in the full attention conditions a number of participants' errors were zero and therefore dual task costs could not be calculated because of division by zero errors.

Figure 2.2 The proportional increase in memory retrieval response times for younger and older adults



Memory retrieval response times in terms of dual task costs were analysed in a 2 (Age Group) x 2 (Working Memory Load) x 2 (Memory Task) analysis of variance. All main effects and interactions were not significant.

<u>Figure 2.3 The proportional increase in secondary task response times for younger and older adults</u>



The next set of analyses investigated age differences in secondary task response times in terms of dual task costs. A 2 (Age Group) x 2 (Working Memory Load) x 2 (Memory Task) analysis of variance was carried out on the response time data. All main effects were not significant. The interaction between secondary task and age group ($F(1,29) = 4.85$, $p < 0.05$, $MSE = 0.09$) showed that older adults' costs were the smaller in the high load condition. Younger adults' dual task costs for the low load and the high load conditions were equivalent. The interaction between age group and memory task approached significance ($F (1,29) = 4.10$, $p = 0.052$, $MSE = 0.07$). Post hoc comparisons using the Bonferroni procedure showed that for the older adults, costs were greater in the episodic condition. For younger adults the costs were greater in the semantic condition. No other interactions approached significance.

Speed error and task trade-off analysis

We were concerned with age differences in dual task performance on both the primary memory retrieval tasks and the secondary memory load tasks. One difficulty in the data is that there could be individual differences in the speed-accuracy and/or between task trade offs. In order to examine whether the possibility that such a trade off influenced the pattern of results, a correlation analysis was carried out. If participants were sacrificing response time to maintain accuracy, negative correlations would be expected between error rates and response time for a particular condition. However, for the episodic task the correlations were not significant ($r=0.19$, $p > 0.05$ for the low load, and $r=0.31$, $p > 0.05$ for the high load). For the semantic task the correlations were not significant ($r=0.30$, $p > 0.05$ for the low load, and $r=0.30$, $p > 0.05$ for high load). For the low load arithmetic task the correlations were positive ($r=0.42$, $p < 0.05$ for episodic retrieval, and $r=0.60$, $p < 0.01$ for semantic retrieval). For the high load monitoring task the correlations were either not significant or positive ($r=0.40$, $p < 0.05$ for episodic retrieval and $r=-0.03$, $p > 0.05$ for semantic retrieval).

A negative correlation would also be expected between the primary and secondary task errors and response times if there was a trade off between tasks. However, for the reaction time data the correlations were either positive or not significant ($r=0.3$, $p > 0.05$ for the low load episodic dual task and $r=0.36$, $p < 0.05$ for the high load episodic dual task). For the semantic task the correlations were not significant

($r=0.1$, $p > 0.05$ for the low load semantic dual task and $r=0.26$, $p > 0.05$ for the high load semantic dual task). For the error rate data the correlations were not significant ($r=0.06$, $p > 0.05$ for the low load episodic dual task and $r=0.29$, $p > 0.05$ for the high load episodic dual task). For the semantic tasks the correlations were not significant ($r=0.18$, $p > 0.05$ for the low load semantic dual task and $r=0.02$, $p > 0.05$ for the high load semantic dual task). Therefore, there does not appear to be any evidence supporting the idea that the earlier findings reflect speed-accuracy trade offs or between task trade offs.

2.2.4. Discussion

The aim of this experiment was to consider two alternative accounts of why older adults are only found to have dual tasking difficulties in certain circumstances. First, we investigated whether the requirement to divide attention is just one of several ways of increasing task difficulty (McDowd & Craik, 1988). Demanding episodic and semantic retrieval tasks were paired with a secondary task, which had different levels of difficulty. Difficulty was manipulated by increasing the amount of information to be held in working memory.

Consider first the effects observed using the absolute measures of reaction time and error rates. As expected older adults' response times and error rates were greater in the retrieval tasks. When performance was examined on the secondary tasks, response times were particularly slowed for older adults, but error rates were equivalent. We were particularly interested in whether older adults' performance was impaired when a concurrent task was introduced. In terms of response times for memory retrieval, older adults were particularly impaired as overall response times were particularly high in the load conditions. However, there was no evidence to suggest that older adults found dual tasking especially problematic in the episodic versions of the task as we would expect. For the secondary tasks there was no interaction with load, but there was a three-way interaction between age, memory task and load. This demonstrated that in the high load condition error rates were the greater in the semantic task for younger adults and error rates were the greater in the episodic task for older adults. Although the results were not very convincing for an episodic/semantic distinction there is some indication that older adults, in conditions of high attentional load, find episodic memory retrieval particularly problematic.

As noted earlier, the analysis of an age x condition interaction, without controlling for baseline differences in performance, has been heavily and justly criticised (Somberg & Salthouse, 1982). In response to this, several methods of assessing dual task costs have been advocated (Salthouse et al., 1995), but the most widely accepted method is the one originally proposed by Somberg & Salthouse (1982). This method of assessing dual task costs was used in this thesis.

Reaction times were transformed into dual task costs, which enabled a comparison between older and younger adults to be made independently of the existing differences in single task performance. For memory retrieval response times, the costs of dual tasking were age invariant and load had no effect overall, or its interaction with age. The addition of a concurrent task did result in retrieval costs but they were equivalent for both age groups and load did not bring about an age effect. In the dual task conditions the memory retrieval task was emphasised and therefore both groups were perhaps able to maintain their performance on the retrieval tasks at the expense of greater costs on the secondary tasks. In fact, a number of authors have found that in dual task conditions, younger and older adults' retrieval performance is largely unaffected but secondary task costs do arise (e.g. Anderson et al., 1998).

For the secondary tasks, younger adults' costs of dual tasking were the greater in the semantic version of the task. As the error rates and response times were the greatest in this task it could be considered the more demanding, so greater dual task costs may be expected. For older adults the secondary task costs were equivalent, although examining Figure 2.3 there is some indication that older adults' costs were greater in the episodic condition. The costs in the mental arithmetic secondary task in the episodic condition were larger for older adults (0.43 and 0.18), although this difference was not significant. For older adults in the high load episodic condition the secondary task costs were surprisingly low. A closer examination of the mean data goes some way to explain this rather complex set of results. For older adults in the high load episodic condition, 11 out of the 15 participants made two or more errors. In other words, a large number of the older adults' performance might have been at chance on the high load digit monitoring task when they were required to concurrently perform an episodic retrieval task. This is why the costs in this condition are so low. Older adults appear to find retrieval from episodic memory particularly problematic under conditions of high load. Older adults seemed to be ignoring the secondary task in order to concentrate on the retrieval task.

The methodological problems with the dual task paradigm make the interpretation of the results problematic. The retrieval tasks were paired with one of two working memory load tasks and measures of both response times and error rates were taken. Therefore, four measures of dual task performance were used which can lead to a complex set of findings. This problem has also been highlighted in previous research and therefore in Experiment 3.1 and 3.2 attempts are made to minimise these problems. In particular, a new paradigm is developed to investigate dual task costs within the context of a single task.

3. The Effects of Concurrent Processing Load on Retrieval from Semantic and Episodic Memory Retrieval

3.1 General Introduction

Although the results from Experiment 2.1 suggested that older adults might have problems with dual tasking when episodic memory retrieval is involved, they were far from conclusive. Consequently, the present experiments aimed to address the methodological problems inherent in the dual task paradigm used in Experiment 2.1. Rather than responding to two separate tasks, the present experiment seeks to examine age differences in concurrent processing by integrating the secondary task into the memory retrieval tasks. In other words, the effects of age on concurrent processing are examined within the context of a single task.

3.2 Experiment 3.1

3.2.1 Introduction

As before, this experiment examined two kinds of memory retrieval task: an episodic paired-associate task and a semantic category-exemplar-generation task. In addition, a working memory requirement was introduced to both tasks and the difficulty of this was manipulated to investigate the effect of increasing task demands. In traditional dual task studies, participants are required to make a response to two separate tasks. As outlined already, this can lead to difficulties in interpreting the data because participants will differ in the trade-off they make between responding to each task. In order to minimise such problems, the working memory element of the present study was integrated into the memory retrieval task by requiring participants to keep a running record of the last two or three trials. On each test trial a cue was presented to indicate which of the past n-trials participants should attempt to respond (see Figure 3.1).

Kirchner (1958) used a perceptual equivalent of the n–back procedure to examine age differences in short-term memory of visual signals. Participants were required to respond on a series of 12 keys to corresponding lights on a visual display. In the no load condition participants simply had to respond to the current light presented. In the load conditions (2-Back and 3-Back) participants were required to respond to the light that had been presented either two or three positions back. So rather than it being a simple reaction time task, in the load conditions there was a concurrent working memory load component. In the load conditions, older adults were found to be more penalised than the young.

This basic methodology was adopted in this thesis to examine age differences in the costs of concurrent processing. The advantage of considering the effects of concurrent processing within the n-Back task is that it minimises potential trade off effects. Furthermore, in the traditional dual task paradigm, a response is given to both the primary and secondary tasks and therefore dual tasks cost may arise because of response competition. In the n-Back procedure by integrating the secondary task (working memory task) in the primary task results in only one response being required, making the interpretation of the data less problematic. Furthermore, a common criticism of the dual tasking ageing literature is that a variety of paradigms have been used to examine age differences in dual task performance. In this thesis by using a standard procedure throughout makes comparisons between experiments easier.

In summary we expand on the experimental findings of experiment 2.1 by using a new paradigm (n-Back procedure) to investigate the effects of domain (episodic versus semantic memory) and task complexity (increasing the working memory load) on age differences in dual task performance. Younger and older participants attempted retrieval from episodic and semantic memory under no-load, low load (up to 2-back) and high load (up to 3-back) conditions. If task domain is the critical factor we expect that age differences in dual task costs would only be observed for the episodic paired associate task since deficits in episodic abilities have been consistently found. Semantic memory is relatively well preserved in old age and the effect of a concurrent task on retrieval performance is likely to be less dramatic. If task difficulty is critical, which the majority of the literature suggests, there will be greater dual task costs in the high load conditions, and task domain will be irrelevant, other than perhaps greater dual task costs for the harder retrieval task.

3.2.2 Method

Participants

Thirty-six younger adults (range 19-31, mean age 22.6 years SD 3.6 years) and 36 older adults (range 63-84, mean age 72.7 years, SD 5.1 years) participated in the experiment. The young volunteers were undergraduate students from the University of Bristol. The older adults were volunteers selected from a pool of older adults registered with the Experimental Psychology Department. Eighteen participants from each age group were randomly assigned to the episodic and semantic test conditions. On average the younger adults were better educated than the older adults (16.4 versus 13.5 years of education respectively, $\underline{t}(70) = 4.5$, $\underline{p}<.01$). Older adults scored more highly on the National Adult Reading Test, (raw scores of 42.1 and 39.0 respectively, $\underline{t}(70) = 2.5$, $\underline{p}<.05$).

Materials

The paired-associates were constructed from high-imagery (score of 300 or higher), high-frequency nouns (greater than 100 occurrences per million), between four and seven letters in length, selected from the MRC Psycholinguistic Database (Coltheart, 1981; see Appendix C). Nine word-pair lists were constructed randomly pairing such items (e.g. trial - water). The word pairs were unrelated and each list was randomly assigned to no load, low load and high load conditions. There was one practice block and two experimental blocks for each of the three episodic conditions. The categories and category members were selected form the Belfast Category Norms (Brown, 1978; see Appendix C). The top six ranked responses for 21 categories were used to create nine lists of 14 category - member pairs (e.g. furniture - bed). Each list was randomly assigned to no load, low load and high load conditions. There was one practice block and two experimental blocks for each of the three semantic conditions. Stimuli were presented on a 14-inch monitor in 36 point Arial font.

Procedure

Figure 3.1 shows a pictorial representation of the sequence of events used in this experiment. Displayed are the no load and load conditions for semantic memory retrieval.

<u>Semantic Memory Task</u>

Prior to the experimental session each participant received detailed instructions regarding the nature of the tasks (Appendix D). A pictorial representation of the no load and the load (2–back and 3–back) conditions accompanied the instructions (see figure 3.1 for example). Participants were required to demonstrate to the experimenter that they understood the instructions by completing the printed example.

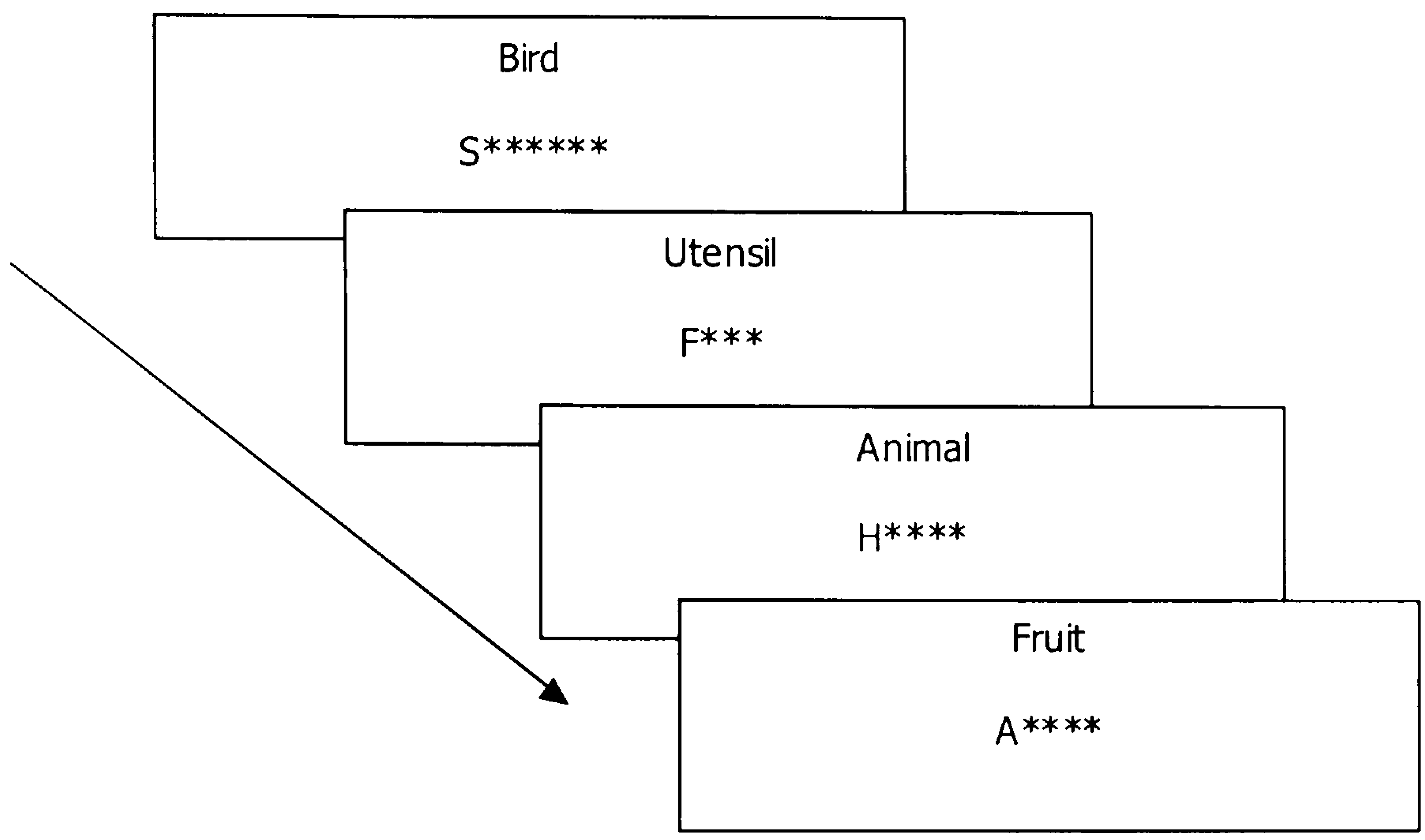
In order to ensure that participants understood the requirements of the task, a practice session of one block for each condition was given before the start of the experimental block. In the experimental block there were two sessions each of the no load, the low load and the high load tasks; presented in counterbalanced order across participants. In each session there were ten test trials.

No Load Condition

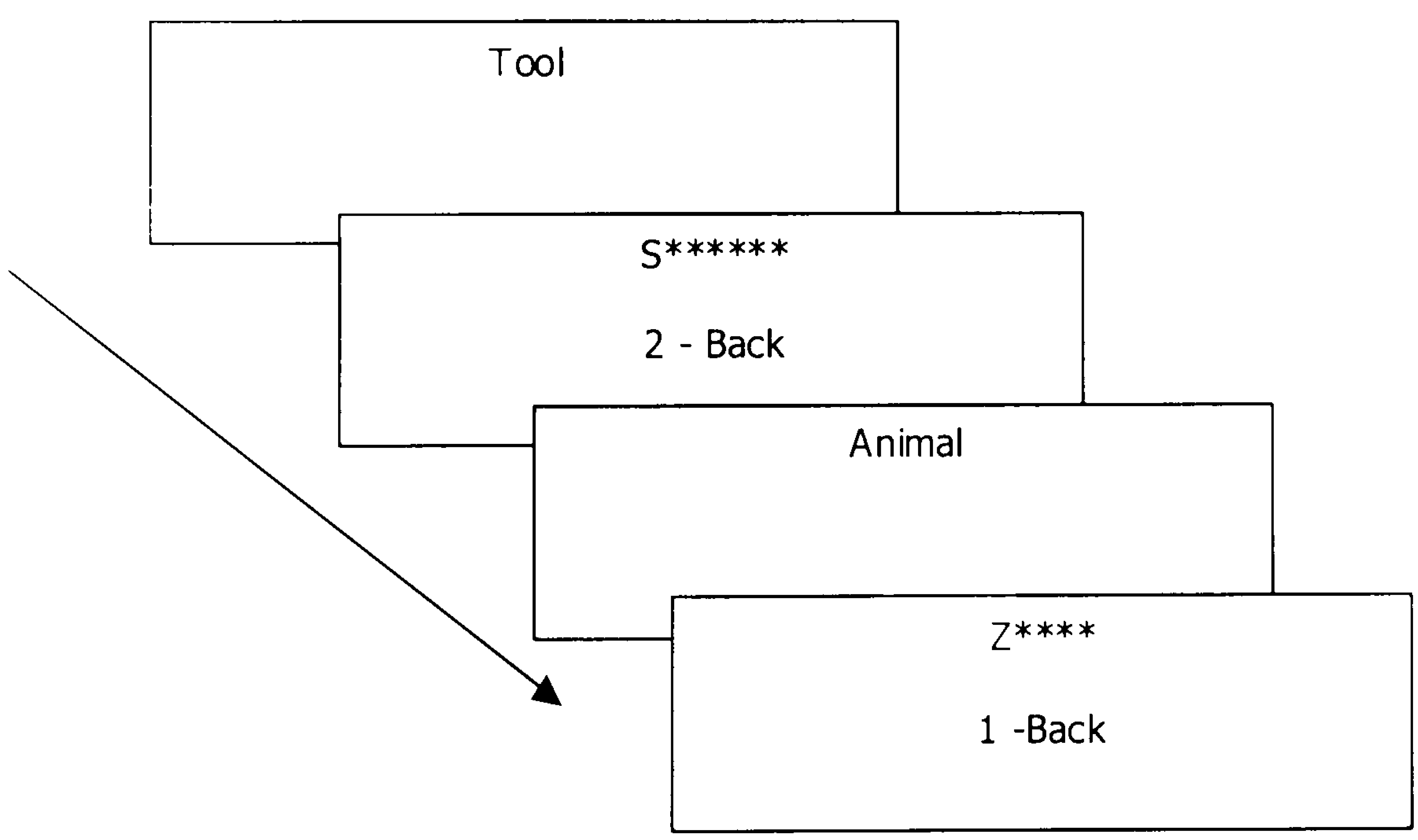
In the no load condition, the category generation task consisted of the presentation of a category name and a category exemplar cue. The category name (e.g. Animal) appeared on the computer screen with a partially completed category exemplar cue (e.g. Z****) underneath. The first letter of the category exemplar was provided and asterisks replaced each of the missing letters. Participants were instructed to respond verbally with an appropriate category member as quickly and as accurately as possible with a maximum time limit of seven seconds. Participants had to produce a category member that started with the specified letter and was exactly the correct length. Category cues were presented at 7 second intervals. No feedback was given and the final response made during the 7 second interval was recorded by a pushbutton operated by the experimenter.

Figure 3.1 Example of the procedure – Semantic memory retrieval no load and load conditions

No Load Condition



Load Conditions (n – Back)



Low Load Condition (2-Back)

In the low load condition, a category was presented for seven seconds. After the category disappeared a prompt was presented on the computer screen for seven seconds. The prompt consisted of one of the following signals: an asterisk (*), 1–Back or 2–Back. If the * prompt appeared this indicated that no response was required on this occasion. When either the 1–Back or the 2–Back prompt appeared, the partially completed category exemplar appeared at the same time above the prompt. If the 1–Back prompt appeared the participant responded by producing a member of the category that had just disappeared from the computer screen. If the 2–Back prompt appeared participants were required to use the category from two positions back. Thus, participants were required to keep in mind the previous two categories presented in order to respond appropriately when the prompt appeared. The 1–Back signal was included so that participants could not prepare a response to the two back signal in advance. The no back signals (*) were included as fillers so that each cue was only tested once and again their inclusion made it difficult for participants to prepare a response. A total of four no response prompts were used in each experimental session. Eighty percent of the prompts were the 2–Back cue and 20% were the 1–Back cue. The experimenter recorded the participants' responses.

High Load Condition

In the high load condition, the task requirements were the same as low load condition except that the participants were required to keep in mind the previous three categories that had been presented. On this occasion as well as the no response (*), the 1-Back and the 2-Back conditions, participants were also required to respond to a 3-Back condition. Again, there were four no response prompts used as fillers. Eighty percent of the test trials were for the 3-Back cue, with 10% for each of the 2–Back and 1–Back cues.

Episodic Memory Task

The procedure for the episodic memory task was identical to the semantic memory task, except that episodic retrieval cues were used instead of category retrieval cues. The episodic retrieval cues referred to a set of paired-associates which were learned in a pre-test training session. It should be noted that the experimenter stressed to the participant that they were required to keep in mind the cues and only attempt to retrieve the paired associate at the test trial. This was done to ensure the task parameters remained constant across tasks. Potentially in the episodic condition participants could generate possible responses as the cues occurred rather than think n – back at the test phase and then generate a response.

Pre-test Training

In the pre-test learning phase participants were trained on each word list before each condition. On each trial, 14 word pairs (e.g. apple-card) were presented, at eight-second intervals, on the computer screen. Participants were asked to memorise each word pair for later recall and were encouraged to use visual imagery mnemonics to aid their recall. Before the final retrieval phase, the experimenter read aloud the first word of each word pair and participants were required to respond, in their own time, with the second word of the word pair. This training procedure continued for six trials or until participants were able to recall at least 10 of the 14 word pairs: a criterion of 71% correct. The word pairs were re-presented, in the same order, on up to six training trials until the criterion was achieved. All participants reached criterion within six presentations of the word lists.

3.2.3 Results

Because the age groups differed in education and vocabulary ability, these measures were initially entered as covariates in the analyses. However, as neither covariate was significant in any analysis, they are not discussed further. Post-hoc analysis were conducted using the Bonferroni procedure with a significance level of $p < 0.05$ unless otherwise stated.

Analysis of Absolute Response Time and Error Rate Data

The absolute response time and error data for the no load and load conditions for both the episodic and semantic memory retrieval tasks are shown in Table 3.1. It should be noted at this point that unlike the raw data from experiment 2.1, the rank ordering of the error rates and reactions indicates almost universally increases in line with load and therefore is a clear manipulation of task difficulty.

Table 3.1 Mean (and SD) response latency (in msec) and errors for the episodic paired associate task, and the semantic category exemplar generation task, under no load, low load (2-back), or high load (3-back) conditions

Retrieval Task								
	Paired Associates				Category Exemplar Generation			
	Response latency		Errors /20		Response latency		Errors /20	
	M	SD	M	SD	M	SD	M	SD
Younger Adults								
No load	2123	281	3.4	3.1	3156	410	6.8	2.4
Low load	2246	428	3.5	2.8	3546	531	9.7	3.1
High load	2493	528	5.1	4.9	3653	453	11.5	3.5
Older Adults								
No load	2580	407	6.3	1.8	3476	426	8.0	2.1
Low load	3767	934	10.3	3.4	4283	725	15.6	2.1
High load	4310	1163	13.7	3.2	4246	618	16.4	2.5

Memory retrieval response times were analysed in a 2 (Age Group) x 2 (Memory Task) x 3 (Memory Load) analysis of variance. This analysis revealed that response times were generally slower for the older adults ($F(1,65) = 58.14$, $MSE = 728962$, $p < 0.01$), were longer in the semantic memory task ($F(1,65) = 45.94$, $MSE = 728962$, $p < 0.01$) and increased in line with working memory load ($F(2,130) = 59.18$, $MSE = 221694$, $p < 0.01$). The interaction between memory task and age group demonstrated that older adults response times were particularly high in the episodic task ($F(1,65) = 9.02$, $MSE = 728962$, $p < 0.01$). The interaction between working memory load and age group demonstrated that older adults were particularly impaired when carrying out a memory retrieval task with a concurrent load ($F(2,130) = 15.73$, $MSE = 221694$, $p < 0.01$). An analysis of simple main effects, using the Bonferroni procedure, found a significant difference in the younger adults' response times between the no load and both the low load and high load conditions. The difference between the high load and low load response times approached significance. For the older adults there was a significant difference between the no load and both the load conditions, but the two load conditions did not differ. There was also an interaction between memory task and working memory load ($F(2,130) = 3.94$, $MSE = 221694$, $p < 0.05$). An analysis of simple main effects, using the Bonferroni procedure, found that in the episodic memory condition response times increased with an increase in working memory load. In the semantic memory condition there was a significant difference between the no load and both the load conditions. Finally, there was a three way interaction between age group, memory task and working memory load ($F(2,130) = 5.78$, $MSE = 221694$, $p < 0.01$). Investigation of the interaction, using the Bonferroni procedure, revealed that in the episodic memory condition there was a significant difference between the younger adults' response times for the no load condition and both the load conditions. For the older adults in the episodic memory condition the response times increased with working memory load. In the semantic memory condition the interaction between working memory load and age group was not significant.

One possible difficulty with the absolute data is that in some cases mean response times were calculated from very few responses. This occurred because mean response times were calculated only for correct responses and older adults' performance in particular was quite poor. In order to determine whether this unduly biased the results, two further analyses were conducted. First, an analysis was conducted after excluding the data where the mean response time was based on fewer than five correct responses. While no participants were excluded on the basis of accuracy in the episodic task, one younger and eight older adults were excluded on the basis of their accuracy in the semantic task. Excluding these data points did not affect the pattern of results reported above and the results of this reanalysis are not reported here.

The next set of analyses was carried out on the memory retrieval errors. It should be noted that there were two types of errors (no response errors and retrieval errors) and these were combined for this analysis. In fact, the no response errors were the most common errors across task and age group. In the episodic task for the younger adults 76%, 78% and 76% of errors comprised nil responses in the no load, low load and high load conditions, respectively. For the older adults 84%, 77% and 69% of errors were no responses in the no load, low load and high load conditions, respectively. In the semantic task for the younger adults 93%, 90% and 89% of errors were no responses in the no load, low load and high load, respectively. For the older adults 94%, 84% and 87% of errors were no responses in the no load, low load and high load, respectively.

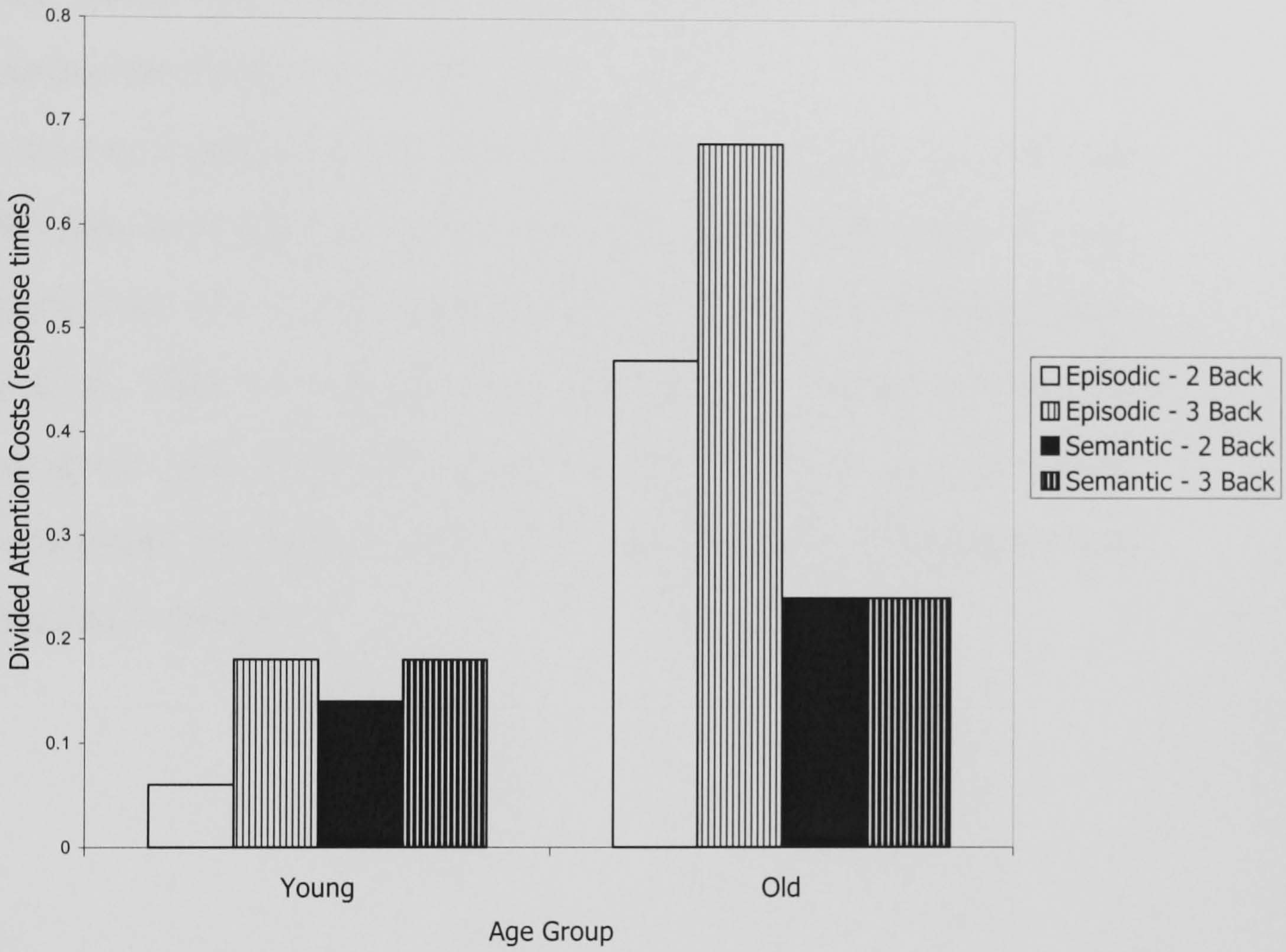
A 2 x (Memory Task) 2 x (age Group) x 3 (Working Memory Load) analysis of variance was carried out on the error data. This analysis showed that the older adults produced more errors ($F(1,68) = 76.48$, $MSE = 17.91$, $p < 0.01$), error rates were greater in the semantic memory condition ($F(1,65) = 55.16$, $MSE = 17.91$, $p < 0.01$) and accuracy was impaired as working memory load increased ($F(2,136) = 120.09$, $MSE = 4.75$, $p < 0.01$). Post-hoc comparisons using the Bonferroni procedure confirmed that accuracy declined as working memory load increased. The interaction between working memory load and age group ($F(2,136) = 25.93$, $MSE = 4.75$, $p < 0.01$) showed that older adults' accuracy was particularly impaired when carrying out a memory retrieval task with concurrent load. In addition, the interaction between memory task and working memory load ($F(2,136) = 10.05$, $MSE= 4.75$, $p < 0.01$) demonstrated that error rates increased mainly in the semantic memory condition with the presence of a concurrent task. Finally, the interaction between memory task and age group ($F(1,68) = 3.36$, $MSE = 17.91$, $p > 0.05$) and the working memory load by age group by memory task interaction ($F(2,136) = 2.08$, $MSE =4.75$, $p > 0.05$) were not significant.

One potential explanation of the difficulty that older adults had with the episodic task is that it might stem from poorer initial learning of the material, despite the training to criterion. To investigate this possibility, the error data was reanalysed, using number of trials to training as a covariate. If those who struggle to learn have poorer encoding, then this covariate might emerge as a factor at retrieval. However, it did not, and it made no difference to the pattern of results reported above.

Dual Task Costs Analysis

In order to control for baseline differences in memory retrieval response times and error rates, a dual task costs analysis was carried out as described previously. The raw data were transformed into a dual task cost measure (i.e., (dual – single)/single). Figures 3.2 and 3.3 show the younger and older adults' performance for memory retrieval response time and error rate in terms of dual task costs.

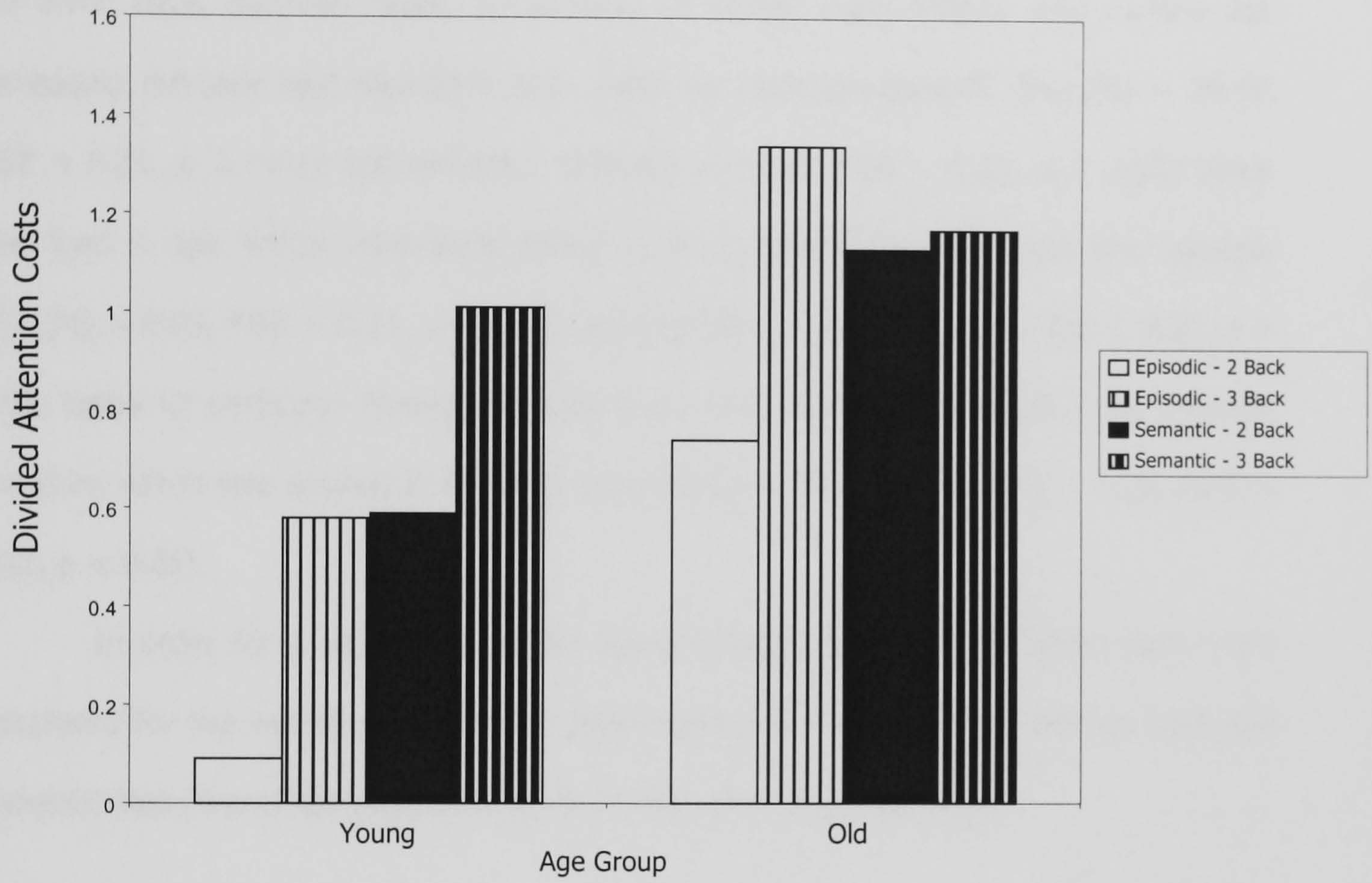
Figure 3.2 The proportional increase in memory retrieval response times for younger and older adults



Memory retrieval response times in terms of dual task costs were analysed in a 2 (Age Group) x 2 (Memory Task) x 2 (Memory Load) analysis of variance. The main effect of age group showed greater proportional cost for older adults ($F(1,65) = 21.27$, $MSE = 0.12$, $p < 0.01$), dual task costs were greater in the episodic memory condition ($F(1,65) = 6.59$, $MSE = 0.12$, $p < 0.05$), and greater costs as working memory load increased ($F(1,65) = 12$, $MSE = 0.02$, $p < 0.01$). The interaction between age group and memory load was unreliable ($F(1,65) = 0.33$, $MSE = 0.008$, $p > 0.05$), as was the three way interaction between working memory load, age group and memory task ($F(1,65) = 1.82$, $MSE = 0.04$, $p > 0.05$). However, the memory task x age group interaction showed that older adults were particularly disadvantaged in the episodic memory tasks ($F(1,65) = 10.39$, $MSE = 0.12$, $p < 0.01$). The interaction between working memory load and memory task showed that increasing the memory load had a greater effect in the episodic memory task ($F(1,65) = 7.54$, $MSE = 0.02$, $p < 0.01$).

In order for a comparison to be made between the experiments presented in this thesis, effect sizes were calculated for the overall age effect of dual tasking. This was particularly important as we were concerned with whether the environmental support hypothesis (Craik, 1986) was consistent with the data from Experiment 3.1 and the experiment reported next (Experiment 3.2). For the episodic memory task and semantic tasks the effect sizes were $d = 1.52$ and $d = 0.45$, respectively. The effect sizes will be discussed in detail in Chapter 7.

Figure 3.3 The proportional increase in memory retrieval error rates for younger and older adults



An equivalent analysis of dual task costs was performed on memory retrieval error rates. Two younger participants were removed from the analysis as they made no errors and therefore a dual task cost could not be calculated. The results showed that there was a greater proportional cost for older adults ($F(1,66) = 6.8$, $MSE = 1.25$, $p < 0.05$), but the main effect of memory task ($F(1,66) = 1.81$, $MSE = 1.25$, $p > 0.05$) and the memory task x age group interaction ($F(1,66) = 0.92$, $MSE = 1.25$, $p > 0.05$) failed to reach significance. A main effect of memory load simply showed that there was a greater proportional cost as working memory load increased ($F(1,66) = 26.31$, $MSE = 0.22$, $p < 0.01$) and the load x memory task interaction ($F(1,66) =4.48$, $MSE = 0.22$, $p <$

0.05) indicated that increasing load had a greater effect in the episodic condition. The age group x memory load (F(1,66) = 0.94, MSE = 0.22, $p > 0.05$) and the working memory load x age group x memory task (F(1,66) = 1.65, MSE = 0.22, $p > 0.05$) interactions were not significant. To investigate the age differences in dual task costs for the error rates between tasks, an analysis of simple main effects was carried out. Increasing memory load increased error rates for both the episodic (F(1,34) = 26.42, MSE = 0.21, $p < 0.01$) and semantic (F(1,34) = 4.525, MSE = 0.23, $p < 0.05$) tasks. The load x age group interaction failed to reach significance for both the episodic (F(1,34) = 0.05, MSE = 0.21, $p > 0.05$) and semantic (F(1,34) = 2.54, MSE = 0.23, $p > 0.05$) tasks. Of particular interest was that there was only a group effect in the episodic condition which was entirely in line with the response time data (F(1,34) = 5.26, MSE = 1.11, $p < 0.05$).

In order for a comparison to be made between experiments, effect sizes were calculated for the overall age effect of dual tasking. For the episodic memory task and semantic tasks the effect sizes were d=0.74 and d=0.44, respectively.

Speed Error Trade-Off

The data so far have indicated that older adults are particularly slowed at retrieval for episodic memory compared to semantic memory, but they make fewer errors on the episodic task. Are these two facts related? Is the poorer performance of older adults on the semantic task a result of a differential speed error trade-off across tasks? In order to examine this possibility, divided attention costs for speed and error rates were correlated. If participants are sacrificing response time to maintain accuracy, negative correlations would be expected. However, for the semantic task, the correlations were not significant ($r = -0.11$, $p > 0.05$ for low load, and $r = -0.17$, $p > 0.05$ for high load). For the episodic task the correlations were both positive ($r = 0.43$, $p < 0.05$ for low load, and $r = 0.22$, $p>0.05$ for high load), thus contradicting the expectation based on a speed error trade-off. Those who were most slowed by the episodic task were also the most inaccurate.

3.2.4 Discussion

The current study set out to further investigate the circumstances in which older adults have difficulties in combining tasks. We were particularly interested in age differences between semantic and episodic memory retrieval and the effects of increasing working memory load. Whereas in experiment 2.1 there were two separate tasks to which to respond, this experiment used the n–Back procedure to minimise task trade off effects. In other words, a response was only made to the retrieval task. The working memory task was integrated into the retrieval task and became a necessary part of that task.

Consider first the effects observed using absolute measures of reaction time and error rates. In addition to slower speed and poorer accuracy in the episodic and semantic tasks under single task conditions, the present data demonstrated that older adults were particularly impaired by concurrent processing demands. This was particularly pronounced in the episodic memory task where the difficulty was observed on both measures of the speed of performance and the number of errors made. In the semantic task the results were less clear. Concurrent processing demands gave rise to a greater increase in errors for the older adults, but did not influence speed. Thus, it is clear that older adults find a current processing load problematic in the episodic paired associate task, but their difficulty in the semantic task appears restricted to accuracy alone. However, accuracy data can be misleading as making errors on the semantic n-Back task could be due to an episodic failure. An error may occur if the participant has forgotten or mis-remembered the category name cue. This is one problem with the error analysis and why the response time data are more reliable. At least with a correct response we know the memory load is appropriate as they can access to n-Back categories. These results, based as they are on absolute measures of performance, are hardly surprising and are consistent with a wide range of previous research on dual task performance in older adults. However, not all studies have considered controlling for baseline differences in performance by for instance assessing dual task costs. Of more importance, no earlier studies have assessed the dual task costs associated with performance in episodic and semantic tasks in the same study.

As noted earlier, the analysis of an age x condition interaction, without controlling for baseline differences in performance, has been criticised (Somberg & Salthouse, 1982). Reaction time and error data were transformed into dual task costs and such a transformation enables a comparison between older and younger adults to be assessed independently of the existing differences in single task performance. For the semantic retrieval task, the results from the analysis were consistent with that of Perfect & Rabbitt (1993): after controlling for the effects of single task performance there was no differential effect of dual tasking. Furthermore, this was the case for both the response time and error rate data. The pattern of results for the episodic retrieval task was quite different. There was a clear effect of age in dual task costs which demonstrates that when episodic memory retrieval was required the older adults were more penalised by the concurrent processing demands. Anderson et al. (1998) also investigated episodic retrieval and found that, based on a dual task cost analysis, that older adults had a particular difficulty with retrieving episodic information. Although this difficulty effect was not observed on the primary episodic memory task, where the dual task costs were equivalent, it was observed on performance in the non-episodic secondary task. The data presented here is consistent with Anderson et al.'s (1998) dual task cost analysis of episodic retrieval, although the use of the n-Back procedure eliminates the need to consider the trade-off that can occur using a traditional dual task paradigm.

The most important aspect of the data reported here is the suggestion that older adults do not show a general memory retrieval deficit in dual tasking. Rather, based on dual task costs, the results reveal a deficit only when episodic retrieval is involved. This raises the question of why there should be a different pattern of dual task costs across the two kinds of memory retrieval. One possible explanation that is frequently favoured is that of task difficulty. The idea here is that the more difficult or complex each of the component tasks is made, the greater the likelihood of disproportionate age-effects when tasks are examined in combination. However, difficulty cannot explain the discrepancy between the older adults' performance on the semantic and episodic memory tasks for two reasons. First, when difficulty was manipulated on the semantic task it did not produce an age effect in dual task costs. While increasing the memory load did increase overall memory retrieval times, it affected both groups in the same way. This result is consistent with the Perfect & Rabbitt (1993) finding that increasing the difficulty of category generation produced slowing, but did not bring about an age difference in dual task costs. Second, it could be argued that even in the high load condition the semantic task was less demanding than the episodic task. However, this explanation can be ruled out because the evidence suggests that the semantic task was more demanding than the episodic one. For example, under single task conditions, speed and accuracy was poorer for category exemplar retrieval compared to paired associate retrieval. If response times and accuracy are an indication of the demands of the two tasks, the more difficult semantic task did not bring about the age effect in dual task costs. It should also be noted that increasing difficulty (working memory load) for both tasks affected both age groups to the same extent.

In this experiment, two demanding tasks were used, as indexed by the single task performance scores, but the crucial question raised by the results is why does the requirement to hold and update material in working memory only affect episodic memory retrieval disproportionately? Adding a load is certainly not just adding to the demands and complexity of the overall situation because this should have affected both tasks equally. It seems that retrieving novel material from episodic memory combined with perhaps another episodic component (attempting to retrieve a cue n back) is particularly problematic for older adults. Since potentially these two task demands share the same processing mechanisms there is greater potential for interference, and it is this that older adults find problematic. In the semantic version of the task, although it is the more difficult task, retrieving over-learned material from memory is carried out in a more automatic manner and older adults' performance is less susceptible to concurrent processing demands.

3.3 Experiment 3.2

3.3.1. Introduction

The goal of Experiment 3.2 was to examine further the episodic/semantic distinction. Domain was shown to be an important moderator variable of dual task costs in older adults. The results replicated the findings by Anderson et al. (1998) who found disproportionate secondary task costs for older adults. In addition, the data replicated the findings by Perfect & Rabbitt (1993) who investigated whether the resource deficit model of ageing could be applied to the retrieval of familiar over-learned material. Perfect & Rabbitt (1993) found no evidence of a dual task deficit when semantic memory retrieval was involved, and this remained the case even when task difficulty was increased within task.

Since there are diverse findings in the literature with regard to dual task effects and ageing, it would be desirable to replicate Experiment 3.1. To this end we used episodic and semantic retrieval tasks similar to those used in the previous two experiments but with a different memory load. In Experiment 3.1 the working memory requirement consisted of the presentation of words at regular intervals and participants were required to hold and update the words in memory in order for them to complete the primary retrieval tasks. There may have been an overlap in the processes involved in the n–Back task and the episodic retrieval tasks that led to the effects. In the present experiment, load was introduced into the episodic retrieval task by presenting two or four words prior to the test trials and participants at the test trial had to decide whether any of the previous words belonged to a particular set of words previously learned. In the semantic retrieval task two or four category exemplars were presented prior to the test trial and at the test trial had to decide whether any of the previous category exemplars belonged to a particular category. In other words load in this experiment involved short-term memory of recently presented words. Memory load differed from experiment 3.2 in that it only involved the brief storage of information rather than the active processing involved in experiment 3.1.

The main difference between the present and previous experiment is that the retrieval task involved recognition rather than recall. According to the environmental support hypothesis (Craik, 1986) recall tasks rely on more self-initiated process and therefore demand more cognitive resources. However, for recognition there is more environmental support because useful information is re-presented which lessens the need for effortful self-initiated processes. Age differences in recognition performance are still found but the magnitude of the effect is smaller. For instance in one dual task study, age differences in secondary task costs were found to be greater in cued recall than recognition (e.g. Anderson et al., 1998). Therefore, the second aim of this study was to examine whether age differences in dual task performance would be observed in a recognition version of the dual task, and whether the magnitude of this effect was smaller than the effect found when we used the n-Back task.

As with experiments 2.1 and 3.1, we were concerned with whether task domain or task difficulty best explains older adults' poorer performance at dual tasking. We expect disproportionate costs of dual tasking when episodic memory retrieval is involved, although we expect the magnitude of the effect to be somewhat smaller due to favourable episodic retrieval conditions.

3.3.2. Method

Participants

Thirty-six younger adults (range 19-26, mean age 20.6 years, SD 1.6 years) and 36 older adults (range 60-79, mean age 70.9 years, SD 5.9 years) participated in the experiment. The young volunteers were undergraduate students from the University of Bristol. The older adults were volunteers selected from a pool of older adults registered with the Experimental Psychology Department. Eighteen participants from each age group were randomly assigned to the episodic and semantic test conditions. On average the younger adults were better educated than the older adults (16.1 versus 12.7 years of education respectively, $t(34) = 6.3$, $p<0.01$). Older adults scored more highly on the National Adult Reading Test, (raw scores of 39.7 and 36.6 respectively, $t(34) = 2.3$, $p<0.05$). These scores were entered as covariates in the main analyses.

Materials

Six lists of nine words were constructed from high-imagery (score equal to or greater than 300; imageability scores have a range of 100 to 700), high-frequency nouns (greater than 100 occurrences per million), between four and seven letters in length, selected from the MRC Psycholinguistic Database (Coltheart, 1981; see Appendix E). Three sets of 3 words were constructed randomly for each of the 9 lists. The nine lists were randomly assigned to no load, low load and high load conditions. There was one practice block and one experimental blocks for each of the three episodic conditions. The categories and category members were selected form the Belfast Category Norms (Brown, 1978; see Appendix E). A master list of the top six ranked responses for 21 categories was used to create 6 lists of 10 category - member pairs (e.g. furniture - bed). Each list was randomly assigned to no load, low load and high load conditions. There was one practice block and one experimental block for each of the three semantic conditions. Stimuli were presented on a 14-inch monitor in 36 point Arial font.

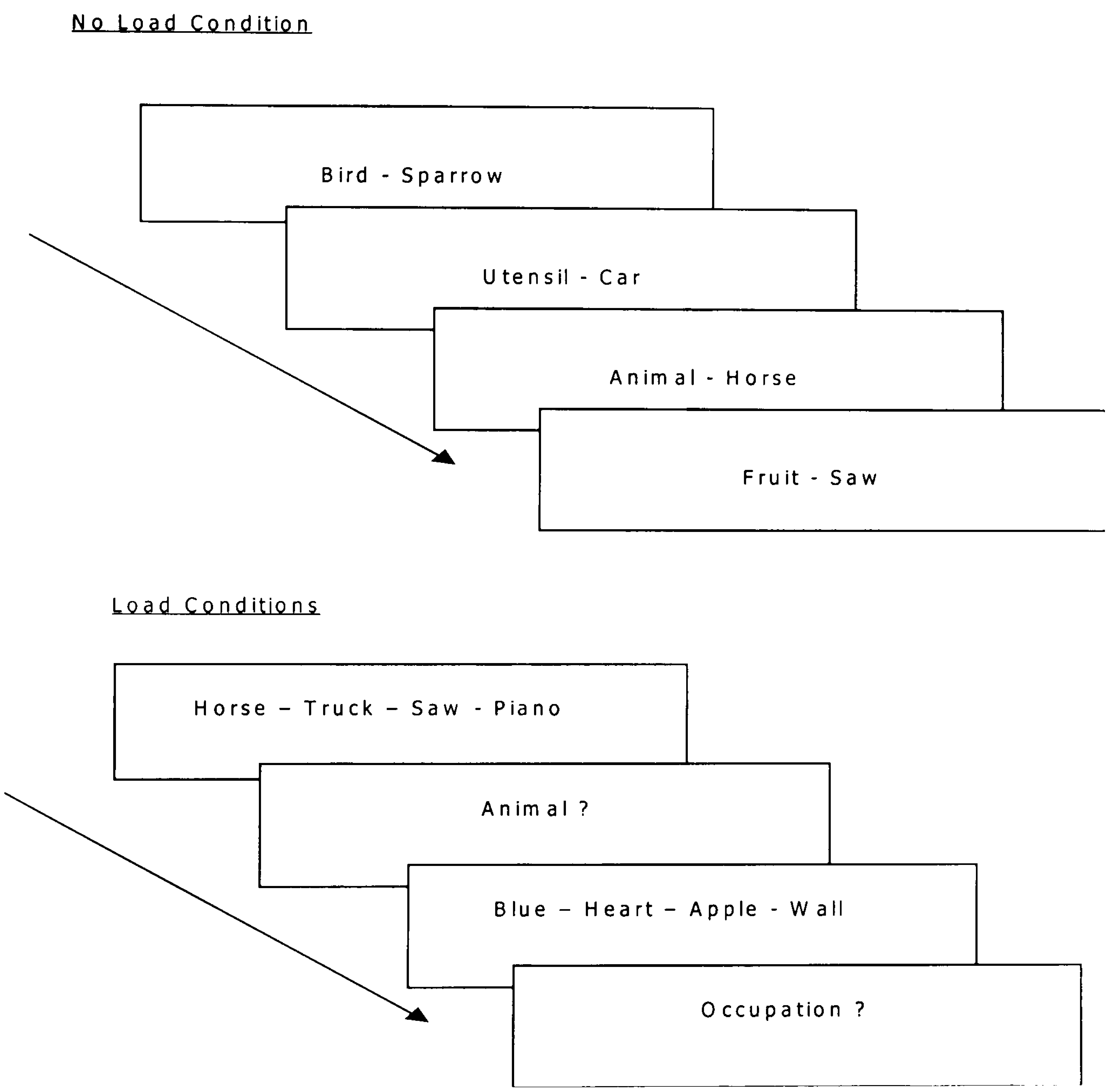
Procedure

An example of the experimental procedure is shown in Figure 3.4. Displayed are the no load and high load conditions for the episodic memory retrieval tasks. All responses were made on a standard IBM keyboard with the 'Z' and '/' keys marked as either 'YES' or 'NO'. Participants used their index fingers and the markings of 'YES' and 'NO' were alternated between the 'Z' and '/' keys, across participants.

Semantic Memory Task

Prior to the experimental session each participant received detailed instructions regarding the nature of the tasks (Appendix F). A pictorial representation of the no load and low load and high load conditions accompanied the instructions (see figure 3.4 for example). Participants were required to demonstrate to the experimenter that they understood the instructions by completing the printed examples.

Figure 3.4 Example of the procedure – episodic memory retrieval no load and load conditions



In order to ensure that participants understood the requirements of the task, a practice session of one block for each condition was given before the start of the experimental block. In the experimental block there was one session each of the no load, the low load and the high load tasks, presented in counterbalanced order across participants. In each session there were ten test trials.

No Load Condition

In the no load condition, the category generation task consisted of the presentation of a category name and a category exemplar. The category name appeared on the computer screen with a category exemplar beside (e.g. zebra – animal). Participants were instructed to respond manually 'yes' on a computer keyboard if the category exemplar belonged to the category, or 'no' if it did not as quickly and as accurately as possible with a maximum time limit of five seconds. Category names and category exemplars were presented at five-second intervals. No feedback was given and the computer recorded the final response made during the five-second interval. There was a total of ten test trial where participants were required to make a response.

Low Load Condition

In the low load condition, two category exemplars were presented simultaneously for five seconds (e.g. chisel – grass). After the category exemplars disappeared a category name was presented on the computer screen for five seconds (e.g. tool?). At this point participant had to decide whether either of the last two category exemplars that had disappeared from the computer screen 5s previously was a member of that category. Participants were instructed to respond on the computer keyboard as quickly and as accurately as possible. Thus, participants were required to keep in mind the previous two category exemplars presented in order to respond appropriately when the category name appeared. There were ten test trials in total.

High Load Condition

In the high load condition, the task requirements were the same as low load condition except that the participants were required to keep in mind the four category exemplars that had been presented. There were ten test trials in total.

Episodic Memory Task

The procedure for the episodic memory task was identical to the semantic memory task, except that set names were used instead of category names. The set names referred to sets of three words which were learned in a pre-test training session.

Pre-test Training

In the pre-test learning phase participants were trained on three sets of four words. A set of words would appear on the computer screen for six seconds (e.g. Set A – coin – screen – lady). After each of the three sets had been presented on the computer screen the experimenter asked the participant to recall each word from each set. This training procedure continued for ten trials or until participants were able to recall all the words on two consecutive occasions. All participants reached criterion within ten presentations of the word sets.

3.3.3 Results

Because the age groups differed in education and vocabulary ability, these measures were initially entered as covariates in the analyses. However, as neither covariate was significant in any analysis, they are not discussed further. Post-hoc analysis were conducted using the Bonferroni procedure with a significance level of $p<0.05$ unless otherwise stated.

Analysis of Absolute Response Time and Error Rate Data

The absolute response time and error data for the no load and load conditions for both the episodic and semantic memory retrieval tasks are shown in Table 3.2.

Table 3.2 Absolute response times and error rates for the no load and load conditions for both episodic and semantic retrieval tasks

	Retrieval Task							
	Episodic Memory Task				Semantic Memory Task			
	Response latency		Errors /10		Response latency		Errors /10	
	M	SD	M	SD	M	SD	M	SD
Younger Adults								
No load	1179	211	0.5	0.9	1424	295	0.6	0.9
Low load	1168	188	0.5	0.7	1086	185	5.2	2.4
High load	1263	401	1.2	0.6	1588	290	1.7	1.3
Older Adults								
No load	2680	471	2.6	2.0	2293	524	0.3	0.5
Low load	3025	583	3.2	2.4	2245	618	1.1	0.5
High load	3391	346	2.3	2.1	2456	442	0.7	0.7

Memory retrieval response times were analysed in a 2 (Age Group) x 2 (Memory Task) x 3 (Memory Load) analysis of variance. This analysis revealed that response times were generally slower for the older adults ($F(1,34) = 390.4$, $MSE = 253951$, $p < 0.01$), were longer in the episodic memory task ($F(1,34) = 11.4$, $MSE = 244175$, $p < 0.01$) and greatest in the high working memory load condition ($F(2,68) = 16$, $MSE = 100817$, $p < 0.01$). The interaction between memory task and age group demonstrated that older adults response times were particularly high in the episodic task ($F(1,34) = 49.6$, $MSE = 244176$, $p < 0.01$). The interaction between working memory load and age group was significant, $F(2,68) = 4.5$, $MSE = 100817$, $p < 0.05$). Examining Table 2.3 the results are less than clear. An analysis of simple main effects, using the Bonferroni procedure, found older adults' response times were slower in the high load condition compared to either of the no load or low load conditions. For younger adults, response times were again slower in the high load condition. The response times were surprisingly slower in the no load condition compared to the low load condition. Finally, there was a three way interaction between age group, memory task and working memory load ($F(2,68) = 3.13$, $MSE = 141320$, $p<0.05$). Investigation of the interaction, using the Bonferroni procedure, revealed that only in the episodic condition was there a interaction between working memory load and age.

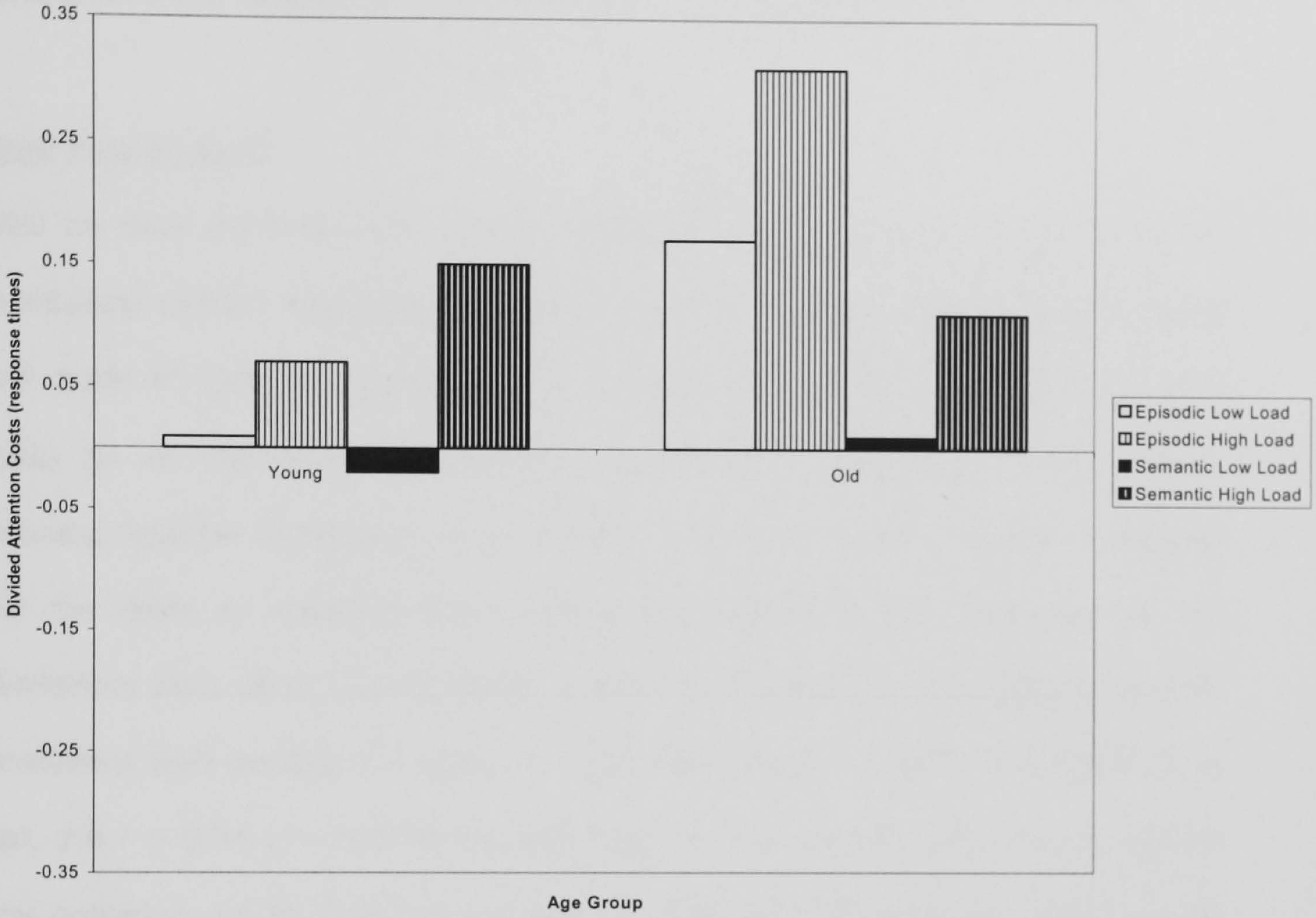
The next set of analysis was carried out on the memory retrieval errors. A 2 x (Memory Task) 2 x (age Group) x 3 (Working Memory Load) analysis of variance was carried out on the error data. This analysis showed that the older adults produced more errors ($F(1,34) = 68.47$, $MSE = 2.81$, $p < 0.01$). A main effect of load demonstrated that there were fewer errors in the no load condition compared to the load conditions. Post-hoc comparisons using the Bonferroni procedure surprisingly found that there were fewer errors in the high load conditions than the low load condition. The interaction between working memory load and age group ($F(2,68) = 15.98$, $MSE = 1.98$, $p < 0.01$) showed that older adults' accuracy was particularly impaired when carrying out a memory retrieval task with concurrent load. There was an interaction between memory task and working memory load ($F(2,68) = 21.24$, $MSE= 1.38$, $p < 0.01$). Examining this interaction using the Bonferroni procedure showed that for the episodic condition the error rates were equivalent for each level of load. For the semantic memory condition error rates were the greatest in the load conditions. However, error rates were surprising higher in the low load condition than the high load condition. Finally, the working memory load by age group by memory task interaction was significant ($F(2,68) = 8.47$, $MSE =1.38$, $p < 0.01$). An analysis of simple interaction effects showed that in the episodic condition, for older adults the error rates were equivalent at the three levels of load. For younger adults the error rates were the greatest in either of the load conditions compared to the no load condition. In the semantic memory task, for older adults the error rates were the greatest in the load conditions. Surprisingly, error rates were the greater in the low load condition than the high load condition. For younger adults the error rates were the highest in the low load condition. There was no difference between error rates in the no load and high load conditions.

Dual Task Costs Analysis

In order to control for baseline differences in performance, dual task costs analysis was carried out. Figure 3.5 shows the younger and older adults' performance for memory retrieval response times in terms of dual task costs. It should be noted that this analysis could only be carried out on the response time data as there were very few errors in some conditions. In some cases there were no errors in the no load conditions and therefore a dual task cost could not be calculated due to division by zero errors.

Memory retrieval response times in terms of dual task costs were analysed in a 2 (Age Group) x 2 (Memory Task) x 2 (Memory Load) analysis of variance. The main effect of age group approached significance and demonstrated a greater proportional cost for older adults ($F(1,34) = 3.65$, $MSE = 0.09$, $p=0.07$), and greater costs as working memory load increased ($F(1,34) = 20.67$, $MSE = 0.02$, $p<0.01$). The interaction between age group and memory load approached significance ($F(1,34) = 3.85$, $MSE = 0.02$, $p=0.06$).

Figure 3.5 The proportional increase in memory retrieval response times for younger and older adults.



We were particularly interested in whether older adults' dual task costs were higher in the episodic condition. Therefore, two separate analyses were carried out on the dual task costs for each memory task. For episodic memory retrieval, the costs of dual tasking increased in line with load ($F(1,34) = 6.4$, $MSE = 0.02$, $p < 0.05$). There was also an effect of age group that demonstrated greater costs for the older adults compared to the young ($F(1,34) = 5.37$, $MSE = 0.13$, $p < 0.05$). The two-way interaction between memory load and age group was not significant. For semantic memory retrieval, costs increased in line with load ($F(1,34) = 16.8$, $MSE = 0.02$, $p < 0.01$). The main effect of age group and two way interaction between age group and memory load were not significant.

In order to compare the age effect in dual tasking between the present experiment and experiment 3.1 the effects sizes were calculated. For episodic and semantic memory retrieval the effect sizes were $d = 0.71$ and $d = 0.05$ respectively.

Speed error trade-off

Since we were concerned with both the speed of memory retrieval and the errors we investigated whether these two measures were related. In order to examine the speed error trade off between participants, we correlated the raw response time and error scores for all conditions. If participants are sacrificing response time to maintain accuracy, negative correlations would be expected. There was no evidence to suggest that the speed of retrieving from memory was related to the error rates as the correlations were either not significant or positive. However, for the episodic task the correlations were positive ($r = 0.46$, $p < 0.01$ for no load, $r = 0.78$, $p < 0.01$ for low load, and $r = 0.34$, $p < 0.05$ for the high load. For the semantic task, the correlations were positive ($r = 0.39$, $p<0.05$ for no load, $r = 0.53$, $p<0.05$ for low load, and $r = 0.28$, $p>0.05$ for the high load). These findings contradict the expectation based on a speed error trade off.

3.3.4 Discussion

Experiment 3.2 had two main aims. First, although evidence was found for an episodic/semantic distinction it was desirable to replicate the findings of experiment 3.1. Although the results of Experiment 3.1 were convincing, the age differences may be specific to the tasks used rather than there truly being a disassociation between episodic and semantic memory retrieval. Evidence for an episodic/semantic distinction would be more persuasive if the finding were replicated, and were consistent with the work carried out previously on episodic (Anderson et al., 1998) and semantic (Perfect & Rabbitt, 1993) memory retrieval. Second, the present experiment was an extension of the previous study in that we were considering recognition rather than recall. Older adults find episodic memory retrieval problematic in general but performance is improved with the increase in environment support. We therefore expected older adults' performance to be particularly impaired but the magnitude of the effect to be smaller than that found in experiment 3.1 where cued recall was used.

Consider first the effects observed using the absolute reaction times and error rates. As expected older adults' response times and error rates were the higher. Of particular interest was that for response times there was an age by load interaction which demonstrated that older adults overall found dual tasking problematic. This effect also interacted with task, showing that it was only in the episodic memory retrieval task that older adults had problems dual tasking.

The analysis of the error rates did not demonstrate any particular problems for older adults. We have already discussed the problems with the error rate analysis for the n-Back tasks. Again, with the tasks used in this study it is difficult to know whether a retrieval error has occurred or whether the error or no response is due to forgetting the items presented in the load conditions. The recognition procedure provided favourable retrieval conditions and both groups were able to maintain their accuracy reasonably well in the load conditions. A comparison of Tables 3.1 and 3.2 demonstrates that the use of the recognition rather than cued recall reduced the error rates for both groups. Furthermore, in experiment 3.1 there were a large number of no response errors and this procedure has minimised this problem. By maintaining accuracy for both groups the focus could be on the correct response data where we could be reasonably sure that load is appropriate. In other words, the participant has remembered the load items and recognised that one of the items belongs to a particular category or set.

As with the previous experiments, a dual task costs analysis was carried out to investigate whether older adults had problems dual tasking over and above the problems they had in the full attention condition. For semantic memory retrieval, older adults' response times in terms of dual task costs were equivalent, and increasing load had a similar effect for both groups. However, for episodic memory retrieval older adults found dual tasking particularly problematic. An analysis was not carried out on the error rate data as in some instance participants made no errors and divided attention costs could not be calculated. Moreover, it has already been noted how the interpretation of the error rate data is misleading.

One explanation for the slower response times in the no load episodic condition compared to the low load for younger adults is that the no load condition had a reading element. In the no load condition an item and episodic cue was presented at test. For the low load condition an episodic cue was only presented. Since for younger adults in the load condition, load was not problematic the reading time influenced performance. For older adults, load had an effect over and above the reading time effect.

So although there was an age effect in both the present study and experiment 3.1 the size of the effect was the greatest in the recall dual task (d = 1.52 compared to

d = 0.71). Under dual task conditions older adults are more penalised when recall memory is involved. Older adults have been shown to benefit from supportive retrieval conditions and although the age effect remained for the recognition version of the dual task used in the present experiment it was substantially smaller. Cued recall does require additional self initiated retrieval processes compared to recognition that has a large familiarity component. Therefore, with concurrent processing demands a more detrimental effect for older adults in cued recall is observed. This is consistent with previous research that have compared retrieval from free recall, cued recall and recognition (e.g. Anderson et al., 1998).

3.4 General Discussion

The primary goal of these experiments was to investigate age related differences in the effects of concurrent task on memory retrieval. In this chapter we attempted to minimise task trade-off effects by having participants perform concurrent processing in the context of a single task. These data provide strong support for the hypothesis that task domain moderates dual task costs in older adults. In Chapter 2 there was some indication that older adults have problems in dual tasking when retrieval from episodic memory is involved. Since reaction times and error rates were recorded for the retrieval tasks and the working memory load tasks, there were four measures to consider. This made the interpretation of the results problematic, and highlighted one of the potential problems with the dual task paradigm, particularly task and speed accuracy trade-offs. These problems were addressed in experiments 3.1 and 3.2 and a clear age effect of dual tasking only for episodic memory retrieval were found. For semantic memory retrieval we found age invariance of dual task cost largely because semantic memory is well preserved in normal ageing. It was also found that when a supportive retrieval environment was introduced (recognition dual task) the age effect was reduced. No doubt task difficulty and complexity have a role in dual task performance, but these results are best explained by a domain specific account. That is, age differences in dual task performance may be observed only in particular domains of cognition, rather than at different levels of difficulty. Difficulty manipulations in the present experiments tend to affect both age groups in the same way.

There have been mixed results in the literature with regard to whether older adults are poorer at dual tasking. The slowing - complexity hypothesis or task difficulty account has been frequently used in the literature to explain the discrepancy (e.g. Somberg & Salthouse, 1982). The task difficulty account of older adults suggests that dividing attention is just one of several ways of increasing the overall complexity of the task. That is, the complexity hypothesis predicts older adults' performance will produce proportionally poorer performance compared to younger adults. There was no support for this in the present experiments as disproportionate dual task costs were found for episodic memory retrieval. This is consistent with a number of studies which have found disproportionate age related dual task costs (e.g. Tsang & Shaner, 1998). Also, it is interesting that age differences have been found in less complex tasks than more complex tasks (e.g. Korteling, 1991). This is consistent with the results of experiment 3.1 in particular where disproportionate dual task costs were found in the episodic version of the task. In this experiment it could be argued that the semantic version of the task was more demanding, as the response times and error rates were larger in this task. Also, the complexity hypothesis would predict that increasing the demands of the dual task would exaggerate the age effect. This was not the case as working memory load affected both groups in the same way. This is against the work of Tsang & Shaner (1998) who found that the age effect was exaggerated when the demands were manipulated within task.

This sort of account is consistent with the resource deficit model of ageing (e.g. Craik, 1986) and an account based on generalised slowing (e.g. Somberg & Salthouse, 1982). The attentional resource account suggests that resources decrease with age resulting in less resource to deploy to the component tasks. The cognitive slowing view suggests that concurrent tasks reduce the amount of time available for processing and since speed of processing declines with age, older adults will be particularly impaired on dual tasks. None of these accounts is sufficient to explain all the instances of age related differences in dual task performance.

Another theory suggests that task domain moderates dual task costs in older adults. For example, Tun et al. (1992) argued against the difficulty account as they found that increasing the demands within task and increasing the demands by the requirement to divide attention do not necessarily bring about the same effect. The authors suggest that it is only in certain domains of cognition that older adults have problems in dual tasking. Semantic memory has been found to be relatively well preserved in normal ageing and retrieval is likely to occur in a retrieval automatic manner. It has already been suggested that memory retrieval involves two components: effortful retrieval processes and a familiarity component. When the material is familiar and over-learned there is less need to draw on effortful retrieval processes. Furthermore, there is no contextual information to retrieve so older adults are as capable in these circumstances.

In domains of cognition, which show the greatest impairment with increasing age like episodic memory, adding a concurrent task will cause more interference. As already discussed in detail, episodic memory retrieval is particularly problematic for older adults. This is particularly the case if the individual has to generate cues. Introducing a concurrent activity will cause more interference for older adults especially if the task overlaps in terms of processing mechanisms. So although the task may be complex, if there is a large familiarity component as in semantic memory no age difference is found. This is consistent with the pattern observed in language processing (Tun & Wingfield, 1993) and the implicit memory domain (Isingrini et al., 1995) where there is either an absence or only a minimal effect of age.

With the particular tasks used in this study, task domain seems to be the critical moderator variable, and replicates earlier work on category exemplar generation (Perfect & Rabbitt, 1993) and episodic memory (e.g. Anderson et al., 1998). Further attention should be focussed on particular task combinations in the dual task setting, particularly those that consider task domain as an important mediator, because this may be central as to why an age effect in dual tasking is sometimes found and sometimes not. To this end, Experiment 4.1 will use the n–Back procedure to further examine whether older adults have problems with dual tasking when familiar overlearned material is used.

4. Age Differences in Dual Task Studies of Language Processing

4.1 Experiment 4.1

4.1.1 Introduction

In the previous chapter it was found that older adults have particular problems co-ordinating tasks when episodic memory is involved. However, when semantic memory is involved, older adults are no more penalised than their younger counterparts. In this experiment we further investigate the effects of concurrent processing on the performance on the familiar activity of language processing. There are two main issues to consider. First, if ageing brings about a general decline in cognitive resources or speed of processing it is expected that if the complexity of a language processing task is increased, older adults will be penalised compared to the young. Second, language processing is an overlearned activity and the process involved may be independent and increasing the complexity of the task by introducing a concurrent activity may have no disproportionate effect on the old.

Ageing and Language Comprehension

There are a number of reasons why it may be expected that older adults find language processing particularly problematic. For instance, speech is carried out in a rapid manner and since speed of processing is know to decline with age (e.g. Cerella, 1990) one would expect older adults to find speech processing more difficult. As well as speech perception it might be expected that comprehension is problematic for older adults as temporary storage of incoming information is required for the integration of sounds into words and the organisation of the words to make the sentence understandable (Tun & Wingfield, 1993). Intuitively you would expect older adults to perform poorly in language perception and comprehension tasks but performance remained stable across the life span. Burke & Mackay (1997) suggested that older adults are as capable as their younger counterparts at language comprehension but language production shows age effects. Burke & Mackay argue that older adults are able to use contextual information to aid their comprehension and compensate for any general declines in cognitive performance.

As already described, older adults have been found to have problems on tasks that depend on fluid intelligence but crystallised intelligence remains stable across the life span. Verbal IQ as measured by such tests as the NART stays stable across the life span and in fact older adults are consistently found to score more highly on such tests. Madden (1988) suggests that although sensory deficit may accompany normal ageing and make word recognition difficult, sentence context benefits older adults. Madden carried out an experiment looking at the effects of stimulus degradation and sentence context on performance. Age differences in lexical speed were greater for the degraded words that suggested age related slowing in the extraction of feature level information. But it was found that older adults could compensate for this difficulty by relying on the sentence context. The author suggests that in the process of recognition of a word, sentence context leads to the automatic activation of semantic information. Since we have already suggested that semantic memory is well preserved in normal ageing we would expect age invariance on language tasks that allow facilitation through sentence context.

The ability to process verbal material is attained at an early age and therefore activities involving language processing may be relatively automatic in some circumstances. It may be the case that language processing is also a domain that is functionally independent and introducing a concurrent activity is unlikely to be detrimental to younger or older adults' performance.

Dual Task Studies of Language Processing

Early studies of divided attention and language processing have investigated age differences in dichotic listening studies. Typically, participants are presented with digits, letters or words simultaneously to both ears and then asked to report digits first from one ear then the other. Tun & Wingfield (1993) reviewed the literature on ageing and dichotic listening tasks and found no age difference in the performance of the first ear reported, but age differences were found on the second, although this was only the case if correct order of recall was not required. For example, an early study by Inglis & Caird (1963) found age equivalence for free recall of digits from the first channel reported, but recall accuracy differences between the first and second channel reported increased significantly with age. The authors suggested that the age effect only in the second channel reported was due to this material being held in short term memory while the material from the first channel was being reported. However, this interpretation can be questioned as some studies that have matched age groups on short-term memory or working memory measures such as digit span have still found age differences in performance.

The pattern of results across a number of studies seem to be in line with the slowing complexity hypothesis as age effects tend to be exaggerated with increases in task difficulty. However, it is questionable whether dichotic listening tasks are in fact truly dual tasks. Kieley (1991, reported in Hartley, 1992) carried out a meta-analysis on a combination of dichotic listening tasks and dual tasks and found a large overall effect size but the effects were not homogeneous. When the studies composed of dichotic listening studies were separated from the dual task studies, there was a strong homogeneous age effect for the dichotic listening tasks. This suggested that the factors that produced the age effect for dichotic listening tasks and dual task are distinct.

Unlike dichotic listening tasks, sentence verification tasks use meaningful language as the stimuli. Studies have consistently found when a sentence verification task is concurrently performed with a secondary task older adults are no more penalised than are the young. For instance, Gick et al. (1988) used a version of the Daneman & Carpenter (1980) working memory task to investigate age difference in dual task performance. Participants were required to verify a series of sentences, and at the end of the series recall the last word of each sentence. There was no effect of divided attention, but when difficulty was increased by using a negative rather than positive grammatical form an age effect emerged. This work is consistent with Tun et al. (1992) who investigated the effects of age and division of attention on rapid speech processing. In the single task condition when speech rates were increased, older adults were differentially affected when they were required to immediately recall a spoken passage. However, the further requirement to divide attention did not exaggerate the effect. The authors concluded that increasing the demands of the task (by varying speech rate) and increasing the demands by the requirement to divide attention are independent and do not necessarily bring about the same effect.

In the present experiment, younger and older participants were compared on a sentence verification task, with and without a concurrent working memory load. The n-Back procedure in experiment 3.1 was used. The sentences used by Daneman & Carpenter (1980) were presented to the participant and they were required to decided whether they were true or not (e.g. cats usually like to hunt mice.) In this experiment we used different sentences which may be more appropriate to investigate linguistic abilities.

Rather than making a semantic judgement participants were required to decide whether sentences were grammatically correct (e.g. the man ate the because).

4.1.2 Method

Participants

Eighteen younger adults (range 17-27, mean age 23.6 years, SD 2.7 years) and 18 older adults (range 60-79, mean age 69.3 years, SD 6.3 years) participated in the experiment. The young volunteers were undergraduate and postgraduate students from the University of Bristol. The older adults were volunteers selected from a pool of older adults registered with the Experimental Psychology Department. On average the younger adults were better educated than the older adults (17.9 versus 12.8 years of education respectively, $t(34) = 6.04$, $p<0.01$). Older adults' scores were equivalent on the NART (raw scores of 40.6 for younger adults and 38.5 for older adults, $t(34) = 1.3$, $p>0.05$). Years of education were entered as a covariate in the main analysis. The same participants also volunteered for Experiments 5.1, 6.1 and 6.2 to be described in Chapters 5 and 6. The order of completion of Experiments 4.1, 5.1, 6.1 and 6.2 was counterbalanced across subjects with a one-week interval between each testing session.

Materials

Half of the sentences used in the verification task were either grammatically correct (e.g. The barrel was very heavy) or grammatically incorrect (e.g. The burglar stole the true). Nine lists were randomly constructed from a master list of 126 sentences (see Appendix G). Each list contained 14 sentences and were randomly assigned to either the practice or experimental sessions. There was one practice session and two experimental sessions for each no load, low load (2-back) and high load (3-back) conditions. Stimuli were presented on a 14-inch monitor in 36 point Arial font.

Procedure

Prior to the experimental session each participant received detailed instructions regarding the nature of the tasks (Appendix H). A pictorial representation of the no load and the load (2–Back and 3–Back) conditions accompanied the instructions (see figure 4.1 for example). Participants were required to demonstrate to the experimenter that they understood the instructions by completing the printed examples.

In order to ensure that participants understood the requirements of the task, a practice session of one block for each condition was given before the start of the experimental block. In the experimental block there were two sessions each of the no load, the low load and the high load tasks; these were presented in counterbalanced order across participants.

An example of the procedure is given in Figure 4.1. The no load and load conditions for the sentence verification tasks are displayed. All responses were made on a standard IBM keyboard with the 'Z' and '/' keys marked as either 'YES' or 'NO'. Participants used their index fingers and the markings of 'YES' and 'NO' were alternated between the 'Z' and '/' keys, across participants.

No Load Condition

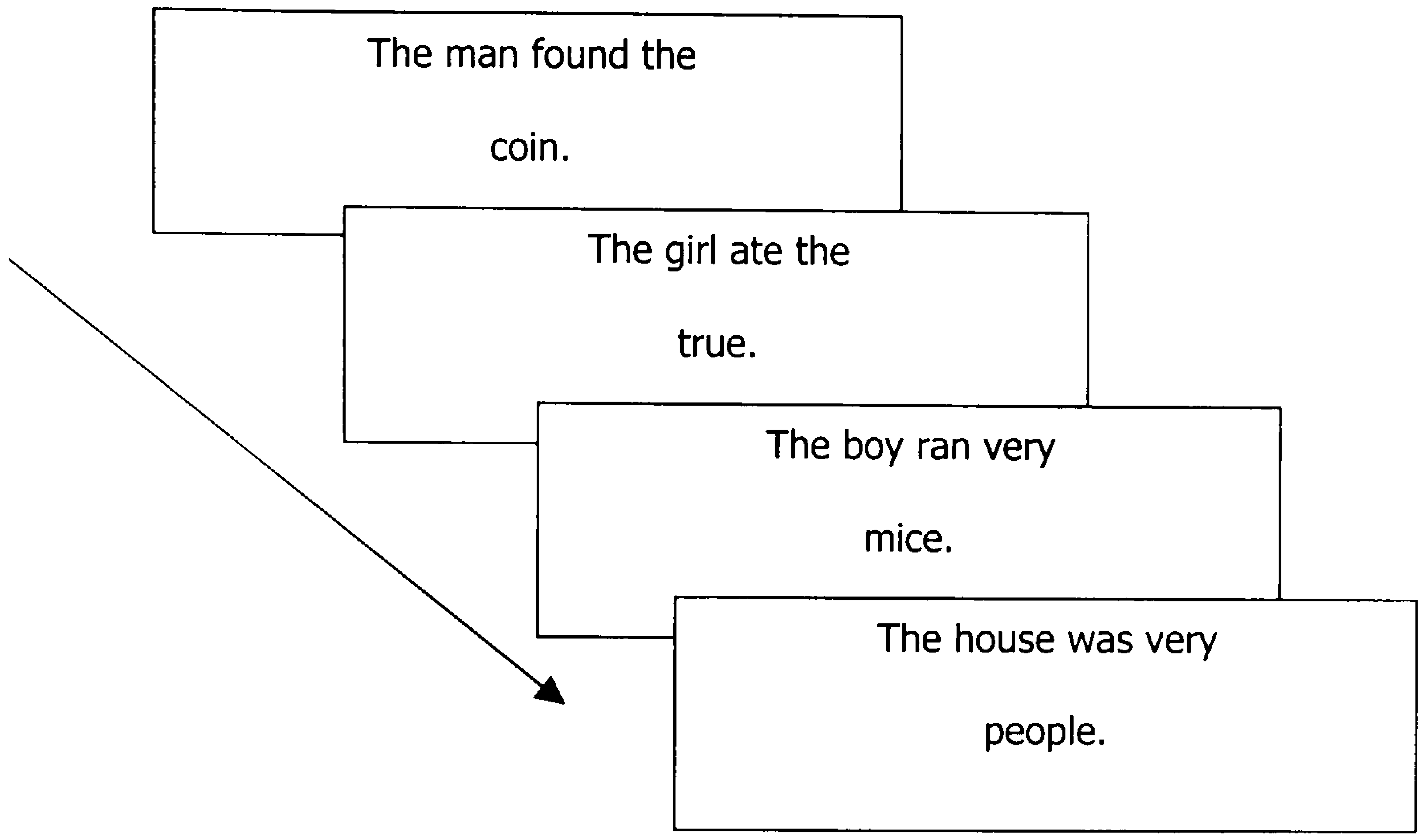
In the no load condition, the sentence verification task consisted of the presentation of either a grammatically correct or incorrect sentence on the computer. A partially completed sentence (e.g. The water was almost) appeared on the computer screen with the final word of that sentence (e.g. clear) underneath. Participants were instructed to decide whether after adding the word underneath to the partially completed sentence above, made a grammatically correct sentence. Participants were required to respond either yes or no on keys marked on a standard computer keyboard as quickly and as accurately as possible with a maximum time limit of seven seconds. Sentences were presented at seven-second intervals. This interval was based on pilot work undertaken prior to the study. No feedback was given to the participant. Participants were able to change their response and the final response made during the seven-second interval was recorded automatically by the computer.

Low Load Condition (2-Back)

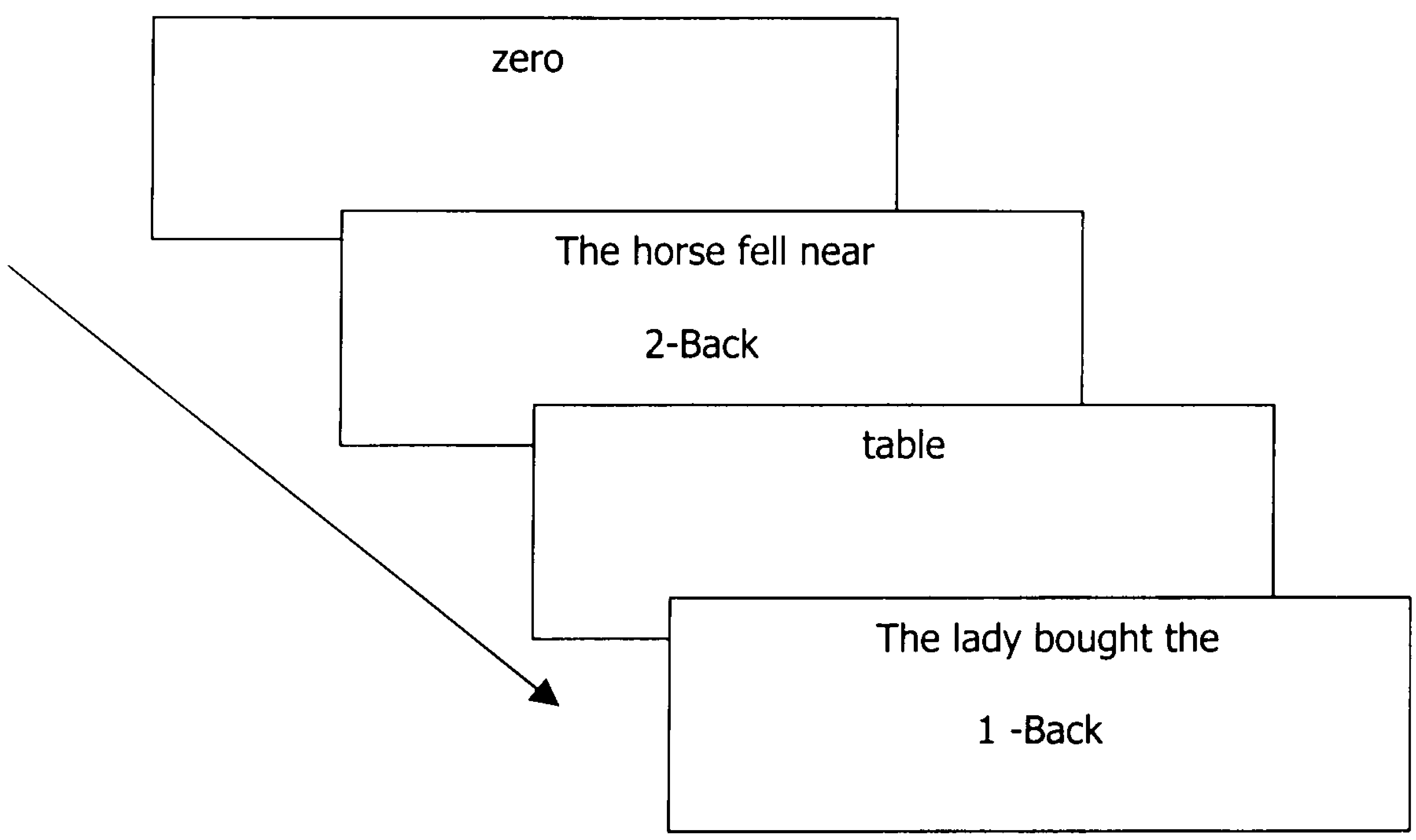
In the low load condition, words were presented on the computer screen for seven seconds. After each word disappeared a prompt was presented on the computer screen for seven seconds. The prompt consisted of either of the following signals, an asterisk (*), 1–Back or 2–Back. If the * prompt appeared this indicated that no response was required on this occasion. When either the 1–Back or the 2–Back prompt appeared a partially completed sentence appeared at the same time above the prompt (see lower panel of Figure 4.1 for an example). If the 1–Back prompt appeared the participant had to think back to the word that that had just disappeared from the computer screen, and decide whether after adding this word to the partially completed sentence on the computer screen, the sentence was grammatically correct, and respond yes or no on the

Figure 4.1 Example of the procedure – Sentence verification no load and load conditions

No Load Condition



Load Conditions (n – Back)



computer keyboard. If the 2–Back prompt appeared, participants were required to use the word from two positions back. Thus, participants were required to keep in mind the previous two words presented in order to respond appropriately when the prompt appeared. The 1–Back signal was included so that participants could not prepare a response to the two back signal in advance. The no back signals (*) were included as fillers so that each cue was only tested once and again their inclusion made it difficult for participants to prepare a response. A total of four 'no response' prompts were used in each experimental session. In each experimental session there were 10 test trials. Eighty percent of the prompts were the 2–Back cue and 20% were the 1–Back cue. The computer recorded the participants' responses.

High Load Condition

In the high load condition, the task requirements were the same as in the low load condition except that the participants were required to keep in mind the previous three words that had been presented. On this occasion as well as the no response (*), the 1-Back and the 2-Back conditions, participants were also required to respond to a 3-Back condition. Again, there were four no response prompts used as fillers. Eighty percent of the test trials were for the 3-Back cue, with 10% for each of the 2–Back and 1–Back cues.

4.1.3 Results

Because the age groups differed in years of education this measure was initially entered as covariates in the analyses. However, the covariate was not significant in any analysis and are not discussed further. Post hoc analyses were conducted using the Bonferroni procedure with a significance level of $p < 0.05$ unless otherwise stated.

Analysis of Absolute Response Time and Error Rate Data

The absolute response time and error rates for sentence verification under conditions of no load and load are shown in Table 4.1.

Table 4.1 Mean (and SD) response latency (in msec) and errors for the sentence verification task under no load, low load (2-back), or high load (3-back) conditions

	Younger Adults				Older Adults			
	Response latency		Errors /20		Response latency		Errors /20	
	M	SD	M	SD	M	SD	M	SD
No Load	1632	366	0.3	0.5	2536	757	1.5	1.2
Low Load	2505	516	1.5	1.3	4219	929	3.3	2.5
High Load	2642	519	1.4	1.2	4570	842	4.8	1.9

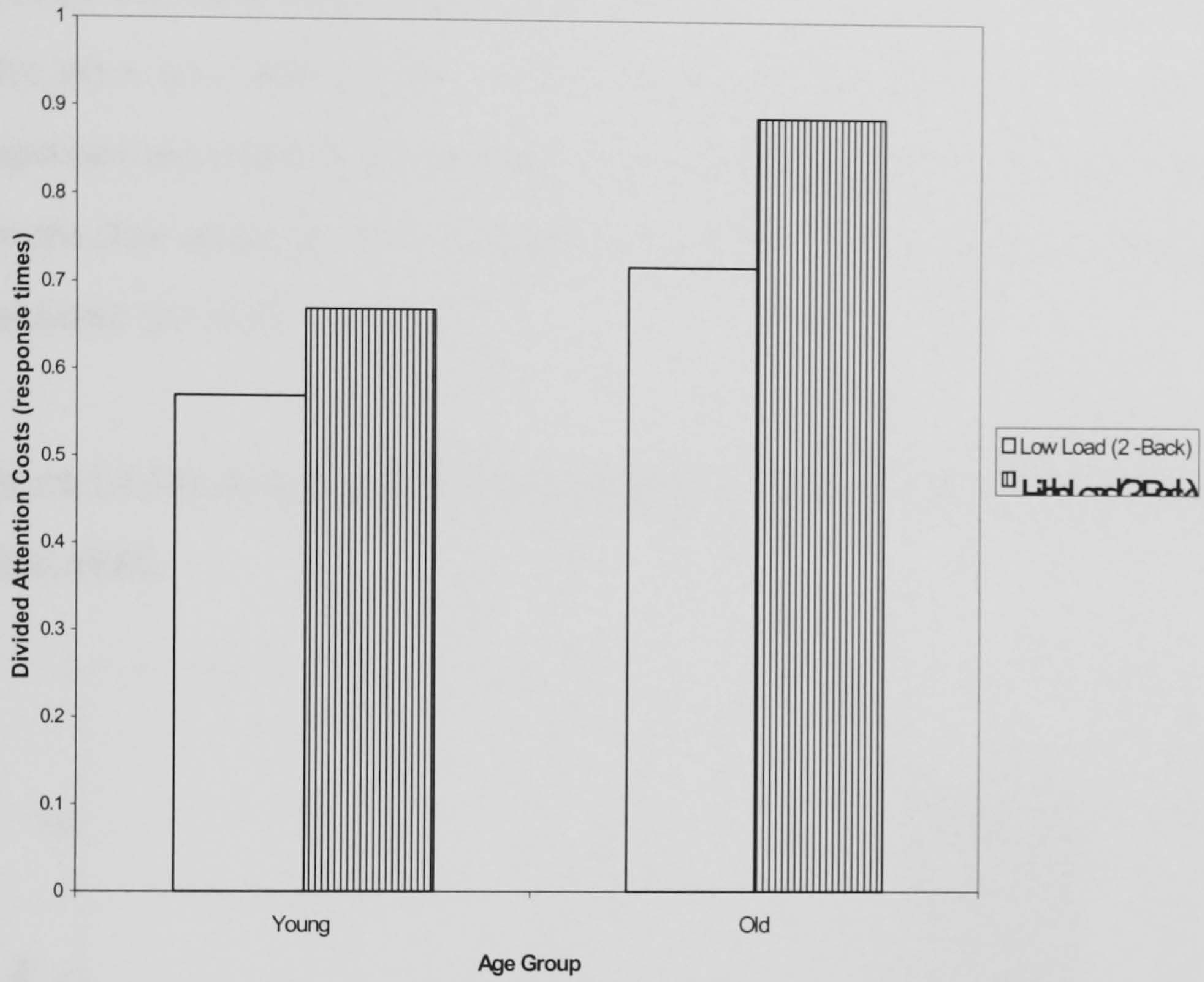
Sentence verification response times were analysed in a 2 (Age Group) x 3 (Memory Load) analysis of variance. This analysis revealed that response times were generally slower for the older adults ($F(1,34) = 53.7$, $MSE = 1154432$, $p < 0.01$) and slowed in line with working memory load ($F(2,68) = 190$, $MSE = 126878$, $p < 0.01$). The interaction between working memory load and age group demonstrated that older adults were particularly impaired when carrying out a sentence verification task with a concurrent load ($F(2,68) = 20.7$, $MSE = 126878$, $p < 0.01$). An analysis of simple main effects, using the Bonnferroni procedure, found that older adults' response times increased in line with working memory load. For younger adults there was a significant difference between the no load and either of the working memory load conditions.

The next set of analysis was carried out on the sentence verification errors. A 2 x (Age Group) x 3 (Working Memory Load) analysis of variance was carried out on the error data. This analysis showed that the older adults produced more errors ($F(1,34) = 30.42$, $MSE = 4.00$, $p < 0.01$) and accuracy was impaired as working memory load increased ($F(2,68) = 28.27$, $MSE = 1.64$, $p < 0.01$). Post-hoc comparisons using the Bonferroni found error rates increased in line with working memory load. The interaction between working memory load and age group ($F(2,68) = 6.59$, $MSE = 1.64$, $p < 0.01$) showed that older adults' accuracy was particularly impaired when carrying out a sentence verification task with a concurrent load.

Dual Task Costs Analysis

In order to control for baseline differences in sentence verification response times and error rates, a dual task costs analysis was carried out, as advocated by Somberg & Salthouse (1982). The raw data were transformed into a dual task cost measure (i.e., (dual – single)/single). Figures 4.2 and 4.3 show the younger and older adults' sentence verification performance for response time and error rate in terms of dual task costs.

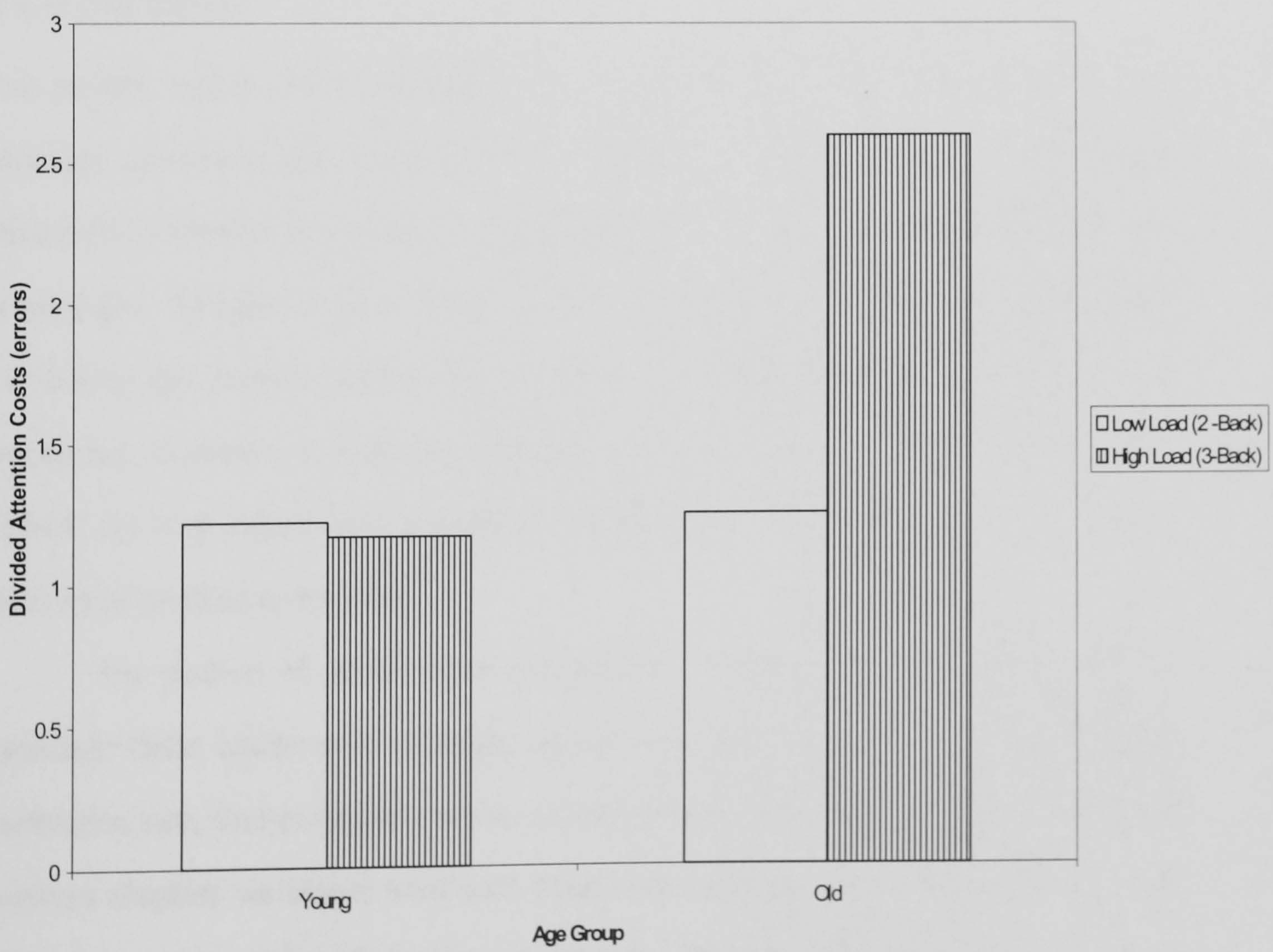
Figure 4.2 The proportional increase in sentence verification response times for younger and older adults.



Age differences between sentence verification response times in terms of dual task costs were analysed in a 2 (Age Group) x 2 (Memory Load) analysis of variance. The main effect of age group was unreliable and demonstrated that the cost of dual tasking was equivalent for both groups. The main effect of working memory load showed that the cost of dual tasking increased as working memory load increased ($F(1,34) = 6.7$, $MSE = 0.04$, $p < 0.05$). The interaction between age group and working memory load was unreliable and showed that the cost of dual tasking was equivalent as working memory load increased. In order to compare the age effect across studies an effect size was calculated ($d = 0.5$).

An equivalent analysis of dual task costs was performed on sentence verification error rates. The main effect of age was unreliable which showed that overall the cost of dual tasking was equivalent for both groups. A main effect of memory load simply showed that there was a greater proportional cost as working memory load increased ($F(1,34) = 5.12$, $MSE = 1.49$, $p < 0.05$).The age group x working memory load was significant and showed that increasing working memory load had a negative impact only for the older adults. In order to compare the age effect across studies an effect size was calculated ($d = 0.4$).

Figure 4.3 The proportional increase in sentence verification error rates for younger and older adults.



Speed Error Trade-Off

Since we were concerned with both the speed of verifying sentences and the errors we investigated whether these two measures were related. In order to examine the speed error trade off between participants, divided attention costs for speed and error rates were correlated. If participants are sacrificing response time to maintain accuracy, negative correlations would be expected. However, for both the low load and high load conditions the correlations were not significant ($r = -0.31$, $p > 0.05$ for low load, and $r = -0.02$, $p > 0.05$ for high load) thus contradicting the expectation based on a speed error trade off.

4.1.4 Discussion

The present experiment investigated whether older adults perform more poorly on a language processing task with concurrent processing demands. We were particularly interested in whether older adults would find concurrent processing demands particularly problematic. Perhaps if older adults suffer a reduction in processing resource with increasing age poorer performance would be expected when a concurrent task is introduced. However, if language processing is carried out in a relatively automatic manner we may expect both younger and older adults' performance to be resilient to concurrent processing demands.

The pattern of performance for absolute measures of performance was as expected. Older adults were generally slower and made more errors on the sentence verification task, and particularly in the concurrent load conditions. However, as with the previous chapters we should treat such results with caution. The results would be more convincing if the confounding effect of baseline differences in performance could be eliminated.

Therefore, more important to the present investigation is the dual task costs analysis. Consider first the dual task costs for the response time data. After controlling for baseline differences in performance there was no evidence that older adults found dual tasking particularly problematic. Furthermore, when the task demands were increased by manipulating the working memory load this did not bring about an age effect. From this it can be concluded that task difficulty cannot account for the pattern of results. Increasing the working memory load was an effective manipulation of task difficulty as the costs did increase the same for both groups. These results are consistent with previous finding which have shown that adding a concurrent task has similar effects for the young and the old. Certainly there is a performance decrement but this is equivalent for both age groups.

An examination of Figure 4.2 shows that although the costs overall were equivalent and increased in line with load they were particularly high (young: 0.57 and 0.67; old 0.72 and 0.89 for the low and high load respectively). Therefore, the dual tasks can be considered demanding. The slowing complexity hypothesis suggests more complex effortful tasks would be more problematic for older adults. This certainly is not the case, as younger adults' costs are particularly high and therefore it would be expected that older adults' costs to be larger under the task complexity view. In chapter 8 we discuss the notion of complexity in more detail but at this point it is worth comparing the results from perhaps experiment 3.2. In the episodic recognition task, for younger adults the cost of dual tasking was minimal but we still find a disproportionate cost for older adults. Therefore, whether we find disproportional dual task costs is unrelated to whether younger adults find the dual task situation particularly problematic. A complex task can not simply be defined as a task that suffers the most under dual task conditions.

What is interesting is that in previous studies when difficulty has been increased within a task rather than by introducing a concurrent task, age effects have emerged (e.g. Daneman & Carpenter, 1980; Tun et al., 1992). This suggests that the processes involved in language abilities are independent and difficulty manipulations within domain can be more detrimental to older adults' performance. However, concurrent activities have little effect for both age groups as perhaps they do not share the same processing mechanism or tap the same processing resources. Much like semantic memory retrieval that was examined in chapter 3, task difficulty is unrelated to dual task costs.

An equivalent analysis was performed on the error rate data. Again there was no overall effect of age. Increasing the working memory load had no effect for the younger participants but it did have a negative impact on older adults' performance. As noted earlier the error rate data should be treated with caution. One problem with the n-Back procedure is that when an error is made, it is difficult to know whether the error has occurred due to a failure to retrieve the cue n-Back, or whether it is a sentence verification error. Since older adults are widely reported to have difficulties in working memory (e.g. Wright, 1981) it is more likely that the cue n-Back had been forgotten and that is why errors increased with load for older adults. The correct response time data can be considered the more appropriate measure of dual task performance. With a correct response we can be sure that the correct word has been retrieved n-Back and used to make an appropriate response on the sentence verification task. Therefore, the slowing that results from concurrently keeping in mind word strings while verifying sentences was the focus here.

The experiment provides further support that it is only in certain domains of cognition that older adults have particular problems in dual tasking. Although intuitively one would expect language processing to be particular problematic for older adults because of the complexity of such processes, this is not necessarily the case. In fact, language processing is so well overlearned that the elderly are able to compensate for any general declines in speed of processing or working memory by using familiar overlearned processes. The dual task costs were high for both groups; therefore, it was more that the processes involved are not impaired in ageing rather than being automatic. Automatic would suggest that the processing operations are carried out without much cognitive effort, but it was an effortful task. It was just that younger and older adults were as capable.

The results of this experiment are also consistent with the environmental support hypothesis (Craik, 1986). In experiment 3.1 we found that for episodic cue recall older adults found the costs of dual tasking particularly problematic. However, in the semantic version of the task there was no age effect due to the familiar nature of the material and the fact that the participants were not required to think back to a previous learning event. In experiment 3.2 again we find no age effect of dual tasking for the semantic version of the task because of the familiarity component. In the episodic recognition version of the task there was again an age effect but not as strong as that found in experiment 3.1 (effect sizes of $d = 1.52$ and $d = 0.71$ respectively). So although older adults find episodic memory problematic, performance is enhanced when tasks benefit from environmental cues and rely less on self initiated processes (Craik, 1986). When tasks draw on effortful retrieval processes rather than those processes involved in familiarity older adults are particularly impaired, and even more so under conditions of divided attention. In language processing tasks you would expect less involvement of self initiated processing and as well as older adults benefiting from the familiarity of the processes involved they are able to capitalise on contextual information to aid their performance.

Experiments 2.1, 3.1 and 3.2 suggest that when tasks involve retrieval of well learned facts from semantic memory, concurrent processing demands are no more detrimental to older adults' performance. In the present experiment we found that the involvement of semantic memory in language processing facilitates performance on dual tasks. That is, language is an overlearned skill and both younger and older adults' performances are impaired to the same extent. In the next chapter we consider another domain of cognition that is learned from an early age and involves the retrieval of well-learned facts from semantic memory, namely, the effects of concurrent processing demands on mental arithmetic.

5. Age Differences in Dual Task Studies of Mental Arithmetic

5.1 Experiment 5.1

5.1.1 Introduction

In the previous chapter, evidence was presented that older adults were no more penalised than the young on a sentence verification task. Since such tasks involve skilled processes and retrieval from semantic memory the addition of a concurrent task may perhaps result in equivalent dual task costs. In such circumstances older adults are able to compensate for more general declines in cognitive performance by drawing on processes and skills that they have developed throughout their lifetime. The present chapter considers another domain of cognition that draws on overlearned information. We consider the effects on performance of concurrent processing demands on mental arithmetic. We will argue that mental arithmetic facts are represented in a semantic language like system (Geary & Brown, 1991) and the access and use of such representations are preserved in normal ageing. What follows is a brief introduction to cognitive ageing and mental arithmetic. The evidence on older adults' mental arithmetic performance within a dual task will be considered before describing the present study.

Mental Arithmetic Performance in Older Adults

Although, there are mixed results in the literature, much of the evidence does point to age equivalence on mental arithmetic tasks. For instance, Birren & Botwinick (1951) found faster retrieval rates for younger adults for a mental addition task but no age difference in error rates. Charness & Campbell (1988) found that in a simple multiplication task there was no age difference in response times but older adults' error rates were lower than the young. Finally, Schaie, Willis, Jay, & Chipuer (1989) found that on a paper and pencil mental addition task, after controlling for age differences in perceptual speed, performance deteriorated with increasing age.

A more recent study has gone further by examining performance in terms of rates of retrieval of arithmetic facts and strategies used to reach a solution. There is evidence that suggests that there are no age differences in the rate of retrieving arithmetic facts from long-term memory. Geary & Brown (1991) suggest that problem solving strategies and the rate of retrieval from semantic memory influence performance on simple mental arithmetic tasks. They proposed that solving a problem involves first setting a confidence criterion followed by an attempt to retrieve the solution of the problem. If the activation of the candidate solution does not pass the confidence criterion, retrieval is attempted again or a backup strategy is used. Two types of strategy are used in simple mental arithmetic. First, decomposition involves the breaking down of the problem into simpler problems. Verbal counting is another strategy often used. Older and younger participants were presented with a simple addition problem (e.g. 4+2) which they were required to solve. After every test trial participants were required to report the strategy they used to reach the solution. The strategy type was either direct memory retrieval, verbal counting or decomposition. The data supported the view that domains of cognition that rely on semantic memory are well preserved in normal ageing. Older adults used memory retrieval the most frequent and relied less on backup strategies to aid their performance. When the retrieval trials were analysed in a multiple regression analysis the age difference in reaction time was restricted to the intercept of the regression equation. This suggested that processes such as stimulus encoding and strategy selection were problematic for older adults. There was also no difference in error rates which suggest both groups had a stringent confidence criterion (i.e. there was no evidence of age differences in speed accuracy trade off). Overall, reaction times were greater for older adults but there was no difference in the retrieval of mental arithmetic facts. However, older adults may have been slower at encoding digits and verbally responding to produce an answer.

A study by Salthouse & Coon (1994) investigated age differences in mental arithmetic by having participants carry out a verification subtraction task. In this experiment participants were presented with problems of which half had borrow operations and half did not. Although older adults' response times were greater overall there was no age difference in borrowing operations after no borrow response times were controlled for. A second study investigated age differences in sequential and hierarchical problems. Sequential problems comprised up to seven mental operations (e.g. 3+3+4+2-6+3+1). A hierarchical problem also involved up to seven mental operation but with brackets inserted (e.g. [3+4]-[2+5]-[3+4]+1). In the hierarchical problem it is necessary to keep in mind intermediate results before the final solution is calculated. It was found that older adults were slower with hierarchical problems and particularly slowed as the number of operations increased. These results were consistent with the idea that older adults have a working memory deficit and when parsing was required it was not surprising that older adults' performance was impaired.

Verhaeghen, Kliegl, & Mayr (1997) carried out a study to investigate two factors that may mediate age related differences in cognitive tasks. We have already discussed a reduction in processing speed as an important factor contributing to age differences in performance. The authors also investigated coordinative factors as a possible source of age related differences in performance that is, those processes that are involved in the scheduling and temporary storage of information. In this study they used the time-accuracy methodology to disassociate the two factors of processing speed and coordinative factors in mental arithmetic tasks.

Like the study carried out by Salthouse & Coon (1994) sequential and hierarchical problems were used in the tasks. Sequential complexity was manipulated by increasing the number of mental operations in the problem. Coordinative complexity was introduced using hierarchical problems that included bracketing. The authors were interested in whether speed of processing and coordinative factors could be disassociated. In the earlier study by Salthouse & Coon (1994) it was found that response times in sequential and hierarchical problems shared over 80% of the age related variance and from this concluded age difference in mental arithmetic performance was in line with a speed of processing account of cognitive ageing. Verhaeghen et al. (1997), using the time accuracy methodology, were able to eliminate the influence of output processes on performance and concentrate on central and input processes. There was no age effect in the sequential tasks that provided evidence for age equivalence in the access of semantic facts needed for the competition of arithmetic problems. However, for the hierarchical tasks there was a clear age effect which led the authors to conclude there are two distinct processing modules involved in cognitive ageing. One module involves access to semantic memory where no age effect was observed. The second module involves the computing of intermediate results, which requires the coordinative processes in working memory.

Dual Task Studies of Mental Arithmetic

From the previous account it would seem that in basic arithmetic tasks semantic memory retrieval is implicated and age differences in performance do not emerge. We now turn to the joint effects of age and divided attention on the performance of mental arithmetic tasks. Babcock & Salthouse (1990) used a working memory paradigm to investigate age related changes in dual task performance. The authors were primarily concerned with whether age differences in performance of complex tasks would emerge when there is an increased need in the central executive involvement (see section 1.2.2 for discussion of the central executive component of working memory). In other words, the authors were concerned with whether the management of additional processing demands would affect task performance. In the study participants were presented with a series of arithmetic problems and had to respond with the correct solution while remembering the last digit in each problem. After a series of problems, participants were required to recall the string of numbers they had been remembering. As might be expected there was a main effect of age indicating that overall older adults' performance was poorer. However, there was no interaction between age and task (single versus dual). This was the case in both absolute and relative terms. A second experiment was carried out using a different group of older adults with a greater age range. Using the same procedure a significant difference in ratio scores was found. The authors suggested that the differences in the groups tested between experiments led to the effect. This assertion is questionable and although there was a significant difference between groups the effect size was relatively small.

In the present experiment, younger and older participants were compared on a mental arithmetic task, with and without a concurrent working memory load. The n-Back procedure that was used in experiments 3.1 and 4.1 was used. Although there are discrepancies in the literature as to whether under conditions of divided attention older adults would find mental arithmetic problematic, the evidence points to age invariance. Since we acquire the skills and knowledge of mental arithmetic from an early age, this overlearned activity is likely to be resilient to concurrent processing demands for both age groups. We expected that in domains of cognition that are relatively well preserved in normal ageing, like mental arithmetic, adding a concurrent task would not result in disproportional costs. However, we may expect an age effect to emerge if the task demands are increased if task difficulty is the important factor.

5.1.2 Method

Participants

Eighteen younger adults (range 17-27, mean age 23.6 years, SD 2.7 years) and 18 older adults (range 60-79, mean age 69.3 years, SD 6.3 years) participated in the experiment. The young volunteers were undergraduate and postgraduate students from the University of Bristol. The older adults were volunteers selected from a pool of older adults registered with the Experimental Psychology Department. On average the younger adults were better educated than the older adults (17.9 versus 12.8 years of education respectively, $t(34) = 6.04$, <0.01). Older adults' scores were equivalent on the NART (raw scores of 40.6 for younger adults' and 38.5 for older adults, $t(34) = 1.3$, $p>0.05$). Years of education were entered as a covariate in the main analysis.

Materials

Simple mental arithmetic problems were constructed each of which required two mental operations and involved either subtraction or addition. Digits in the problem and the solution were greater than zero and lower than 10 (e.g. 3+1+4 = 8). There was an equal number of true and false solutions. There was a master list of 126 problems, and each problem was randomly assigned to nine lists of 14 problems (see Appendix I). Each list was then randomly assigned to each of the nine conditions (i.e. the no load, low load and high load practice sessions, and two experimental sessions each for the no load, low load high load conditions). Stimuli were presented on a 14-inch monitor in 36 point Arial font.

Procedure

Prior to the experimental session each participant received detailed instructions regarding the nature of the tasks (Appendix J). A pictorial representation of the no load and the load (2–Back and 3–Back) conditions accompanied the instructions (see Figure 5.1 for example). Participants were required to demonstrate to the experimenter that they understood the instructions by completing the printed examples.

In order to ensure that participants understood the requirements of the task, a practice session of one block for each condition was given before the start of the experimental block. In the experimental block there were two sessions each of the no load, the low load and the high load tasks, presented in counterbalanced order across participants.

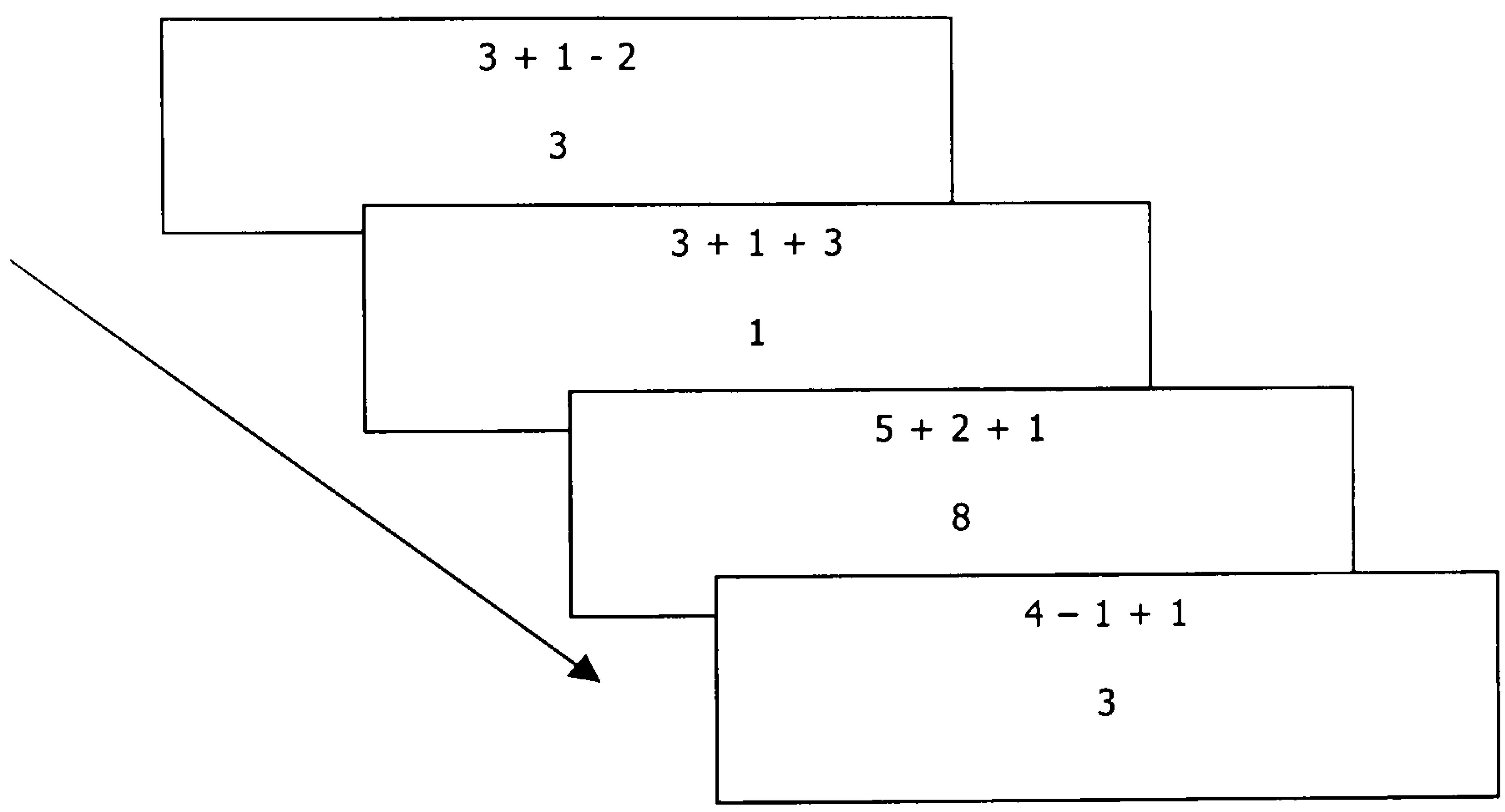
An example of the procedure is given in Figure 5.1. Displayed are the no load and load conditions for the mental arithmetic task. All responses were made on a standard IBM keyboard with the 'Z' and '/' keys marked as either 'YES' or 'NO'. Participants used their index fingers and the markings of 'YES' and 'NO' were alternated between the 'Z' and '/' keys, across participants.

No Load Condition

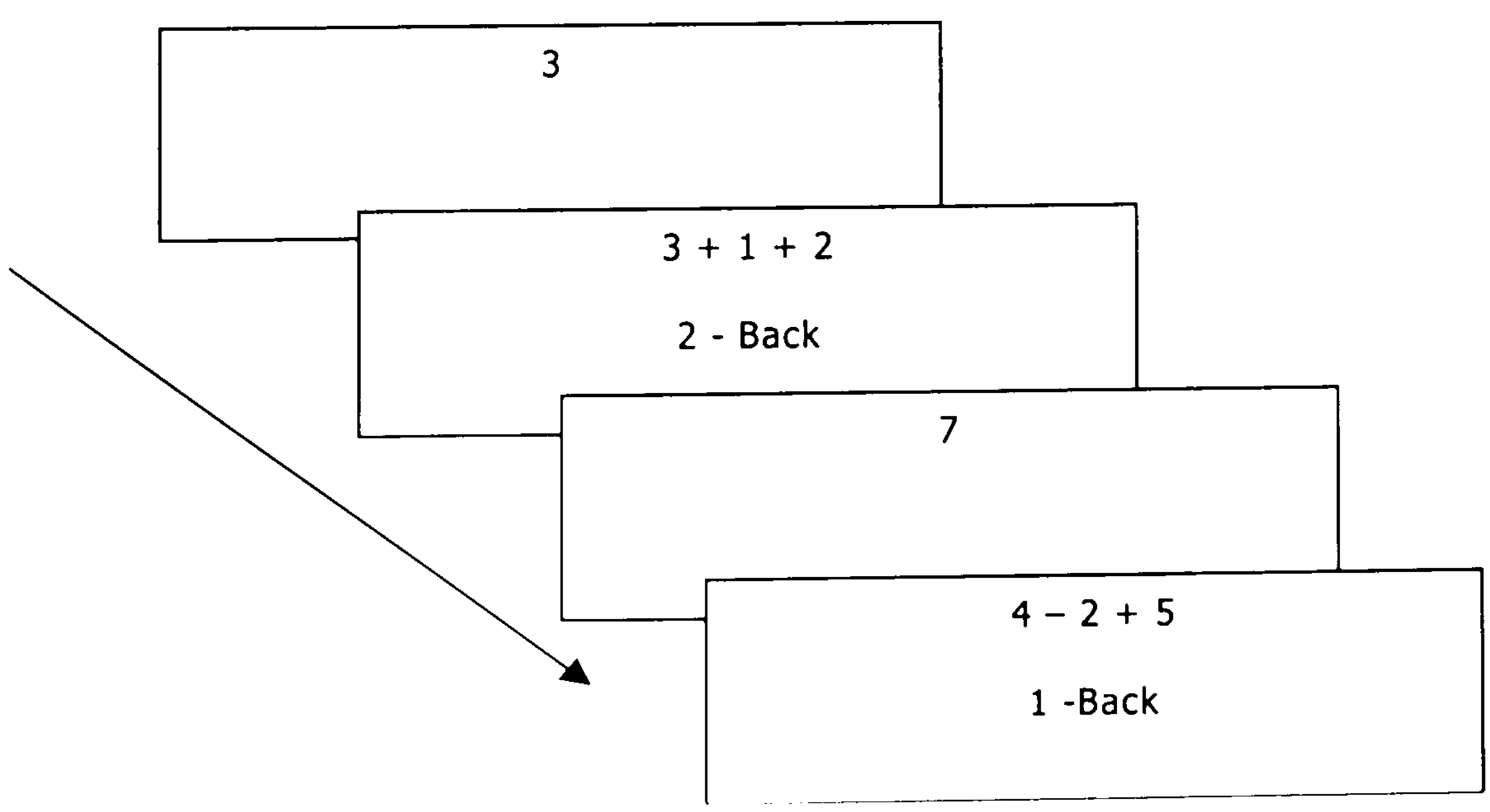
In the no load condition, the mental arithmetic task consisted of the presentation of a simple arithmetic problem and a solution. The arithmetic problem (e.g. 3+5-1) appeared on the computer screen with a solution underneath. Participants were instructed to decide whether the presented solution corresponded to the actual solution of the problem. Participants were required to respond either 'yes' or 'no' on a computer keyboard as quickly and as accurately as possible with a maximum time limit of seven seconds. Arithmetic problems and solutions were presented at seven-second intervals. No feedback was given and the final response made during the seven-second interval was recorded automatically by the computer.

Figure 5.1 Example of the procedure – Mental arithmetic no load and load conditions

No Load Condition



Load Conditions (n – Back)



Low Load Condition (2-Back)

In the low load condition, a single digit solution was presented on the computer screen for seven seconds. After the digit disappeared a prompt was presented on the computer screen for seven seconds. The prompt consisted of one of the following signals: an asterisk (*), 1–Back or 2–Back. If the * prompt appeared this indicated that no response was required on this occasion. When either the 1–Back or the 2–Back prompt appeared an arithmetic problem appeared at the same time above the prompt (see lower panel of Figure 1 for an example). If the 1–Back prompt appeared, the participant had to think back to the digit that had just disappeared from the computer screen, and decide whether this number was the solution to the current problem on the computer screen, and respond yes or no on the computer keyboard. If the 2–Back prompt appeared participants were required to use the digit from two positions back. Thus, participants were required to keep in mind the previous two digits presented in order to respond appropriately when the prompt appeared. The 1–Back signal was included so that participants could not prepare a response to the two back signal in advance. The no back signals (*) were included as fillers so that each cue was only tested once and again their inclusion made it difficult for participants to prepare a response. A total of four no response prompts were used in each experimental session. In each experimental session there were ten test trials. Eighty percent of the prompts were the 2 – Back cue and 20% were the 1 –Back cue. The computer recorded the participants' responses.

High Load Condition

In the high load condition, the task requirements were the same as in the low load condition except that the participants were required to keep in mind the previous three digits that had been presented. On this occasion as well as the no response (*), the 1-

Back and the 2-Back conditions, participants were also required to respond to a 3-Back condition. Again, there were four no response prompts used as fillers. Eighty percent of the test trials were for the 3-Back cue, with 10% for each of the 2–Back and 1–Back cues.

5.1.3 Results

Because the age groups differed in education this measure was initially entered as covariate in the analyses. However, this covariate was not significant in any analysis, and therefore is not discussed further. Post hoc analysis were conducted using the Bonferroni procedure at a significance level of $p < 0.05$ unless otherwise stated.

Analysis of Absolute Response Time and Error Rate Data

The absolute response time and error rates for the metal arithmetic task under conditions of no load and load are shown in Table 5.1.

Table 5.1 Mean (and SD) response latency (in msec) and errors for mental arithmetic task under no load, low load (2-back), or high load (3-back) conditions

	Younger Adults				Older Adults			
	Response latency		Errors /20		Response latency		Errors /20	
	M	SD	M	SD	M	SD	M	SD
No Load	2683	657	1.1	1.0	3308	888	1.8	0.9
Low Load	3881	620	1.4	2.0	4992	926	3.4	2.6
High Load	4024	680	2.1	1.5	5132	900	5.2	3.0

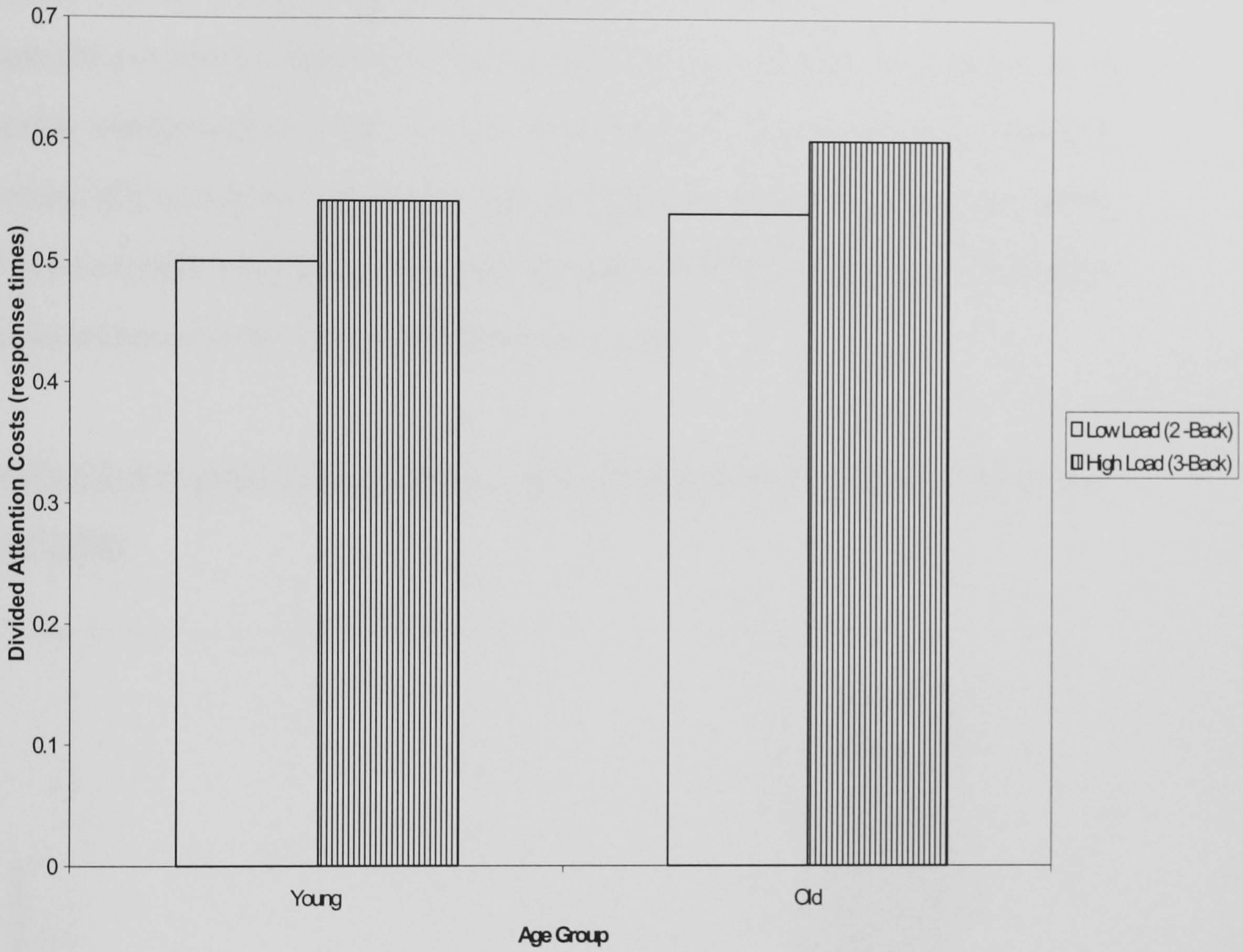
Mental arithmetic response times were analysed in a 2 (Age Group) x 3 (Memory Load) analysis of variance. This analysis revealed that response times were generally slower for the older adults ($F(1,34) = 15.45$, $MSE = 1569684$, $p < 0.01$) and slower in the working memory load conditions ($F(2,68) = 186$, $MSE = 148466$, $p < 0.01$). The interaction between working memory load and age group demonstrated that older adults were particularly impaired when carrying out a simple mental arithmetic task with a concurrent load ($F(2,68) = 4.75$, $MSE = 148466$, $p < 0.05$). An analysis of simple main effects, using the Bonferroni procedure, found a significant difference in the both younger and older adults' response times between the no load and both the low load and high load conditions. The difference between the high load and low load was not significant.

The next set of analyses was carried out on the mental arithmetic errors. A 2 x (Age Group) x 3 (Working Memory Load) analysis of variance was carried out on the error data. This analysis showed that the older adults produced more errors ($F(1,34) = 16.57$, $MSE = 6.05$, $p < 0.01$) and accuracy was impaired as working memory load increased ($F(2,68) = 15.32$, $MSE = 2.91$, $p < 0.01$). Post-hoc comparisons using the Bonferroni procedure confirmed that accuracy declined as working memory load increased. The interaction between working memory load and age group ($F(2,68) = 4.23$, $MSE = 2.91$, $p < 0.05$) showed that older adults' accuracy was particularly impaired when carrying out a mental arithmetic task with a concurrent load.

Dual Task Costs Analysis

In order to control for baseline differences in mental arithmetic response times and error rates a dual task costs analysis was carried out, as advocated by Somberg & Salthouse (1982). The raw data were transformed into a dual task cost measure (i.e., (dual – single)/single). Figure 5.2 and Figure 5.3 show the younger and older adults' mental arithmetic performance for response time and error rate in terms of dual task costs.

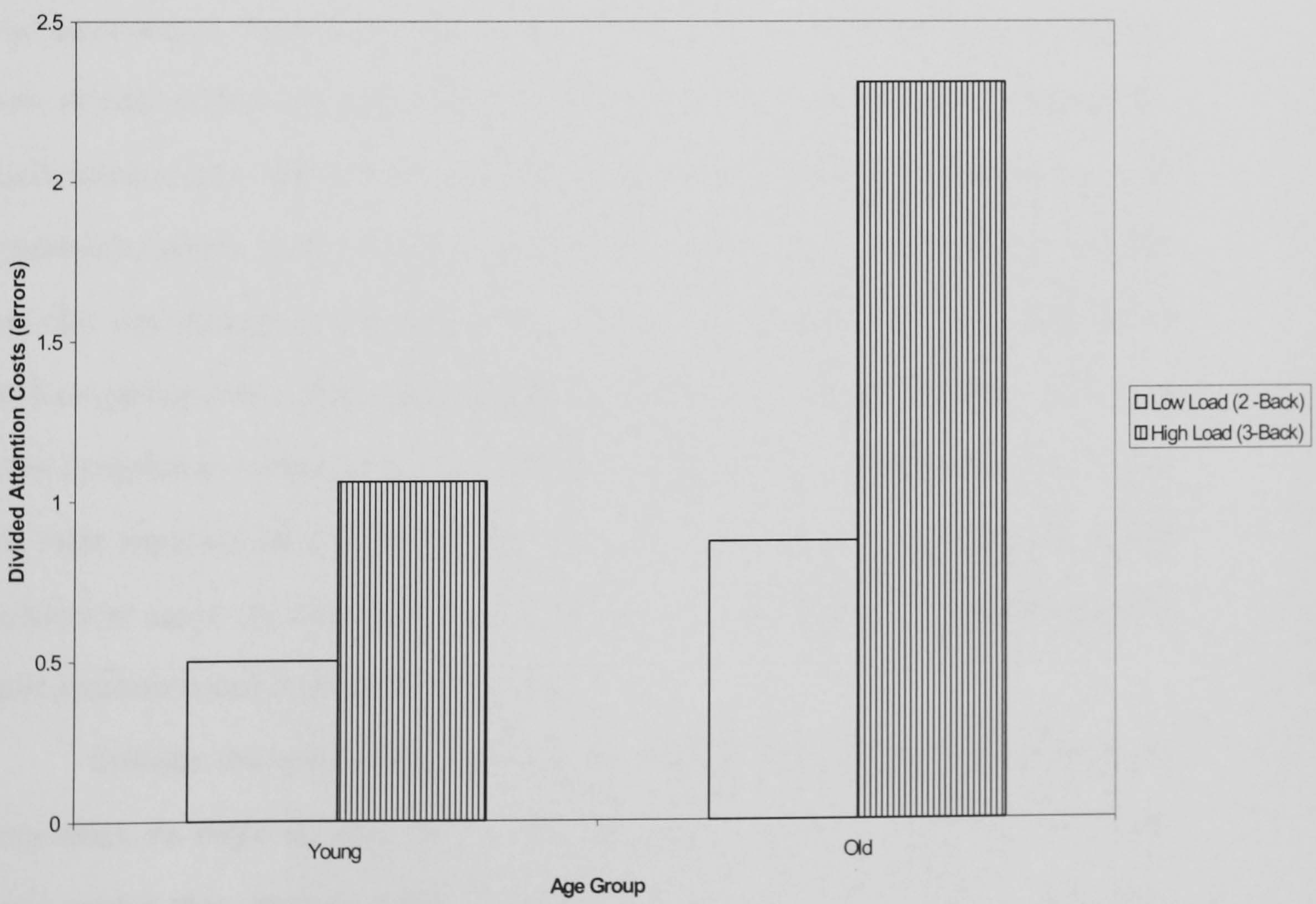
Figure 5.2 The proportional increase in mental arithmetic response times for younger and older adults.



Mental arithmetic response times in terms of dual task costs were analysed in a 2 (Age Group) x 2 (Memory Load) analysis of variance. The main effect of age group was unreliable and demonstrated that the cost of dual tasking was equivalent for both groups. The main effect of working memory load showed that the cost of dual tasking increased in line with load ($F(1,34) = 4.3$, $MSE = 0.01$, $p < 0.05$). The interaction between age group and memory load was unreliable and showed that the cost of dual tasking was equivalent as working memory load increased. In order to compare the age effect across studies an effect size was calculated (*d*= 0.15).

An equivalent analysis of dual task costs was performed on mental arithmetic error rates. The main effect of age was not significant and demonstrated that the cost of dual tasking was equivalent for both groups ($F(1,34) = 3.60$, $MSE = 3.32$, $P > 0.05$). A main effect of memory load simply showed that there was a greater proportional cost as working memory load increased ($F(1,34) = 8.69$, $MSE = 2.07$, $p < 0.01$).The age group x working memory load interaction was not significant and demonstrated age equivalence in dual task costs as working memory load increased. In order to compare the age effect across studies an effect size was calculated (*d* = 0.48).

Figure 5.3 The proportional increase in mental arithmetic error rates for younger and older adults



Speed Error Trade-Off

Since we were concerned with both the speed of carrying out the mental arithmetic problem and the errors, we investigated whether these two measures were related. In order to examine the speed error trade off between participants we correlated divided attention costs for speed and error rates. If participants are sacrificing response time to maintain accuracy, negative correlations would be expected. However, for both the low load and high load conditions the correlations were not significant ($r = 0.04$, $p > 0.05$ for low load, and $r = 0.00$, $p > 0.05$ for high load) thus contradicting the expectation based on a speed error trade off.

5.1.4 Discussion

This chapter considered another domain of cognition where older adults are skilled in their performance. Mental arithmetic is acquired from an early age and begins to develop from as early as four years old (Geary, 1994), and is a skill that we use in everyday life. Consequently, older adults are more familiar with this type of skill and older adults can be considered experts. Furthermore, younger adults may not have fully developed this skill and may rely perhaps on backup strategies such as verbal counting or decomposition to aid their performance. Older adults are more likely to use overlearned retrieval operations when completing mental arithmetic problems. We proposed that although older adults are more penalised on a variety of cognitive tasks due to a general decline processing resource or speed of processing, they are able to compensate using knowledge that they have acquired across a life span of learning.

Consider the effects observed using the absolute measures of reaction time and error rates. As might be expected, overall older adults' response times and error rates were greater than younger adults' response times and error rates. When a concurrent working memory load was introduced older adults' response times and error rates increased more than younger adults' response times and error rates. Therefore, in terms of absolute levels of performance there was some indication of a dual task impairment for older adults. However, this effect may have resulted from baseline differences in performance. As with the previous experiments a dual task costs analysis was carried out.

When response times were transformed into a measure of dual task costs, the age effect was removed. The introduction of concurrent processing demands impaired mental arithmetic performance but the costs of dual tasking were equivalent for both groups. This result is consistent with experiment 4.1 (sentence verification) and the semantic n-Back task in experiment 3.1. In three experiments using the n-Back procedure it has been shown that when tasks involve the retrieval of information from semantic memory, older adults are no more penalised than the young by the introduction of a concurrent task. When working memory load was increased, both age groups' response times in terms of dual task costs increased to the same extent. According to accounts based on generalised slowing or reduced attentional capacity any manipulation of task difficulty might be expected to disproportionately affect older adults' performance.

An equivalent dual task costs analysis was carried out on the error rate data. On this occasion the age effect approached significance so there was some indication that older adults were more penalised than the young. An increase in working memory load had the same effect for both groups. It was noted in the previous chapter how the error rate data may be misleading. If an error is produced the participant may have either miscalculated the problem or mis-remembered the digit they were keeping in mind. We consider the correct response time data to be the more appropriate measure of performance. With a correct response we know that the digit has been recalled n-Back and the calculation was correct.

The results from the experiment again suggest that domain is an important moderator variable of dual task costs in older adults. Evidence was provided demonstrating that when an individual is skilled at a particular task, there is minimal interference from concurrent processing demands. This is consistent with previous work on mental arithmetic tasks and also on tasks that involve other skilled processes like those involved in language processing. Therefore, although there is evidence pointing to a dual task deficit in older adults it is important to consider whether skill, expertise or familiarity modulates dual task performance. Furthermore, a more generalised decrease in cognitive performance as a result of perhaps generalised slowing can be compensated for by using more efficient problem solving strategies, particularly in domains of cognition where older adults have considerable knowledge (Charness, 1981).

It has been argued that mental arithmetic facts are represented in a semantic language like system (Geary & Brown, 1991) and such representations are preserved in old age. Much like the findings from experiments 3.1 and 3.2 we concluded the semantic memory is a domain that is preserved in normal ageing. The familiarity of the arithmetic facts to be retrieved results in less reliance on effortful control processes usually thought to be involved in retrieval. Consequently, older adults would have more resources to manage a competing activity.

Having examined the effects of concurrent processing on episodic (experiments 2.1, 3.1 and 3.2) and semantic (experiments 2.1, 3.1, 3.2, 4.1 and 5.1) retrieval, in the next chapter we aim to add to the database of findings in the dual tasking literature by considering the visual spatial domain.

6. The Effects of Concurrent Load on Performance of Visuospatial Tasks

6.1 General Introduction

In the previous chapters we have considered older adults' dual task performance across the semantic - episodic domains. In previous studies reported here, task domain has been identified as an important moderator variable of dual task costs in older adults, rather than task difficulty, and the evidence suggests that mechanisms such as speed of processing and attentional resource are insufficient to explain all instances of age differences in dual task performance. It was further suggested that in domains of cognition that are relatively well preserved in normal ageing there may be little interference caused by concurrent activities. In particular, older adults seem able to compensate for more general declines in cognitive abilities by utilizing for example, environmental support, and seem less impaired on tasks involving general knowledge or overlearned skills. Since it appears that the task, and task combination may be crucial in whether age differences are observed, it is therefore desirable to examine other task combinations. We now turn to visual spatial processing and the joint effects of age and concurrent task.

6.2 Experiment 6.1

6.2.1 Introduction

Previous research has invariably found age related declines in sensory systems, and in particular vision (Birren & Schaie, 1990). For instance, older adults are less able on measures of visual acuity, contrast sensitivity and depth perception (see Fozard, 1990, for review). However, such measures do not reflect the complexity of visuospatial processing tasks. In this chapter we consider older adults' performance on more complex visuospatial tasks which involve the interaction between vision, perception, memory and attentional processes. We first discuss older adults' performance on a variety of visuospatial tasks before discussing older adults' dual task performance when visuospatial abilities are required.

Visuospatial Abilities in Old Age

A number of tests have been used to examine older adults' visuospatial abilities. An early study by Reitan (1955) compared the performance on the verbal and visuospatial measures of the Wechsler Adult Intelligence Scale (WAIS). Older adults were found to have particular difficulties on the visuospatial measures such as the block design and object assembly tasks compared to the verbal measures. Age equivalence on the measures of vocabulary, comprehension and general knowledge was consistent with the idea that language abilities and semantic memory are well persevered in normal ageing (see section 4.1.2)

Wahlin, Baeckman, Wahlin, & Winblad (1993) examined visuospatial ability using the block design test and clock setting and reading test. In the block design test participants are presented with red and white coloured blocks. Each block has two white and two red sides. Also, the blocks have two half white and half red sides which are divided across the diagonal. The task involves using the blocks to copy a pattern presented by the experimenter. In the clock setting test participants are presented with circles and then asked to indicate a particular time by drawing the hands on each circle (clock face). In the clock reading task, again circles are presented with hands indicating the time. Participants were required to tell the time indicated. In both tests there were no numbers on the clock faces (circles). Performances on both clock tests are indicators of spatial orientation ability. The results from this study demonstrated age related deterioration in visual spatial ability, assessed by the block design and clock tests. The block test data showed that when time restraints were removed from the task older adults' performance improved. Therefore, in part older adults' poorer performance was due to cognitive slowing. Furthermore, it was found that the degree of the age effect was related to the complexity of the task.

A more recent study by Jenkins, Myerson, Joerding, & Hale (2000) compared the performance on visuospatial and verbal speeded tasks with verbal and visuospatial working memory tasks. In one experiment older adults were slower on both visuospatial and verbal speeded tasks, although slowing was more pronounced in the visuospatial tasks. In a second experiment contrasting visuospatial and verbal working memory the same pattern of results were observed with larger age differences in performance for the visuospatial versions of the tasks. In a final experiment, older adults were found to be impaired in acquiring novel visuospatial information compared to verbal information. The authors suggested that this provides compelling evidence that ageing adversely affects visuospatial information processing compared to verbal processing. The authors argued against visuospatial abilities being particularly sensitive to cognitive slowing with increased age, as the visuospatial deficit was not only found on speeded tasks but also working memory tasks. The authors suggested that older adults perhaps gained greater expertise over a lifespan on verbal tasks. Furthermore, in the laboratory setting visuospatial tasks may be more novel and this familiarity component influences the age effect.

In previous sections we have discussed how semantic memory is relatively well preserved in normal ageing. Sharps (1998) proposed a theory to link the findings of impaired visuospatial and relatively well preserved semantic processing in ageing. In their study, the results demonstrated an age related decline in visuospatial abilities. However, the authors proposed that the environmental support hypothesis (Craik, 1986) could be applied to the visuospatial domain. That is, in verbal memory tasks older adults are able to compensate by using environmental cues to aid their performance. Since in visuospatial abilities self initiated processes are primarily involved the authors were able to demonstrate that by providing environmental cues in visuospatial tasks, the age effects could be minimised or eliminated, much like we observed on verbal memory tasks.

The Joint Effects of Age and Divided Attention on Visual Spatial Abilities

Visual spatial ability in a dual task setting is of considerable practical importance. Owsley, Sloane, Ball, Roenker, & Bruni (1991) assert that standard tests of visual ability are not good indicators of performance on more complex and ecologically valid measures of visual spatial abilities. Of particular interest in the current investigation is that the authors stress the need to investigate dual tasking which is usually a component in visuospatial activities. In section 1.2.1 we discussed driving ability in old age. This skill is heavily reliant on visual perceptual and motor skills and dual tasking. In this study the investigators devised the useful field of view task. The task involved the presentation of a two-lane road on a computer screen with either a car, truck or blank in each lane. One of the tasks involved a same/different judgement. A stop sign would also appear at times in an unpredictable location. Participants were required to make a judgement about the location of the target that was sometimes embedded among distracters and sometimes not. The authors suggested three mechanisms that may be responsible for poorer performance by older adults (i.e. processing speed, divided attention and distractibility).

Measurements of processing speed could be considered by analysing the performance of the same/different aspect of the task. Divided attention ability could be measured by considering concurrent performance of the same judgement and stop sign aspect of the task. To examine the influence of distractibility a comparison could be made between the dual task aspects and the dual task plus distracter task. In this study there was a strong relationship between task performance and frequency of car accidents. The study illustrated that visuospatial ability, particularly where dual tasking is involved, declines with age and is a good predictor of accident frequency.

Kirchner (1958) used a visual perceptual version of the n-Back task to investigate age differences in dual task performance. In this experiment participants were required to concurrently process continually changing visual information which involved the short term retention of the location of visual information and response processes. We have discussed the procedure in detail in section 3.2.1. In brief, participants were either required to respond to the location of a target on a visual display or to a target that had been presented on previous trials (n–Back condition). Age differences in dual task performance were observed and the authors pointed to central organisational processes as the locus of the deficit. Older adults found it particularly difficult to keep in mind and update visuospatial information and concurrently respond when required to do so.

In section 1.2.4 we described an early study investigating age differences in dual task performance. Somberg & Salthouse (1982) employed two visual target detection tasks presented concurrently to investigate age differences in dual task performance. It was found that after controlling for baseline differences in performance, the costs of dual tasking were equivalent for both groups. This provided evidence to suggest that when dual tasks involve largely peripheral processes older adults are no more penalised than the young. Such tasks are largely data driven and do not call on more central cognitive processes that may be involved in visuospatial abilities. Therefore, perhaps simple perceptual tasks of this nature are no more taxing for the elderly. McDowd & Craik (1988) investigated dual task performance on simple perceptual tasks in more detail. The authors suggest a possible three-way interaction between age, divided attention and task difficulty. The first experiment contrasted decision making in a choice reaction time task between physical (easy version) versus semantic (hard version) features. Much like the results of Somberg & Salthouse (1982) they found little effect of age and divided attention when relatively simple perceptual task were involved. However, when task parameters were manipulated so that participants were required to draw on central or higher order processes (semantic version) age differences in dual task performance were considerable. However, the results should be treated with caution as this was only the case when the absolute measures of performance were considered.

Tsang & Shaner (1998) examined dual task performance across a range of dual tasks. The authors were concerned with the effects of age, expertise and structural similarity on performance. Structural similarity was manipulated by examining dual task interference caused by tasks tapping the same processing resources, according to the multiple resources theory (Wickens, Vidulich, & Sandry Garza, 1984). This was achieved by task manipulations across the three dimensions of: stages of processing (perceptual/central versus response processing), codes of processing (verbal versus spatial) and input and output modalities (visual versus auditory/manual versus speech). The results were consistent with the multiple resource view of cognitive ageing. For instance, those tasks that involved visuospatial processing across the three dimensions were particularly problematic for older adults.

In this experiment rather than using dual tasks which may draw on peripheral sensory processes we choose a task that would be expected to draw on visual spatial abilities. That is, we used a procedure where participants would be required to actively manipulate visuospatial material and utilise visuospatial memory. The reasoning behind this is that such tasks would be similar in complexity to visuospatial activities in the real world. To this end the n-Back procedure was used to investigate whether older adults are more penalised when required to hold and update information in visual memory while concurrently performing a visual processing task. McDowd & Craik's (1988) results were inconclusive when they manipulated the central cognitive nature of the visual perceptual tasks. It could be argued that their manipulation may not have been sufficient to tax older adults' visual spatial abilities. Therefore, we would expect older adults to be more penalised with the more complex versions of our n-Back task and would support the findings of Owsley et al. (1991) and Kirchner (1958) where perhaps the tasks could be regarded as a more reliable measure of visuospatial ability.

6.2.2 Method

Participants

Eighteen younger adults (range 17-29, mean age 23.6 years, SD 2.7 years) and 18 older adults (range 60-79, mean age 69.3 years, SD 6.3 years) participated in the experiment. The young volunteers were undergraduate and postgraduate students from the University of Bristol. The older adults were volunteers selected from a pool of older adults registered with the Experimental Psychology Department. On average the younger adults were better educated than the older adults (17.9 versus 12.8 years of education respectively, $t(34) = 6.04$, $p<0.01$). Older adults' scores were equivalent on the NART (raw scores of 40.6 for younger adults and 38.5 for older adults, $t(34) = 1.3$, $p>0.05$). Years of education were entered as a covariate in the main analysis.

Materials

One hundred and twenty six pairs of two by two grids were constructed with a black block filling one of the corners in each grid (Appendix K). Underneath the first grid there was an instruction of up, down, left or right. The second grid also had a black block filling one of the corners. The overall aim of the tasks was to move the block in the first grid as per the instruction and compare this to the second grid. Half of the comparisons required a correct and half an incorrect response. Each pair of grids was randomly assigned to 9 list of 14 pairs. Each list was then randomly assigned to each of the nine conditions (i.e. the no load, low load and high load practice sessions, and 2 experimental sessions each for the no load, low load high load conditions). Stimuli were presented on a 14-inch monitor.

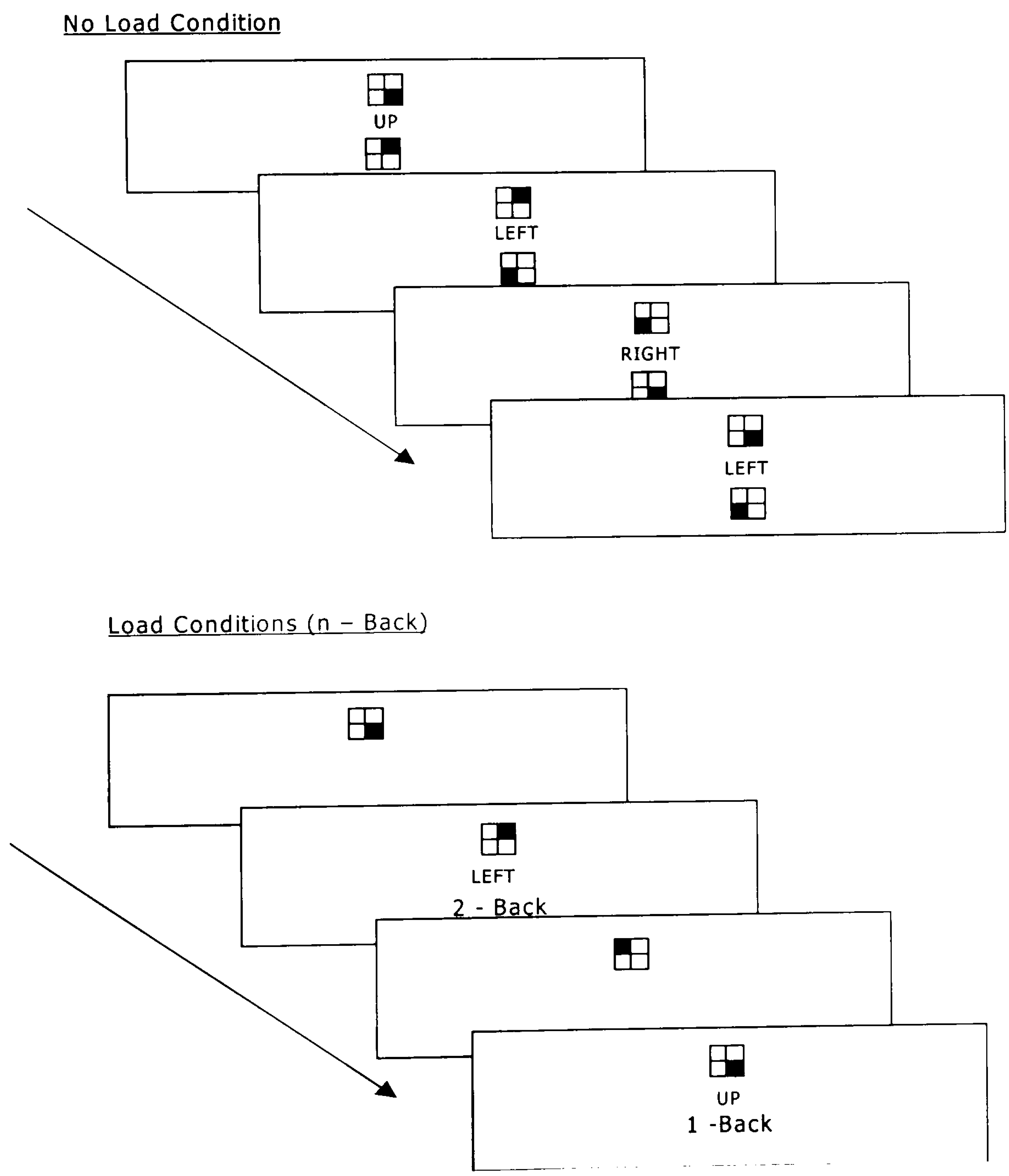
Procedure

Prior to the experimental session each participant received detailed instructions regarding the nature of the tasks (Appendix L). A pictorial representation of the no load and the load (2–Back and 3–Back) conditions accompanied the instructions (see Figure 6.1 for example). Participants were required to demonstrate to the experimenter that they understood the instructions by completing the printed examples.

In order to ensure that participants understood the requirements of the task, a practice session of one block for each condition was given before the start of the experimental block. In the experimental block there were two sessions each of the no load, the low load and the high load tasks; presented in counterbalanced order across participants.

An example of the procedure is shown in Figure 6.1. Displayed are the no load and load conditions for the visuospatial task. All responses were made on a standard IBM keyboard with the 'Z' and '/' keys marked as either 'YES' or 'NO'. Participants used their index fingers and the markings of 'YES' and 'NO' were alternated between the 'Z' and '/' keys, across participants.

Figure 6.1 Example of the procedure – Grid comparison no load and load conditions (see also Appendix K)



No Load Condition

In the no load condition, the visual spatial task consisted of the presentation of the first grid with the instruction underneath, and below this, the second grid. Participants were required to look at the grid at the top of the screen and read the instruction underneath. Participants were then required to move the position of the block according to the instruction in their mind, and then compare both grids. Participants were instructed to decide whether the two grids matched and to respond either yes or no on a computer keyboard as quickly and as accurately as possible with a maximum time limit of seven seconds. The stimuli were presented at seven-second intervals. No feedback was given and the final response made during the seven-second interval was recorded automatically by the computer.

Low Load Condition (2-Back)

In the low load condition, the second grid of the pairing was presented on the computer screen for seven seconds. After the grid disappeared a prompt was presented on the computer screen for seven seconds. The prompt consisted of one of the following signals: an asterisk (*), 1–Back or 2–Back. If the * prompt appeared this indicated that no response was required on this occasion. When either the 1–Back or the 2–Back prompt appeared a grid plus instruction appeared at the same time above the prompt (see lower panel of Figure 6.1 for an example). If the 1 – Back prompt appeared the participant had to think back to the grid that had just disappeared from the computer screen, and decide whether this grid was the same as the grid on the computer screen after moving the block in their mind. A response of either yes or no was then made on the computer keyboard. If the 2–Back prompt appeared participants were required to use the target grid from two positions back. Thus, participants were required to keep in mind the previous two grids presented in order to respond appropriately when the prompt appeared. The 1–Back signal was included so that participants could not prepare a response to the two back signal in advance. The no back signals (*) were included as fillers so that each cue was only tested once and again their inclusion made it difficult for participants to prepare a response. A total of four no response prompts were used in each experimental session. In each experimental session there were ten test trials. Eighty percent of the prompts were the 2–Back cue and 20% were the 1–Back cue. The computer recorded the participants' responses.

High Load Condition

In the high load condition, the task requirements were the same as low load condition except that the participants were required to keep in mind the previous three grids that had been presented. On this occasion as well as the no response (*), the 1-Back and the 2-Back conditions, participants were also required to respond to a 3-Back condition. Again, there were four no response prompts used as fillers. Eighty percent of the test trials were for the 3-Back cue, with 10% for each of the 2–Back and 1–Back cues.

6.2.3 Results

Because the age groups differed in years of education this measure was initially entered as a covariate in the analyses. However, the covariate was not significant in any analysis and is not discussed further. Post hoc analysis were conducted using the Bonferroni procedure with a significance level of $p < 0.05$ unless otherwise stated.

Analysis of Absolute Response Time and Error Rate Data

The absolute response time and error rates for the visual spatial task under conditions of no load and load are shown in Table 6.1.

Table 6.1 Mean (and SD) response latency (in msec) and errors for the visual spatial task under no load, low load (2-Back), or high load (3-back) conditions.

	Younger Adults				Older Adults			
	Response latency		Errors /20		Response latency		Errors /20	
	M	SD	M	SD	M	SD	M	SD
No Load	1766	308	0.6	0.6	3075	938	1.2	1.1
Low Load	2991	422	2.1	1.2	4638	509	7.0	2.3
High Load	3239	413	2.5	1.5	4929	747	8.7	3.8

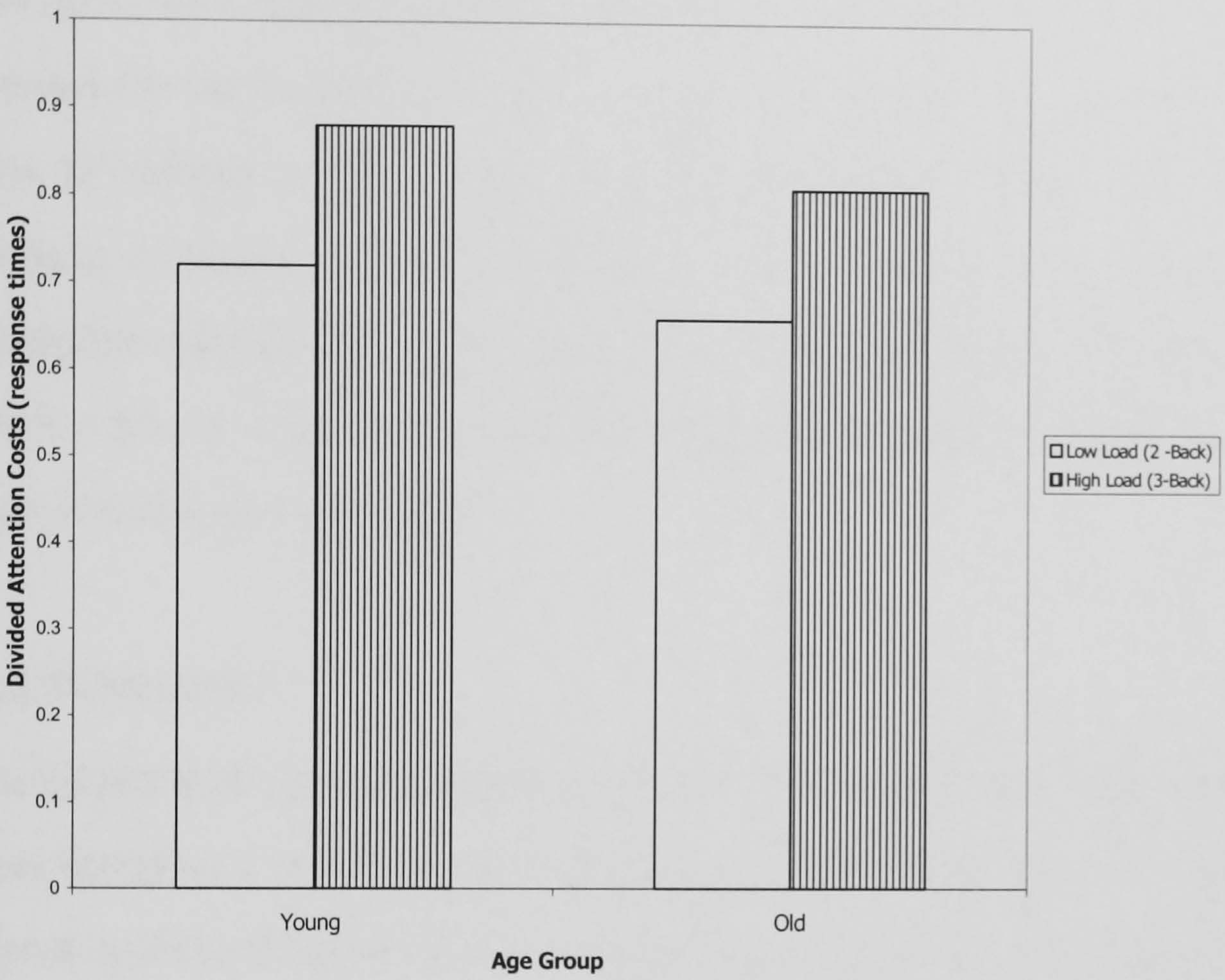
Response times in the visual spatial task were analysed in a 2 (Age Group) x 3 (Memory Load) analysis of variance. This analysis revealed that response times were generally slower for the older adults ($F(1,33) = 157.01$, $MSE = 370158$, $p < 0.01$) and slower in the working memory load conditions ($F(2,66) = 116.94$, $MSE = 258288$, $p < 0.01$). The interaction between working memory load and age group approached significance ($F(2,66) = 2.68$, $MSE = 258288$, $p = 0.08$) and suggests that older adults were particularly impaired when carrying out the visual spatial task with a concurrent load. An analysis of simple main effects, using the Bonferroni procedure, found a significant difference between the no load condition and both of the load conditions for older adults. For younger adults response times increased in line with load.

The next analysis was carried out on the error rates. A 2 x (Age Group) x 3 (Working Memory Load) analysis of variance was carried out on the error data. This analysis showed that the older adults produced more errors ($F(1,34) = 61.53$, $MSE = 6.6$, $p < 0.01$) and accuracy was impaired as working memory load increased ($F(2,68) = 76.6$, $MSE = 2.82$, $p < 0.01$). Post-hoc comparisons using the Bonferroni procedure confirmed that accuracy declined as working memory load increased. The interaction between working memory load and age group ($F(2,68) = 26.98$, $MSE = 2.82$, $p < 0.01$) showed that older adults' accuracy was particularly impaired when carrying the visual spatial task with a concurrent load.

Dual Task Costs Analysis

In order to control for baseline differences in response times for the visual spatial task a dual task costs analysis was carried out, as advocated by Somberg & Salthouse (1982). The raw data were transformed into a dual task cost measure (i.e., (dual – single)/single). It should be noted that this analysis could not be carried out on the error rates as there was a high proportion of participants with 100% accuracy in the no load condition. This made it impossible to transform the data to a measure of dual task cost. Figure 6.2 shows the younger and older adults' response times in terms of dual task costs.

Figure 6.2. The proportional increase in response times on the visuospatial task for younger and older adults.



Response times in terms of dual task costs were analysed in a 2 (Age Group) x 2 (Memory Load) analysis of variance. The main effect of age group was not significant and showed that the cost of dual tasking was equivalent across groups. The main effect of working memory load simply showed that the cost of dual tasking increased in line with working memory load ($F(1,33) = 9.4$, $MSE = 0.03$, $p < 0.01$). Finally, the interaction between age group and memory load was not significant and showed that the cost of dual tasking was equivalent for the two age groups as working memory load increased.

In order for a comparison of the age effects between experiments, an overall effect size was calculated ($d = 0.13$).

Speed error trade-off

Since we were concerned with both the speed carrying out the visual spatial task and the errors, we investigated whether these two measures were related. In order to examine the speed error trade off between participants we carried out a correlation analysis between the raw response times and error rates. If participants are sacrificing response time to maintain accuracy, negative correlations would be expected. There was no evidence to suggest that the response time was related to the error rates as the correlations were positive ($r = 0.52$, $p<0.01$ for no load, $r = 0.83$, $p < 0.01$ for low load, and $r = 0.71$, $p < 0.01$ for the high load). Those who were slower on the visual spatial task were also more inaccurate.

6.2.4 Discussion

The current study set out to further investigate the circumstances in which older adults have difficulties in combining tasks. We were particularly interested in the visuospatial domain and the effects of increasing working memory load. We again used the n–Back procedure to minimise task trade off effects. In other words, a response was only made to the visuospatial task. The working memory task was integrated into the primary task and became a necessary part of that task.

Consider first the effects observed using absolute measures of reaction time and error rates. In addition to slower speed and poorer accuracy in visual spatial tasks under single task conditions, the present data demonstrated that older adults were particularly impaired by concurrent processing demands as indicated by the age by condition interaction. Keeping in mind the visual stimuli, and manipulating the visuospatial material at test, was more detrimental to older adults.

In line with the previous studies, a dual task cost analysis was carried out to remove the confounding effect of baseline differences in performance. This analysis was performed on the response time data only as there were a number of participants who made no errors and this precludes the use of a dual task costs measure for the error rates due to division by zero errors. In any case, we have already outlined how the error rate data should be treated with caution and the response time data is a more reliable measure of performance. When the correct response data were transformed into a measure of dual task costs older and younger adults' dual task performance was equivalent. It could be argued that perhaps the difficulty of the visual spatial task and the n-Back component led to the absence of an age effect. However, there was no evidence of this because when the working memory load was increased cost increased but was the same for both age groups. Increasing the working memory load requirement was an effective manipulation of task difficulty but there was no evidence that task difficulty or complexity mediates dual task cost in older adults. Furthermore, examination of Figure 6.2 shows large costs for both age groups. The dual task is demanding, but the costs are equivalent for both age groups.

Accounts based on generalised slowing or reduced attentional resource with increased age would predict that any manipulation of difficulty would cause greater slowing for older adults. As observed increasing load was effective in increasing the difficulty or complexity of the task but the age effect of dual tasking did not emerge. The findings are somewhat surprising, but are in agreement with Somberg & Salthouse (1982) findings that suggested older adults are no more penalised than younger adults by concurrent processing demands. They used a simple perceptual manual reaction time task and it was argued that the failure to find an age effect was due to the tasks being relatively simple. The costs of the younger and older adults were 0.52 and 0.56 respectively which suggests that the dual tasks were effortful. In the current experiment we used visuospatial tasks that would be expected to tap more central processing components. In the n-Back component of the task, older adults would be expected to find this problematic as age effects in the visuospatial components of short term memory have been observed (e.g. Bruyer & Scailquin, 1999). Moreover, having to concurrently manipulate visuospatial information may be more difficult for older adults to manage due to an overlap in the processes involved in the two components of the task. This would be consistent with the study carried out by Tsang & Shaner (1998). They found greater dual task performance costs when both the component tasks had a substantial visuospatial processing component. Furthermore, more difficult versions of the tasks made no impact on the pattern of results. However, other studies investigating the effects of age and concurrent processing demands on visuospatial ability are not consistent with the present study (Kirchner, 1958; Owsley et al., 1991).

One potential problem with the present study is that rather than the participant keeping in mind the grids, they may have been giving verbal labels to each corner of the grid. Indeed, some older participants reported using this strategy. Therefore, at test the demands may have been minimised compared to if the participant was attempting to keep in mind the visuospatial information from previous trials. It would have been interesting to consider age differences in the strategies being used as it appeared older adults used verbal labelling largely as they were unable to keep in mind the visuospatial information. Furthermore, since the processing codes (verbal versus visual) were different, less interference might be expected. In the next experiment we minimise such problems by using stimuli that would be difficult to verbally label.

6.3 Experiment 6.2

6.3.1 Introduction

In this experiment we further consider the effects of concurrent processing on visual spatial processing. In experiment 6.1 we investigated whether older adults find concurrent processing demands particularly problematic when carrying out a visuospatial activity. The aim of this experiment was to minimise the problem of the verbal labelling strategy that may have been employed in the previous experiment. Rather than using 2 by 2 grids, the stimuli comprised seven to eight point angular shapes. Participants were again required to keep in mind these stimuli while carrying out a visuospatial task. The visuospatial task involved mental rotation.

Mental Rotation and Ageing

In tasks that involve mental rotation, participants are presented with two visual stimuli which are either identical, mirror images or are of different orientation. Participants are then required to decide whether the stimuli are identical or not. The most common finding on these tasks is that when the angular disparity is manipulated, response times increase in line with the degree of rotation. This finding has been observed with a variety of stimuli such as natural objects, line drawings of natural objects and two and three dimensional nonsense objects (for review, see Cohen & Kubovy, 1993).

Shepard & Metzler (1971) were two of the first to suggest that the time required to determine whether two objects were identical increased linearly with the angular difference between those objects. Furthermore, this was the case when objects were rotated in two dimensional space and when the object was rotated about an axis in depth. Shepard & Metzler argued that such tasks involved the mental rotation of one of the objects until it either matched the second object or not.

Cooper (1975) used a mental rotation task where participants were required to discriminate between standard and reflected versions of two dimensional shapes. The authors were also concerned with the complexity of the shapes and whether this was a factor that affected performance. The complexity of the shapes was manipulated by increasing the number of angles in the shape. The procedure involved the training of the subject on the standard and reflected versions of the shapes. At test a standard or reflected form would be presented in a variety of different orientations. Participants were required to respond manually whether the shape was a standard or reflected version of the shape that they had previously learned. It was found that response times increased in line with angular disparity irrespective of whether the shape was more complex (i.e. more angles). It was suggested that the complexity of the external stimuli may not have been coded in the internal representation

Cerella, Poon, & Fozard (1981) required participants to distinguish between normal and reflected forms of alphanumeric characters. In that experiment participants were instructed to mentally rotate the character into the upright position and then make a judgement on whether the character was a reflected or normal form. The results showed that letter identification times were a linear function of the degree of rotation for both the young and the older age group. However, when the slopes of the regression function were compared, an age difference in the rate of mental rotation was observed. The results were in line with a general slowing account of normal ageing.

More recent studies have attempted to separate the processes involved in the encoding of the stimuli, rotation and decision making processes in mental rotation tasks. For instance, Hertzog & Rypma (1991) presented participants with a standard two dimensional figure (and an arrow denoting the top) on a computer screen. The participants were required to study the figure until they were sure they could visualise it. The shape would then disappear from the screen to be replaced with three arrows. The first arrow indicated the direction of rotation. The second was a cue to the position of the top of the original shape. The third arrow indicated the new position of the top of the shape after rotation. After the participant had mentally rotated the figure, they pressed a response key which caused a comparison shape to appear. Participants were required to decide whether the comparison shape was either the same, identical but at the wrong orientation or a mirror image. As expected, older adults took longer to encode the standard figure. Since there was no information regarding the rotation in the encoding phase, angle of rotation had no effect. In the rotation phase the results were consistent with the previous finding and demonstrated that response time increased with degree of rotation, and particularly for older adults. At the decision making stage, response times were increased with degree of angle and again the effect was greater for older adults. In previous experiments rotational effects have been contaminated by processes involved in encoding and the decision making stages of the tasks to be performed. Hertzog & Rypma (1991) separated these processes and found that not only are there age differences in mental rotation, but also in decision making when a comparison has to be made. Therefore, although there are age differences in rotational processes these differences do not completely account for older adults' poorer performance on rotational tasks.

Dual tasks and Mental Rotation

A number of studies have investigated the effects of concurrent processing demands on mental rotation performance. Logie & Salway (1990) used a mental rotation task that involved the presentation of an eight pointed angular shape. After a short period of time an orientation arrow was presented on the screen. The procedure for the single task condition was the same as the study by Cooper (1975) that has already been described. A concurrent task was introduced to investigate the components of the working memory system (Baddeley & Hitch, 1974). It was hypothesised that the visuospatial scratch pad and the central executive were involved in mental rotation. Therefore secondary tasks that tap the resources of these systems would create the most interference. To investigate the role of the central executive, visuospatial scratchpad and the articulatory loop, random number generation, spatial suppression and articulatory suppression were used, respectively. There was an effect of spatial suppression on performance as might be expected and a much larger effect of random number generation on performance. Therefore, as well as recruiting visuospatial resources, mental rotation tasks require substantial attentional processes which are the responsibility of the central executive. Since central executive functioning is thought to decline in normal ageing (see section 1.2.2), its involvement in mental rotation and task co-ordination may produce substantial age differences in performance.

Wexler, Kosslyn, & Berthoz (1997) used the dual task paradigm to investigate the involvement of motor processing in mental rotation tasks. Participants were required to carry out a mental rotation task using two-dimensional stimuli similar to those used by Cooper & Shepard (1973). In the first phase of the task, a shape was presented on the computer screen. In the second phase, this shape disappeared and was replaced by an arrow indicating a new location. In the final phase a shape would appear in the new location and participants were required to decide whether the shape was a rotation of the original or a rotation plus a mirror image. In the concurrent motor task, participants were required to continually move a joystick either clockwise or anticlockwise at a particular speed. Feedback was given regarding whether their speed matched the target speed. The results demonstrated a close relationship between motor and mental rotation and when both were compatible in term of both direction and speed, performance was enhanced.

In the present experiment we used a mental rotation task similar to that used by Logie & Salway (1990). Participants were presented with angular shapes at different orientations and were required to keep in mind up to two of these shapes. At test, a cue indicated which of the shapes should be used for the comparison with the test shape, which was identical, except that it may be at a different orientation and be a mirror image. In the present experiment we will consider both increasing task difficulty with the introduction of concurrent processing demands and by increasing degree of rotation. This will be an interesting comparison since it has been suggested that increasing task difficulty and increasing concurrent processing demands do not necessarily bring about the same effect.

6.3.2 Method

Participants

Eighteen younger adults (range 17-27, mean age 23.6 years, SD 2.7 years) and 18 older adults (range 60-79, mean age 69.3 years, SD 6.3 years) participated in the experiment. The young volunteers were undergraduate and postgraduate students from the University of Bristol. The older adults were volunteers selected from a pool of older adults registered with the Experimental Psychology Department. On average the younger adults were better educated than the older adults (17.9 versus 12.8 years of education respectively, $t(34) = 6.04$, $p<0.01$). Older adults' scores were equivalent on the NART (raw scores of 40.6 for younger adults and 38.5 for older adults, $t(34) = 1.3$, $p>0.05$). Years of education was entered as a covariate in the main analysis.

Materials

Each of the stimuli was either a 7 or 8 point shape, similar to those used by Cooper (1975). A master list of 100 shapes was constructed with various orientations (Appendix M). Each shape was then paired with a comparison shape, which was either the same shape rotated, or a mirror image of the original shape rotated. The overall aim of the tasks was to mentally rotate the first shape and decide whether it matched the second shape, or it was a mirror image of the first shape. Two lists of 10 shape pairs (practice), and four lists of 20 shape pairs were constructed. Half of the comparisons required a correct response and half an incorrect response. Difficulty of comparison was also manipulated by increasing the degree of rotation of the comparison shape. Half the shape pairs were easy comparisons (10-40 degrees rotation) and half the shape pairs were difficult comparisons (90-110 degrees rotation). Also, half the comparison shapes were rotated clockwise and half were rotated anti-clockwise. Stimuli were presented on a 14-inch monitor.

Procedure

Prior to the experimental session each participant received detailed instructions regarding the nature of the tasks (Appendix N). A pictorial representation of the no load and the load conditions accompanied the instructions. Participants were required to demonstrate to the experimenter that they understood the instructions by completing the printed examples.

In order to ensure that participants understood the requirements of the task, a practice session of one block for each condition was given before the start of the experimental block. In the experimental block there were two sessions for each of the no load and load conditions which were presented in counterbalanced order across participants.

For an example of the procedure for the no load and load conditions for the mental rotation tasks refer to figure 6.3. All responses were made on a standard IBM keyboard with the 'Z' and '/' keys marked as either 'YES' or 'NO'. Participants used their index fingers and the markings of 'YES' and 'NO' were alternated between the 'Z' and '/' keys, across participants.

No Load Condition

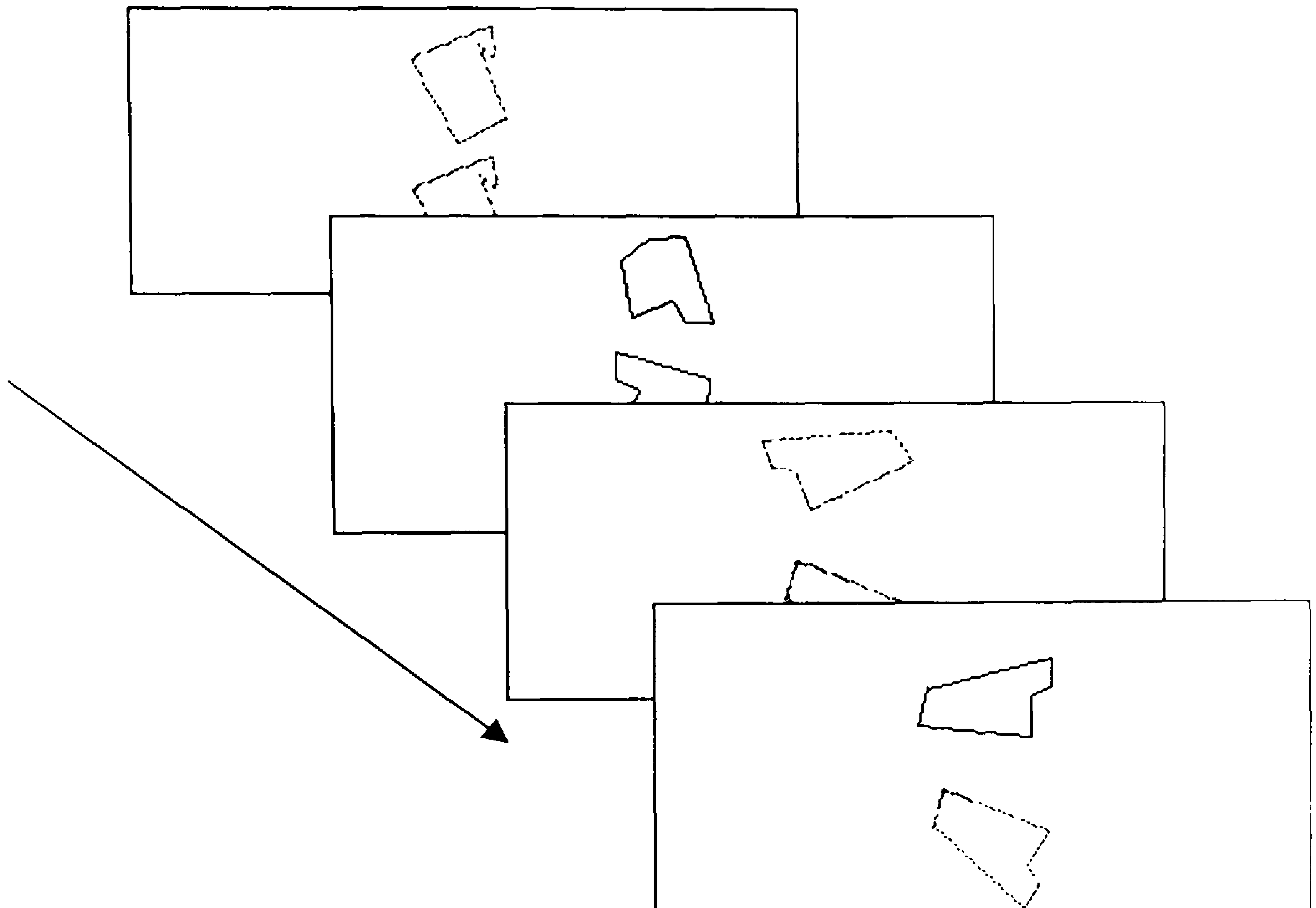
In the no load condition, the mental rotation task consisted of the presentation of an angular shape and the second underneath. Participants were then required mentally rotate the first shape and decide whether it matches the second shape. Participants were instructed to respond either 'yes' if the second shape was just a rotated version of the first, or 'no' if the second shape was a mirror image and rotated version of the first. Responses were made on the computer keyboard as quickly and as accurately as possible with a maximum time limit of five seconds. The stimuli were presented at five second intervals. No feedback was given and the final response made during the five second interval was recorded automatically by the computer.

Load Condition (2-Back)

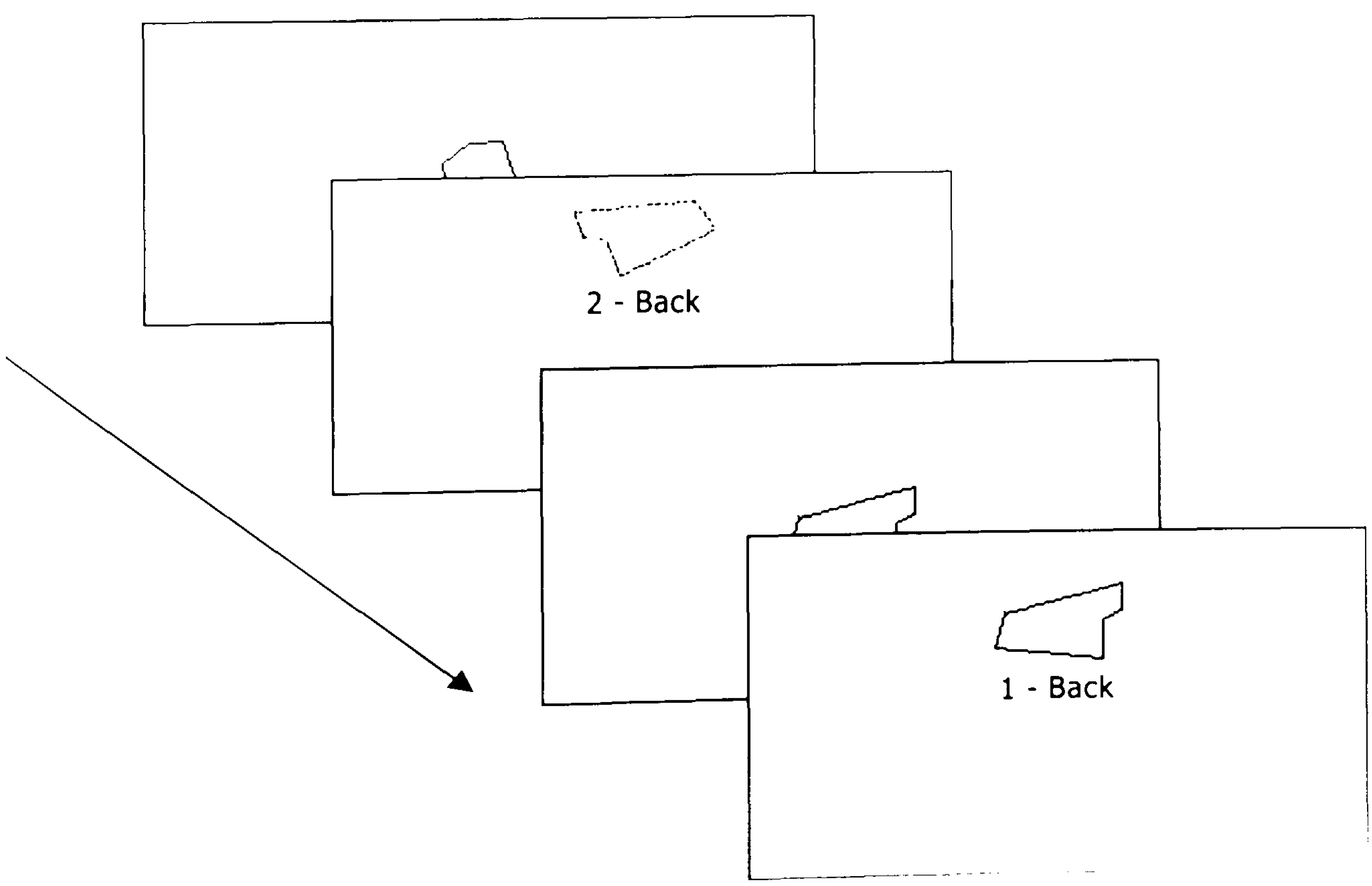
In the load condition, the second shape of the shape pairing was presented on the computer screen for five seconds. After the shape disappeared a prompt was presented on the computer screen for five seconds. The prompt consisted of one of the following signals: an asterisk (*), 1–Back or 2–Back. If the * prompt appeared this indicated that no response was required on this occasion. When either the 1–Back or the 2–Back prompt appeared a shape appeared at the same time above the prompt. If the 1–Back prompt appeared the participant had to think back to the shape that that had just disappeared from the computer screen, and decide whether this shape was the same as the current shape on the computer screen or a mirror image. A response of either 'yes' or 'no' was then made on the computer keyboard. If the 2–Back prompt appeared participants were required to use the shape from two positions back. Thus, participants were required to keep in mind the previous two shapes presented in order to respond appropriately when the prompt appeared. The 1–Back signal was included so that participants could not prepare a response to the two back signal in advance. The no back signals (*) were included as fillers so that each cue was only tested once and again their inclusion made it difficult for participants to prepare a response. A total of four no response prompts were used in each experimental session. In each experimental session there were ten test trials. Eighty percent of the prompts were the 2–Back cue and 20% were the 1–Back cue. The computer recorded the participants' responses.

Figure 6.3 Example of the procedure – Mental rotation no load and load conditions

No Load Condition



Load Conditions (n – Back)



6.3.3 Results

Because the age groups differed in education this measure was initially entered as covariates in the analyses. However, the covariate was not significant in any analysis and therefore is not discussed further.

Analysis of Absolute Response Time and Error Rate Data

The absolute response time and error rates for the mental rotation task under the conditions of load and difficulty are shown in Table 6.2. Post hoc comparisons were conducted using the Bonferroni procedure with a significance level of $p < 0.05$ unless otherwise stated.

Table 6.2 Mean (and SD) response latency (in msec) and errors for the mental rotation task under no load (easy and hard) and load (easy and hard) conditions

	Younger Adults				Older Adults			
	Response latency		Errors /20		Response latency		Errors /20	
	M	SD	M	SD	M	SD	M	SD
No Load (easy)	2044	332	0.44	0.62	3124	566	3.78	2.07
No Load (hard)	2221	403	1.5	1.62	3300	443	4.89	2.85
Load (easy)	2753	412	7.06	2.46	3251	376	9.28	1.53
Load (hard)	2611	465	8.11	2.49	3215	496	9.72	1.9

Response times in the mental rotation task were analysed in a 2 (Age Group) x 2 (Load) x 2 (Difficulty) analysis of variance. This analysis revealed that response times were generally slower for the older adults ($F(1,34) = 45.5$, $MSE = 524681$, $p<0.01$) and slower in the load conditions ($F(2,34) = 19.61$, $MSE = 149097$, $p<0.01$). The main effect of difficulty was not significant. The interaction between load and age group was significant ($F(1,34) = 16.86$, $MSE = 149097$, $p < 0.01$). An analysis of simple main effects, using the Bonferroni procedure, found that load slowed response times only in the younger age group. The interaction between load and difficulty showed that increasing the difficulty of the mental rotation task only had an effect in the no load condition ($F(1,34) = 15.52$, $MSE = 40839$, $p < 0.01$).

The next set of analyses was carried out on the error rates. A 2 x (Age Group) x 2 (Working Memory Load) x 2 (Difficulty) analysis of variance was carried out on the error data. This analysis showed that the older adults produced more errors ($F(1,34) = 37.72$, $MSE = 6.6$, $p < 0.01$) and errors were greater in the working memory load compared to the no load condition ($F(1,34) = 283.4$, $MSE = 4.4$, $p < 0.01$). There was a main effect of difficulty which demonstrated that error rates were the greatest in the difficult version of the mental rotation task ($F(1,34) = 13.01$, $MSE = 2.33$, $p < 0.01$). There was also a working memory load by group interaction ($F(1,34) = 4.26$, $MSE = 4.41$, $p < 0.05$). Post hoc comparisons using the Bonferroni procedure reveal that load increased error rates particularly in the older age group. All other interactions were not significant.

Dual Task Costs Analysis

The mean data presented above suggested that in the load conditions performance was indistinguishable from guessing. This was particularly the case for older adults. Therefore, these data are not presented in terms of dual task costs.

Speed error trade-off

Since we were concerned with both the speed of carrying out the mental rotation task and the errors, we investigated whether these two measures were related. In order to examine the speed error trade off between participants we used the raw response times and error rates. If participants are sacrificing response time to maintain accuracy, negative correlations would be expected. There was no evidence to suggest that the response time was related to the error rates as the correlations were either positive or not significant ($r = 0.7$, $p < 0.01$ for the no load easy version, $r = 0.56$, $p < 0.01$ for the no load hard version, $r = 0.43$, $p < 0.01$ for the load easy version, and $r = 0.29$, $p > 0.05$ for the load hard version of the tasks). Those, who were most slowed by the visual spatial task, were also the most inaccurate.

6.3.4 Discussion

This experiment was carried out to minimise the problem of verbalisation encountered in experiment 6.1. There was evidence to suggest that when participants are required to hold and update visual spatial information concurrently with an additional visual spatial task, older adults are no more penalised than the young. However, we suggest that participants might have been using different strategies to keep the visual spatial information in mind in the n-Back task. Certainly, participants may have been giving verbal labels to the location of the coloured block in the grid. Therefore, it was desirable to use stimuli which were difficult to give verbal labels; to this end, a mental rotation version of the n-Back task was used.

Consider the effects observed using the absolute measures of response time. As one would expect, overall older adults' response time were the greatest. What was surprising was that overall response times were no more slowed with increased difficulty (i.e. degree of rotation). However, when we consider the response times separately for the no load and load condition we see that response times were slowed with increased difficulty in the no load condition. This is consistent with previous findings that have demonstrated poorer performance as angular disparity is increased (e.g. Shepard & Metzler, 1971). With reference to the main aim of thesis, were older adults more penalised in a visual spatial processing task with concurrent processing demands? In terms of the absolute measures of performance it would seem that it is only the younger age group that had particular problems with dual tasking. This is a surprising result, but we will first consider the error rate data before considering this curious finding. Overall older adults produced more errors as one would expect. There were also more errors produced in the load condition compared to the no load condition. Overall, the difficulty manipulation influenced the amount of errors being made. The comparison between the no load and load conditions for younger and older adults again produced a unexpected result. Introducing a concurrent load increased error rates for both groups, but more so for the younger adults. The demands of the current visuospatial memory load was problematic for both groups. The opposite pattern than expected can be explained by a ceiling effect. A large number of older adults' performances were at chance.

A closer examination of the mean data suggested that perhaps keeping in mind the geometric shapes was particularly difficult for both age groups as indicated by the number of errors. For instance, for the older adults in the more difficult load condition their accuracy was at chance. These data then should be treated with caution and since the accuracy was poor, the reliability of the response time measure is also questionable. Considering the response times again, for younger adults adding a concurrent load increased response times. However, for younger adults the response times were equivalent across conditions. An age effect may have emerged if the task was such that both groups were able to keep in mind the shapes n-Back, but for older adults the task was so difficult performance was indistinguishable from guessing and this resulted in no additional slowing under load conditions.

The dual task cost analysis revealed similar results with the costs being greater for younger adults. Dual task costs were the greatest in the easy dual task condition. Considering the mean data again, we can see that since error rates were particularly high in the more difficult dual task for both groups this finding is to be expected because of the probable high rate of guessing in the more difficult task.

This experiment set out to eliminate the potential problem of age differences in strategy used in experiment 6.1. We were concerned with whether concurrent visuospatial working memory load would differentially affect the performance of older adults compared to the young. Unfortunately, the n-Back procedure using this particular material was found to be an inappropriate paradigm to investigate age differences in concurrent processing demands. Older adults have been widely reported to have difficulties in visuospatial working memory (e.g. Bruyer & Scailquin, 1999). Furthermore, on tests of mental rotation older adults perform more poorly (e.g. Cerella et al., 1981). Therefore, under dual task conditions the task demands were too high in the present experiment and older adults' performance in particular was at chance. What is needed is a further investigation of the costs of dual tasking when mental rotation is involved, perhaps with an easier secondary task, or easier materials.

6.4 General Discussion

The major purpose of this chapter was to examine further whether task domain moderated dual task costs in older adults. In the previous chapters it was suggested that in domains of cognition which show the greatest impairment with increasing age like episodic memory (Chapters 2 and 3), adding a concurrent task will cause more interference. In other domains, tasks may be quite complex, but if there is a large familiarity component as in semantic memory, no age difference is found.

In this chapter we were concerned with visuospatial processes and concurrent processing demands. This is an important line of inquiry as the interaction between visuospatial and dual tasking skills are required in everyday activities such as driving (Owsley et al., 1991). Unlike semantic memory and language skills that can draw on overlearned processes, in the visuospatial domain, performance is less reliant on accumulated knowledge and everyday practice like verbal abilities. We used the n-Back procedure to examine the impact of different ways of increasing task complexity. In experiment 6.1 there was evidence in absolute terms that older adults find visuospatial processing particularly problematic with concurrent processing demands. However, when we controlled for baseline differences in performance, age differences in performance were removed. We were cautious about interpreting these findings because of the nature of the stimuli being used. However, much like chapters 4 and 5 we observed large dual task costs for both groups but no age effect. This finding suggests effort or difficulty of the dual task is unrelated to whether age differences in performance are observed. This is consistent with Somberg & Salthouse (1982) who found costs of 0.52 and 0.56 for the young and the old respectively, and no age effect of dual tasking. They argued that the absence of the age effect was the result of a simple task being used. In experiment 6.2 we further investigated age differences in performance by manipulating both difficulty within the task and by introducing a concurrent working memory load. The demands were found to be too high for both groups, so a further investigation using different visuospatial tasks is desirable.

7. A Meta-analysis of Dual Task Ageing Studies

7.1.1 Introduction

In the previous chapters it was argued that task domain is an important moderator variable of dual task costs in older adults. The domain of cognition or perhaps the particular combination of task is crucial in whether an age effect on dual tasking is observed. Methodological differences were also outlined as potential reasons why there is great variability in the literature as to whether age differences in dual task performance are detected. In the present chapter we further investigate the critical task components which result in older adults' poorer dual task performance by conducting a meta-analysis on previous dual task ageing studies.

One of the reasons why there is discrepancy in the literature regarding age differences in dual task performance is methodological variation across studies (see Somberg & Salthouse, 1982; Salthouse et al., 1995). There are three methodological factors that could influence whether an age effect is found in dual task studies: absolute versus relative measures of performance, task complexity and task domain. Age differences in dual task performance have been considered in both absolute and relative terms. As already noted, older adults are poorer at dual tasking in absolute terms but this is hardly surprising since they are poor on a large number of tasks when they are performed alone. Therefore, what is of interest is whether older adults have a dual task deficit greater than that predicted from single task performance. It was argued that proportional differences in performance might be a more valid measure of dual task performance. Second, task difficulty or complexity of the dual task situation may be critical. When the tasks are relatively automatic or data driven, performance may be relatively resilient to concurrent task demands even for older adults. If old age brings about a decline in processing resources or speed of processing is slowed with increased age this would have little impact in older adults' performance if the capacity of older adults were not reached. In the previous chapter it was found that task difficulty is not the whole story as to whether an age effect is found. This conclusion was reached because disproportionate dual task costs are found sometimes in less difficult rather than more difficult tasks (see also Korteling, 1991). Also, a number of studies have found that increasing difficulty within a task and by divided attention manipulation do not necessarily bring about the same effect (Tun & Wingfield, 1993). Therefore, task domain may be the important moderator variable.

In this chapter a meta-analysis is carried out on dual task ageing studies ranging from 1981 and 2001 (years available on the Web of Science citation index). The aims were to discover whether the age effect is robust and to see whether the average effect size was sufficient to describe the pattern of results across studies. If as we expect, this is not the case, we would use the findings from the previous literature and the present set of experiments to group the effect sizes according to hypothesised moderator variables. Particularly we will consider the magnitude of the effect sizes according to different domains of cognition.

7.1.2 Meta-analysis

Meta-analysis is a statistical procedure used to combine the results of several independent studies. Glass (1976, p.3) defined meta-analysis as "...an analysis of analyses" and is ideal for investigating the magnitude of a treatment effect across studies. Since there has been a large number of studies on age differences in dual task performance, sometimes giving conflicting results, carrying out a meta-analysis is highly desirable. First, it will enable a summary of research findings across studies by extracting a common metric such as the effect size. It is then important to establish whether any variation observed in the effect sizes is due to sampling error or variation due to study characteristics. An examination of study characteristics can then be made to uncover moderator variables of the variation in effect size.

Kieley (1991, in Hartley, 1992) was the first to carry out a meta-analysis on age differences in dual task performance. The Hedges & Olkin (1985) method was applied to the data and a large average effect size was found ($d = 0.99$). The effect size d refers to the most commonly used effect size estimator and represents the standardised difference between the control and experimental groups ($g = (Mean_e - Mean_c)/SD$)) transformed to take into account sample bias ($d = (1-(3/4*N-9))*g$). That is, with small sample sizes g is unreliable. Hedges & Olklin (1985) described effect sizes of 0.2, 0.5 and 0.8 as small, medium and large, respectively. However, the effects were not homogeneous which suggests that there were different factors determining the effect. To investigate this further, dichotic listening tests were eliminated from the analysis as it could be argued that such tasks are not dual tasks in the strictest sense. Studies were also sub-divided according to study characteristic and tested for homogeneity within each sub group. The studies were grouped based on such factors as whether baseline differences in performance had been considered, difficulty or modality of tasks and the dependent measure used. Unfortunately, no exact details were given of the subgroups analysed and the effect sizes. However, Hartley (1992) reported that there was some suggestion that older adults are particularly disadvantaged at dual tasking when the tasks are difficult or when there is a substantial memory or motor component.

Chen (2000) carried out a similar analysis on 25 studies between 1981 and 1997.

This author found an overall effect size that was significantly greater than zero (g = 0.79). Studies were then divided according to whether relative or absolute measures of performance had been used. It was found that the effect size for the studies reporting the relative measures of performance were greater than that of those reporting the absolute measures of performance (g = 1.18 and g = 0.51 respectively). This was somewhat surprising, as one would expect those studies that did not control for baseline differences in performance to report larger age effects. A separate analysis was also carried out on the reaction time and accuracy data and those studies using a reaction time measure had the greatest effect sizes. The final finding related to whether tasks shared either the same input modality, output modality or the same internal codes of processing. It was found that the age effect was the greatest in those tasks that shared the same internal codes of processing. From this it was concluded that older adults' problems with dual tasking result from problems at the central stages of processing. Again, details of the subgroups and effect sizes were not given in this study.

This meta-analysis further examined age differences in dual task performance by trying to replicate the earlier studies by Kieley (1991) and Chen (2000). We expanded on the previous meta-analyses by considering in more detail the task characteristics that might influence the magnitude of the age difference in dual task performance. To this end, we decided to compare dual task studies that were either simple or relied on relatively automatic processing with tasks that relied on controlled processing (e.g. memory retrieval) or with tasks that had a motor component. Our expectations were that a large overall effect size would be obtained but the effect sizes would not be homogeneous. It was also expected that tasks that required effortful controlled processing or had a motor component would have a larger effect size than those studies that were relatively automatic or data driven. A comparison between the reaction time data and the accuracy data was carried out. Also, since baseline differences in performance could be a potential confound we consider this as a potential moderator variable. In addition, we integrated our findings into the meta-analysis to investigate whether our results were in line with previous research.

7.2 Method

Literature Search

A computer-based search was carried out using the Web of Science bibliographic database. Using both the science and social science citation index, 31 articles were selected from 1981 to 2001. This was achieved by performing a keyword search using various combinations of terms such as 'dual task', 'dual tasking', 'divided attention', 'ageing' etc. Unfortunately, we were not able to establish whether all those studies used in Kieley (1991) and Chen (2000) were present in the current meta-analysis as they failed to give details.

Effect Size Calculations

The published studies included in the meta-analysis are shown in Table 7.1. and the experiments included from this thesis are summarised in Table 8.1. The majority of the studies did not report means and standard deviations necessary for the calculation of the effect size. Therefore, effect size estimates were calculated from statistics such as F, t and R^2 (see chapter five, Glass, McGaw, & Smith, 1981). The unbiased effect size estimation was used in the analysis.

A meta-analysis was carried out using the procedures described by Hedges & Olkin (1985). The first aim of the meta-analysis was to decide whether the studies share the same overall effect size. This was achieved by calculating the fit statistic Q_T. (see Hedges & Olkin, 1985). If the fit statistic is significant this demonstrates that the effect sizes are not homogeneous across studies. This suggests that there are different factors contributing to the magnitude of the effect size.

In the second stage of the analysis, the studies are partitioned into subgroups based on what are believed to be the most important factors contributing to the magnitude of the effect size. The next stage is to carry out a comparison of the effect sizes between and within the subgroups much like a standard analysis of variance. That is, between group fit and within group fit must be calculated and evaluated. The fit statistic Q_W is calculated so that we can ascertain whether the studies within the subgroups have to be partitioned further. The Q_B statistic is calculated to see whether there is a difference in the magnitude of the effect size between subgroups.

Table 7.1 Component Tasks, Sample Size, Mean Age of the Younger and Older Participants, Dependent Variables, Controls for Baseline Differences in Performance and Effect Size for 31 Published Articles between 1981-2001

Id	Reference	Task One	Task Two	Task*	n	Mean Age	Dependent Variable	Control for Baseline Differences	*d*
1	Wright (1981)	Digit load (vocal response)	Reasoning (manual response)	C	12	19.4	Task one – Accuracy	No	1.6
2				C	12	68.2	Task two – Accuracy	No	1.2
3	Salthouse & Somberg (1982)	Visual Discrimination (manual response)	Auditory reaction time task (vocal response)	A	8 8	22.9 68.8	Task two – reaction time	No	3.8
4	Somberg & Salthouse (1982)	Visual target detection (manual response)	Visual target detection (manual response)	A	16 16	19.8 65.1	P.O.C. analysis - accuracy	Yes	0.24
5	Macht & Buschke (1983)	Word recall after sorting	Visual reaction time (manual response)	C	48 48	19.6 70.3	Task two – reaction time	Yes	0.92
6	Duchek (1984)	Semantic, rhyme or arithmetic questions (manual response)	Auditory reaction time (manual response)	C	32 32	20.4 68.3	Task two – reaction time at encoding	No	0.34
7				C			Task one – accuracy at retrieval		1.26

8	Salthouse et al. (1984)	Visual digit span (vocal response)	Visual letter span (vocal response)	C	24 24	18.9 69.5	P.O.C. analysis - accuracy	Yes	0.7
9				C	16 16	18.6 70.1			0.5
10				C	16 16	19.1 66.6			0.9
11	Baddeley, Logie, Bressi, Della Sala & Spinnler (1986)	Tracking	Auditory digit Span (vocal response)	M	20 28	24.3 64	Task two - accuracy	Yes	0.3
12	McDowd (1986)	Tracking	Auditory reaction time (manual response)	M	6 6	22.5 69.5	Task one and two – time on target and reaction time	Yes	1.2
13	Craik & McDowd (1987)	Cued recall and recognition (vocal response)	Visual reaction time task (manual response)	C	15 15	20.7 72.8	Task two – reaction time	yes	0.63
14	Guttentag & Madden (1987)	Letter matching (manual response)	Tone detection (manual response)	C	14 14	19.9 68.9	Task two – reaction time	Yes	0.95
15	Morris, Gick & Craik (1988)	Free recall	Sentence verification (manual response)	C	16 16	21.4 71	Task two - accuracy	No	0.66
16	McDowd & Craik (1988)	Auditory word monitoring (manual response)	Visual reaction time (manual response)	C	16 16	19.4 69	Task one and two – reaction time	Yes	1.27

17		Auditory digit monitoring (vocal response)	Visual reaction time (manual response)		18 18	21 71.9	Task two – reaction time		
			Task A – as experiment one	C					1.9
18			Task B –faces tasks	C					0.7
19	Lorsbach & Simpson (1988)	Letter matching task (manual response)	Auditory reaction time (manual response)	C	18 18	20.2 66.8	Task two – reaction time	Yes	2.0
20	Ponds et al. (1988)	Tracking	Dot counting (manual response)	M	17 41	27.5 68.6	P.O.C. analysis - accuracy	Yes	0.8
21	Baron & Mattila (1989)	Memory scan – visual and auditory (manual response)	Memory scan – visual and auditory (manual response)	C	12 12	18-25 65-76	Task one and two – reaction time	Yes	0.68
22	Park et al. (1989)	Word recall	Auditory digit monitoring –	C	64 62	19 72.3	Task one - accuracy	No	0.7
23			manual response	C	16 16	18.8 67.3			0.74
24	Brouwer et al. (1990)	Tracking (steering)	Dot counting (manual response)	M	22 22	30.2 66.2	Task one and two - accuracy	Yes	0.8
25	Mellinger, Lehman, Happ & Grout (1990)	Recall visual and auditory words	Visual reaction time (manual response)	C	32 32	20 68	Task two – reaction time	Yes	1.08

26	Morris et al. (1990)	Word recall	Sentence verification (manual response)	A	16 16	21.4 71	Task one - accuracy	No	0.6
27 28	Brouwer et al. (1991)	Tracking	Visual reaction time task (manual and vocal responses)	M M	12 12	26.11 64.4	Task one – time on target Task two - accuracy	Yes	1.0 1.7
29	Marquie & Baracat (1992)	Typing task	Auditory reaction time (manual response)	C	12 12	22.2 62.2	Task two – reaction time	Yes	0.9
30 31	Hawkins et al. (1992)	Visual reaction time (manual response)	Auditory reaction time (manual response)	A A	14 14	27.5 68	Task one and two – reaction time	Yes	1.08 1.03
32 33	Tun et al. (1992)	Recall of spoken passages	Picture recognition	A A	25 25	20.3 68	Task one – accuracy Task two – reaction time	No	0.29 0.82
34	Korteling (1993)	Tracking	Tracking	M	14 14	25.8 69.7	Task one and two - accuracy	Yes	1.02
35	Korteling (1994)	Tracking (steering)	Motor (pedal push)	M	12 12	27 70	Task one - accuracy	Yes	1.14
36	Tun & Wingfield (1994)	Speech recall	Letter matching (manual response)	A	18 18	20.1 69.8	Task one - accuracy	No	0.41
37 38	Kramer et al. (1995)	Monitoring task (manual	Alphabet – arithmetic task	C C	29 30	20.8 67.8	Task one – reaction time Task one – accuracy	No	0.54 0.62

39		response)	(manual response)	C			Task two – reaction time		0.9
40	Light & Prull (1995)	Naming task	Number addition task (manual response)	A	24	21.2	Task one – reaction time	No	0.0
41				A	24	72	Task two – accuracy		0.7
42				A	48	21.8	Task one – reaction time		0.0
43				A	48	73.6	Task two - accuracy		0.5
44	Salthouse et al. (1995)	Letter memory	Visual reaction time (manual response)	C	40	20.9	Task one - accuracy	Yes	0.6
45				C	40	66.8	Task two - accuracy		0.2
46				C			Task two – reaction time		0.1
47	Anderson et al. (1998)	Free recall	Visual reaction time task (manual response)	C	24 24	22.5 68.6	Task two – reaction time	Yes	1.64
48		Cued recall		C	24	21	Task one – accuracy		0.34
49				C	24	67.9	Task two – reaction time		1.91
50		Recognition		C	24 24	19.7 68	Task two – reaction time		0.89
51	Clarys et al. (2000)	Word fragment completion	Memory load	A	24 24	30.8 74.7	Task one – accuracy	No	0.10
		Cued recall	Memory load	C	24 24	30.8 74.7	Task one – accuracy	No	0.12

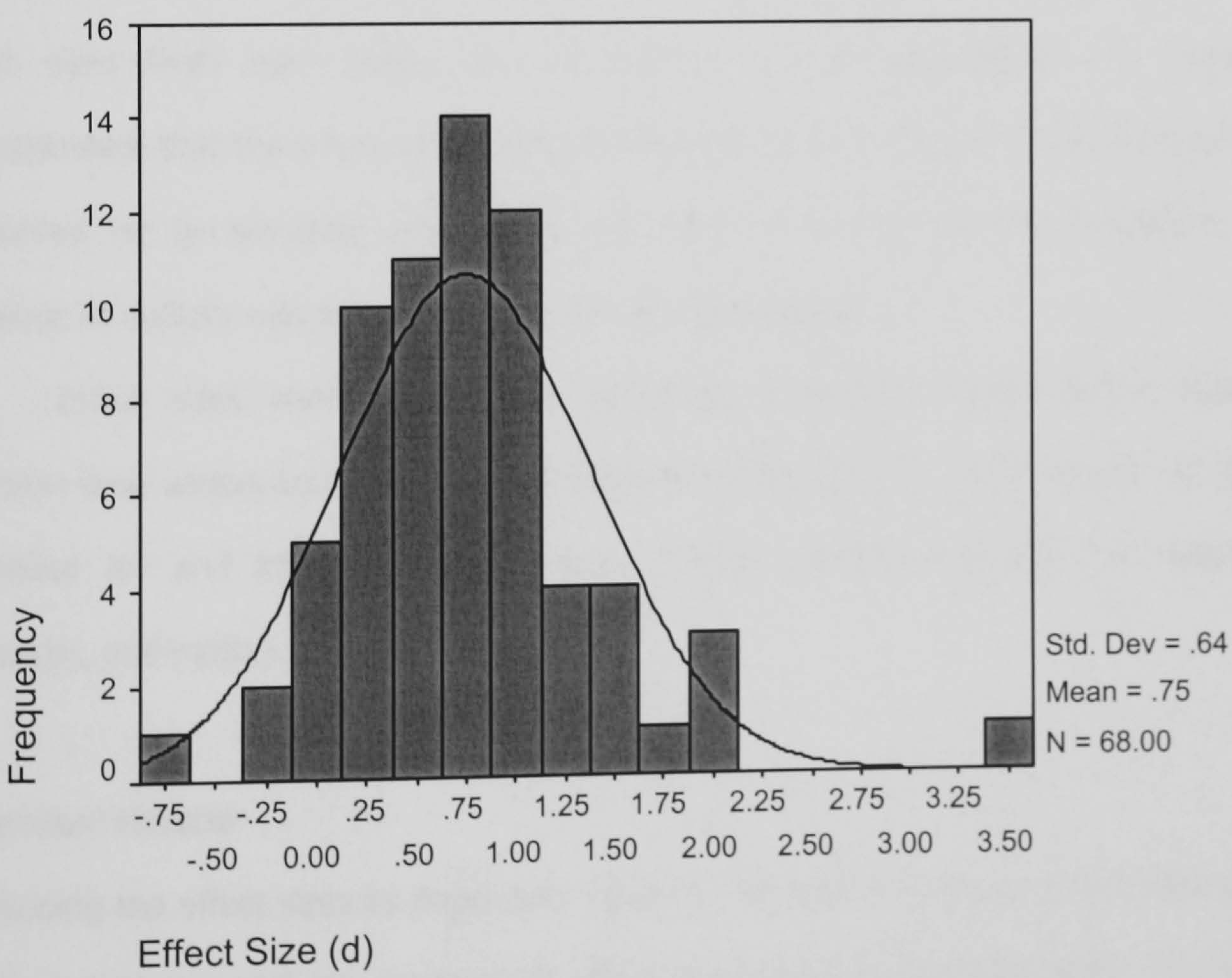
**C, A and M represent controlled, automatic and motor processing tasks respectively*

7.1.4 Results

Overall Effect Size

The first aim of the meta-analysis was to calculate the overall mean effect size (*d*) and then determine whether this measure best describes our data. The analysis performed was based on the procedures outlined by Hedges and Olkin (1985). Figure 7.1 shows the distribution of the effect sizes (*d*). The mean weighted effect size was *d* = 0.75, with a 95% confidence interval from 0.07 to 1.42. To determine whether this mean weighted effect size was a good representation of the effect sizes from each study, the fit statistic Q_T was calculated. This analysis demonstrated that the effect sizes were heterogeneous, Q_T (67) = 169.5, p<0.05.

Figure 7.1 The Distribution of the Effect Sizes (*d*)



Moderator Variable Search

Since the weighted mean effect size was a poor fit to the data, it was necessary to investigate the variability in the effect sizes. Before an examination of moderator variables was undertaken, a further analysis was performed on the effect sizes eliminating one outlier (Id 19) and one extreme value (Id 3). In addition, experiments 2.1, 6.1 and 6.2 were eliminated from the analysis due to the methodological problems discussed. In experiment 2.1 the results were not interpretable due to task and speed-accuracy trade offs. In experiment 6.1 the results were misleading due to the verbal labelling strategy that might have been used. In Experiment 6.2 the performance was indistinguishable from guessing (see sections 2.3.3 and 6.10 for further details). The mean weighted effect size was 0.74, with a 95% confidence interval from 0.09 to 1.40. To determine whether this mean weighted effect size was a good representation of the effect sizes from each study, the fit statistic Q_T was calculated. This analysis demonstrated that the effect sizes were heterogeneous and this variability could not be accounted for by sampling error alone, Q_T (60) = 111.96, $p<0.05$. Therefore, the presence of outliers was not responsible for the heterogeneity.

Effect sizes were divided into subgroups according to dependent variable (reaction time versus accuracy), whether base line differences in performance had been controlled for and into three task groups (central, simple perceptual or relatively automatic, and motor).

Dependent Variable

Partitioning the effect sizes by dependent variable produced one group of 32 effect sizes based on accuracy and one group of 29 effect sizes based on reaction times. The mean weighted effect size for the accuracy group was 0.67, with a 95% confidence interval from 0.03 to 1.31. The mean weighted effect size for the reaction time group was 0.80, with a 95% confidence interval from 0.15 to 1.45. One effect size (Id. 12) was removed from the analysis as the effect size represented a combined measure of the accuracy and reaction times of the two component tasks in the study. Since the overall fit statistic Q_T was statistically significant in the overall analysis (Q_T (59) = 68.36, p<0.05) the between group statistics Q_B and the within group statistic Q_W were calculated ($Q_T = Q_B + Q_W$). The first analysis investigated the homogeneity of effect sizes across groups. In this analysis Q_B was lower than 95 percent critical value of the chi squared distribution and showed that there was no difference between the effect sizes between groups (Q_B (1) = 1.5, p>0.05). The within group fit was next calculated and this demonstrated that there was a lack of fit within groups (Q_W (58) = 109.76, p<0.05). Each group was then examined for poor fit. This analysis demonstrated that the effect sizes within the accuracy group were homogeneous (Q_W (30) = 36.48, p>0.05). However, for the reaction time group Q_W exceed the 95 percent critical value of the chi squared distribution so the variability within the reaction time group could not be explained by sampling error alone (Q_W (28) = 73.28, p<0.05). At this point it is necessary to partition the reaction time group to investigate other moderator variables of the dual task age effect. This will be examined under the task characteristics section below.

Controls for Baseline Differences in Performance

One possible source of variation in the effect size estimates is whether investigators have controlled for baseline differences in performance. Without such control it is difficult to establish whether any age related difference in performance is due to a general performance decrement or a specific problem in dual tasking. Baseline differences in performance can be controlled for by either adjusting the levels of difficulty of the component tasks according to each individual's performance or by statistically controlling for differences in single task performance (see Somberg & Salthouse, 1982; Salthouse et al., 1995).

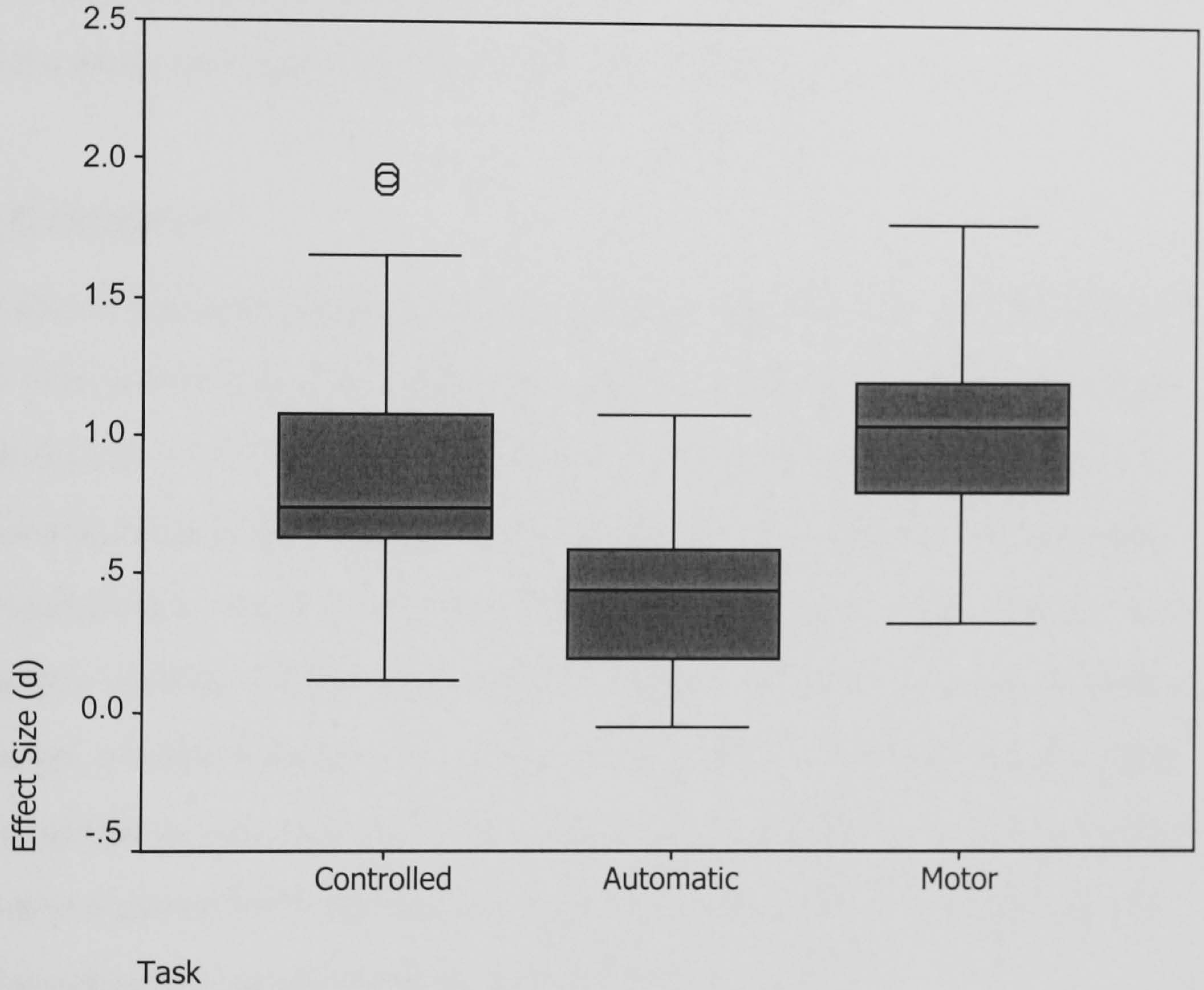
Partitioning the effect sizes, by whether baseline difference in performance had been controlled for, produce one group of 20 effect sizes based on absolute measures of performance and one group of 42 effect sizes based on age differences in performance after single task performance difference were eliminated. The mean weighted effect size for the group where baseline differences in performance were not taken into account was 0.61, with a 95% confidence interval from 0.03 to 1.20. The mean weighted effect size for the group where single task performance differences were controlled for was 0.81, with a 95% confidence interval from 0.12 to 1.5. Since the overall fit statistic Q_T was statistically significant in the overall analysis (Q_T (60) = 111.96, $p<0.05$) the between group statistics Q_B and the within group statistic Q_W were calculated. The first analysis investigated the homogeneity of effect sizes across groups. In this analysis Q_B was lower than the 95 percent critical value of the chi squared distribution and showed that there was no difference between effect sizes between groups (Q_B (1) = 4.78, $p>0.05$). The within group fit was next calculated and this demonstrated that there was a lack of fit within groups (Q_W (59) = 107.18, $p<0.05$). Each group was then examined for poor fit. This analysis demonstrated that the effect sizes within the no baseline control group were heterogeneous (Q_W (19) = 33.14, $p<0.05$), and similarly for the control for baseline difference group the effect sizes were heterogeneous (Q_W (40) = 74.04, $p<0.05$).

Task Characteristics

The next analysis was carried out to investigate whether the variability in the effect sizes can be accounted for by the type of the component tasks in the dual task situation. An examination of Table 7.2 shows that a large variety of tasks and combinations have been used and few use the exact same tasks and combinations. Therefore, three broad classes of tasks were constructed and we acknowledge that there may be some overlap in processes involved in the tasks. Table 7.2 shows the group to which each study was assigned. Group one contained those studies deemed to have a large central processing component (e.g. episodic memory tasks and reasoning tasks), group two contained those tasks which were data driven or relied on relatively automatic processing (e.g. simple perceptual, implicit memory and language processing tasks), and group three contained tasks with a large motor component (e.g. tracking).

Partitioning the effect sizes by task group produced one group of thirty one effect sizes based on tasks with a large central processing component, 19 effect sizes based on tasks which relied on relatively automatic processing and eight effect sizes based on tasks that had a large motor component. The mean weighted effect size for central processing (group 1) was 0.86, with a 95% confidence interval from 0.22 to 1.50. The mean weighted effect size for automatic processing (group 2) was 0.43, with a 95% confidence interval from –0.19 to 1.79. The mean weighted effect size for motor processing (group 3) was 0.76, with a 95% confidence interval from 0.11 to 1.41. Figure 7.2 shows the distribution of these effect sizes for each of the three task groups. Since the overall fit statistic Q_T was statistically significant in the overall analysis (Q_T (59) = 111.96, $p<0.05$) the between group statistic Q_B and the within group statistic Q_W were calculated. The first analysis investigated the homogeneity of effect sizes across groups. In this analysis Q_B was higher than 95 percent critical value of the chi squared distribution and showed that there was a significant difference between effect sizes between groups (Q_B (2) = 28.15, $p<0.05$). The within group fit was next calculated and this demonstrated that the effects sizes were heterogeneous within classes (Q_W (43) = 52.3, $p<0.05$).

Fig. 7.2 The Distribution of Effect Sizes (*d*) for the Three Task Groups



Since the effect sizes were not homogeneous within the groups, each group was examined for poor fit. The effect sizes within groups 2 and 3 were homogeneous (Q_W (18) = 17.19, $p>0.05$ and Q_W (7) = 7.50, $p>0.05$ respectively). However, for group 1 the effect sizes were heterogeneous (Q_W (32) = 66.62, $p<0.05$). The data was re-analysed with two outliers removed (id. 17 and 49; also shown in Fig. 7.2). Since the overall fit statistic Q_T was statistically significant in the overall analysis (Q_T (57) = 89.22, $p<0.05$) the between group statistics Q_B and the within group statistic Q_W were calculated. The first analysis investigated the homogeneity of effect sizes across groups. In this analysis Q_B was higher than the 95 percent critical value of the chi squared distribution and showed that there was a significant difference between effect sizes between groups (Q_B (2) = 24.52, $p<0.05$). The within group fit was next calculated and this demonstrated that the effects sizes were homogeneous within classes (Q_W (55) = 64.69, $p>0.05$).

7.1.5 Discussion

The aims of this meta-analysis were to examine the magnitude of the age differences in dual task performance and whether the combined effect size estimate is a good representation of the pattern of results across studies. If the effect sizes were found to be heterogeneous it would be necessary to examine task characteristics that may explain the heterogeneity. Therefore, the second part of the meta-analysis analysed the role of moderator variables that may influence the variability in effect sizes across studies. Moreover, we were concerned with whether the variability in the magnitude of the effect sizes reported in this thesis were in line with previous research. We chose to use the procedures outlined by Hedges and Olkin (1985) to partition effect sizes into rationally derived subgroups and examine the fit within and between groups.

Consider first the mean weighted effect size calculated from the 31 published articles. The effect size was particularly high at 0.75 which simply represents the standardised mean difference between younger and older adults' dual task performance. As noted earlier, effect sizes of 0.2, 0.5 and 0.8 are considered low, medium and high, respectively (Hedges & Olkin, 1985). This result is similar to the findings by Kieley (1991) and Chen (2000) who found mean effect sizes of 0.99 (*d*) and 0.79 (*g*) respectively. The present meta-analysis replicates previous findings that overall age differences in dual task performance are high. Like these two earlier meta-analyses we sought to explain the variability in the effect sizes across studies by considering task characteristics.

Having reviewed the dual tasking literature and discussed the findings in the previous chapters, we argued that methodological variations, task difficulty and task domain influence dual task performance in older adults. Therefore, these factors were considered in the present meta-analysis. Effect sizes were first partitioned into groups according to the dependent measure used. Chen (2000) reported that the effect size was greater when a reaction time measure was used, but there was no indication whether the effect was significantly greater than the effect size when an accuracy measure was used. The present meta-analysis found similar results with effect sizes of 0.67 and 0.80 for reaction time and accuracy, respectively. However, this difference failed to reach significance so we conclude that both accuracy and response time measures are equivalent in the analysis of age differences in dual task performance and the distribution does not account for the variability in effect sizes across studies.

Somberg & Salthouse (1982) were the first to criticise the majority of findings regarding age differences in dual task performance as generally early studies failed to take into account baseline differences in performance. When the studies were partitioned into groups according to whether baseline difference in performance had been considered it was found that the mean effect sizes were equivalent. However, the effect sizes were heterogeneous within the two groups. Intuitively, one would expect the effect size based on absolute differences in performance to be greater than that when a proportional or relative measure is used. This would be consistent with studies that have initially observed age differences in dual task performance, but found that this difference was eliminated when using proportional or relative measures of performance (e.g.

Somberg & Salthouse, 1982). Chen (2000) did compare the few studies that reported both measures and found similar effect sizes. They found the opposite pattern expected when studies reported either absolute or relative measures of performance. We found the same result except the difference was not significant (absolute: 0.61, controlled for baseline differences: 0.81). This pattern can be accounted for by examining Table 7.2 which clearly shows that a large majority of the tasks only reporting absolute measures of performance used tasks involving relatively simple or automatic tasks (e.g. language processing and implicit memory).

Our main concern was the examination of task as a moderator variable of dual task costs in older adults. It was problematic categorising the studies into groups as there has been a large variety of tasks and combinations used. However, the results from the experimental chapters presented in this thesis suggest that older adults find dual tasking particularly difficult when tasks involve controlled processing compared to relatively automatic processing. Therefore, two broad classes were constructed including either tasks requiring primarily controlled processing compared to automatic processing. In addition, a third group comprising tasks which required largely motor processing was constructed.

The results were in line with our expectations. Those tasks with a large central or controlled processing element produced a large effect size of 0.86. Those tasks with a large memory component in particular made up group one. Also in this group were the data from experiments 3.1 and 3.2 and since the effect sizes did not stand as outliers the results were consistent with previous findings in the literature. The mean effect size from the automatic processing group (group 2) produced an effect size of 0.43 and again our results were in line with previous research which have found either no or small age differences in dual task performance in domains of cognition which rely on overlearned or relatively automatic processing. Our final group consisted of those tasks where motor processing is primarily required and much like group one a large overall effect size was produced ($d = 0.76$). This finding is consistent with previous research that has found age effects both at the cognitive and motor processing level (e.g. Crook et al., 1993). Furthermore, it has been identified that when complex tasks (e.g. driving) require motor skills, older adults are particularly impaired (e.g. Korteling, 1991).

The findings of the present meta-analysis have highlighted the usefulness of such techniques in integrating data from a number of studies. Such procedures enable the comprehensive review of studies relating to a particular hypothesis; in this thesis are there age differences in dual task performance? As well as being able to investigate the magnitude and reliability of a combined effect size, such an analysis enables the examination of the influence of moderator variables within each task. In the present study this is invaluable as in the dual task ageing literature there are mixed findings. In previous chapters it has been discussed how a number of study characteristics influence the magnitude of age differences in dual task performance. Here we found that this information may be used to uncover the sources of variation between different study results.

8. General Discussion

8.1 Overview

The experiments in this thesis examined older adults' ability to co-ordinate two tasks. Craik (1977, p. 391) suggests "...one of the clearest results in the experimental psychology of ageing is the finding that older adults are more penalised when they must divide their attention." However, more recent research investigating dual tasking has given mixed results. These mixed results can be traced to three major issues: methodological problems, differences in the difficulties of the dual tasks, and the large variety of task combinations employed. In this research a standard procedure (n-Back task) was developed to compare performance across a number of task domains and levels of difficulty to examine the mechanisms responsible for age differences in dual task performance. General factor models (e.g. generalised slowing) were found to be inadequate in explaining all instances of age differences in dual task performance. It is argued that executive processes responsible for task co-ordination decline in ageing.

When older adults' performance has been analysed in absolute terms, invariably age differences in dual task performance are found. However, it is arguable that such differences simply reflect underlying differences in performance when the tasks are performed alone (Somberg & Salthouse, 1982). Therefore, an important methodological requirement is to control for baseline differences in performance. Salthouse et al. (1995) carried out a study to investigate the methodological difficulties and examined different methods of controlling for baseline differences in performance. Unfortunately, the authors did not evaluate the relative merits of each method. In this thesis, to be consistent with previous research the most common method of analysing dual task performance was used. That is, a dual task cost measure based on the absolute difference in performance between dual and single task performance, divided by the single task performance score. Therefore, the experiments presented in this thesis investigated whether older adults have a disproportionate dual task deficit. A second methodological criticism of previous research is lack of control of the emphasis each individual places on the concurrent tasks. These problems are highlighted in experiment 2.1 and led to the development of the n-Back procedure where dual task costs could be investigated in the context of a single task.

Another crucial factor that may perhaps explain why there are mixed findings in the literature is that there have been a variety of tasks used. Tasks have ranged from simple perceptual tasks (e.g. Somberg & Salthouse, 1982) to quite complex memory (e.g. Anderson et al., 1998) and motor (e.g. Korteling, 1991) tasks. Furthermore, the tasks have varied in their difficulty. Salthouse et al. (1995) suggest that future studies should provide a systematic evaluation of dual task performance across a range of dual tasks. In this thesis not only were methodological issues addressed but also older adults' performance was compared across a range of dual tasks by systematically examining a variety of task domains. Furthermore, the development of the standard dual task procedure enabled a clear comparison between task domains which has been lacking in previous research due to a variety of paradigms been used.

Most recent studies have avoided the methodological criticisms at least in part, and have found age differences in performance. However, there is still much debate on the underlying mechanism responsible for age differences in dual task performance. By avoiding the methodological criticisms, considering performance across a range of dual task, and at different levels of difficulty, this thesis aimed to evaluate the contribution of such factors as speed of processing, attentional capacity and executive control processes in dual task performance.

In summary, this thesis evaluated alternative accounts of age difference in dual task performance by examining performance across a range of dual tasks and across different levels of difficulty. It also addressed and evaluated some of the methodological and measurement issues that have clouded the interpretation of previous findings.

In this chapter a summary of the findings presented in this thesis is given. This is followed by a discussion of age differences in dual tasking when memory retrieval is involved since this formed a large portion of this thesis. The next two sections considered the findings presented in this thesis and suggest expertise, skill and novelty influence age differences in dual task performance. The data presented in this thesis and previous research is then examined in relation to the possible mechanism underlying older adults' poorer performance. Before discussing future work and conclusions, methodological issues are also considered.

8.2 Summary of Finding

In this section a brief review of the findings from the current experiments is given (see Table 8.1). Since we were concerned with whether older adults have a disproportionate dual tasking deficit, Table 8.1 also shows the results from the dual task costs analysis. Younger and older adults' mean dual task costs are shown for each experiment. Also indicated is whether an overall age and age by load (age by difficulty in experiment 6.2) effect was found, and the effect size for the overall age effect. Younger adults' baseline scores are also displayed.

Table 8.1 Summary of Findings: Younger and Older Adults Dual task Cost, Overall Age Effect, Age by Load Effect and Effect Size *d*

Task	Dependent Measure	Young Adults D.T.C – Low Load	Young Adults D.T.C – High Load	Older Adults D.T.C – Low Load	Older Adults D.T.C – High Load	Dual Task Cost Age Effect	Dual Task Cost Age by Condition Effect	Effect Size *d* (Age Effect)
2.1 Episodic Retrieval Primary Task	R.T.	0.32	0.26	0.08	0.12	X	X	0.69 (-)
	Errors					*	*	*
2.1 Episodic Retrieval Secondary Task	R.T.	0.18	0.23	0.43	0.14	X	-	0.14
	Errors					*	*	*
2.1 Semantic Retrieval Primary Task	R.T.	0.07	0.14	0.13	0.11	X	X	0.24
	Errors					*	*	*
2.1 Semantic Retrieval Secondary Task	R.T.	0.33	0.40	0.28	0.22	X	X	0.29 (-)
	Errors					*	*	*
3.1 Episodic Retrieval n – Back Task	R.T.	0.06	0.18	0.47	0.68	✓	X	1.52
	Errors	0.11	0.65	0.74	1.34	✓	X	0.74
3.1 Semantic Retrieval n – Back Task	R.T.	0.14	0.18	0.25	0.26	X	X	0.45
	Errors	0.59	1.00	1.10	1.16	X	X	0.44
3.2 Episodic Retrieval – Recognition Task	R.T.	0.01	0.07	0.17	0.31	✓	X	0.71
	Errors					*	*	*
3.2 Semantic Retrieval – Recognition Task	R.T.	-0.02	0.15	0.01	0.11	X	X	0.05 (-)
	Errors					*	*	*
4.1 Sentence Verification n – Back Task	R.T.	0.57	0.67	0.72	0.89	X	X	0.50
	Errors	1.22	1.17	1.25	2.61	X	✓	0.40
5.1 Mental Arithmetic n – Back Task	R.T.	0.50	0.55	0.54	0.60	X	X	0.15
	Errors	0.50	1.06	0.87	2.31	X	X	0.48
6.1 Visual Spatial n – Back Task	R.T.	0.72	0.88	0.66	0.81	X	X	0.13 (-)
	Errors					*	*	*
6.2 Mental Rotation n – Back Task	R.T.	0.36	0.19	0.06	-0.01	X	X	1.43 (-)
	Errors					*	*	*

* Dual task costs could not be calculated due to division by zero errors, - Effect in the unexpected direction, ✓ Yes, X No

Experiment 2.1 studied dual task performance on tasks involving retrieval from episodic and semantic memory. We considered two alternative accounts, one based on domain and one based on difficulty or complexity, of why an age effect in dual task studies are only sometimes found. To investigate the effect of task domain, both an episodic paired associate task and a semantic category exemplar generation task were given to participants. To investigate the effect of task difficulty on performance two, secondary tasks were used. The two secondary tasks differed in the amount of information that had to be held in working memory. Unfortunately, the results were unclear and highlighted the problem of task trade-off effects inherent in the dual task methodology. However, there was some evidence that older adults find retrieval from episodic memory particularly problematic under conditions of high load. Older adults in this condition seemed to maintain performance on the primary task while ignoring the secondary task.

The data from Experiment 2.1 highlighted some of the methodological problems with the dual task paradigm. Consequently, the n – back procedure was developed to minimise the difficulties associated with having to make responses to separate tasks. Experiment 3.1 explored retrieval from episodic and semantic memory in more detail using this procedure. An age effect was found for the episodic version of the task but there was no additional cost for older adults when retrieving from semantic memory. This replicates earlier work on episodic memory retrieval (e.g. Anderson et al., 1998) and semantic memory retrieval (e.g. Perfect & Rabbitt, 1993). Task difficulty did not explain the different pattern of results across task since the difficulty manipulation did not bring about the desired age effect in the semantic task. Furthermore, increasing task difficulty in the episodic version of the task did not exaggerate the age effect. The findings suggested that older adults do not suffer a general memory retrieval deficit in dual tasking. We suggest that in the semantic version of the task retrieving over-learned material from memory is carried out in a more automatic manner and performance of both the young and the old is less susceptible to concurrent processing demands.

Experiment 3.2 was carried out with two aims in mind. First, although evidence for an episodic – semantic distinction was observed in the previous experiment it was desirable to replicate the finding with a different set of episodic and semantic tasks. Second, we focused on whether manipulating the amount of self-initiated processes required in the retrieval task would influence the age effect. In this instance, a recognition dual task was used and it was of interest whether there would be a difference in the magnitude of the age effect within the episodic domain. Age differences in dual task performance have been found across a range of episodic tasks so we expected a similar pattern of results to experiment 3.1, although the magnitude of the age effect may be somewhat smaller than that found for episodic cued recall. The environmental support hypothesis would predict that age effects would increase as a function of the amount of self initiated processes required by the task (e.g. free recall versus cued recall versus recognition). The results were in line with those found in experiment 3.1. Furthermore, we found that introducing more favourable episodic retrieval conditions, the age effect of dual tasking is reduced. This was consistent with previous research that has manipulated the amount of self-initiated processes required by the task (e.g. Craik, 1986; Anderson et al., 1998).

In experiment 4.1, the focus was on whether older adults find concurrent processing demands problematic in the language domain. Intuitively one would expect older adults' performance to be poorer because of the complexity of language processing, but largely older adults' performance is comparable to that of younger adults (see section 4.1.1). In this experiment it was found that the costs of dual tasking were age invariant.

In terms of errors, increasing load had a greater impact on older adults' performance but we have already argued how we should treat the error rate data with caution. Much like semantic memory retrieval, language processing is an overlearned skill attained at an early age and perhaps is carried out in a relatively automatic manner. Furthermore, older adults may be able to capitalise on the familiarity of the processes and material and possibly use contextual information to aid their performance.

Experiment 5.1 investigated the effects of concurrent processing demands on another domain (mental arithmetic) that draws on overlearned material from a semantic like memory system. Much like language processing tasks, older adults may be able to compensate for any general decline in cognitive performance by drawing on processes and skills they have developed throughout their lifetime. It was found that for both response times and error rates, there was age invariance in terms of dual task costs. In addition, when the complexity of the mental arithmetic task was manipulated by increasing the working memory load, older adults' performance was not differentially affected. Therefore, although increasing the working memory load was an effective manipulation of task difficulty, response times and error rates were affected to the same extent.

The final experiments 6.1 and 6.2 moved away from the distinction between effortful episodic memory retrieval and retrieval of well learned facts from semantic memory and turned to the visuospatial processing domain. Unlike verbal abilities, older adults have consistently been found to perform more poorly on visuospatial tasks. As opposed to semantic memory and language skills that can draw on overlearned processes, in the visuospatial domain performance is less reliant on accumulated knowledge and everyday practice. The results of experiment 6.1 were somewhat surprising as no disproportionate cost of dual tasking was observed. Somberg &

Salthouse (1982) found similar results when simple perceptual tasks were used. However, in experiment 6.1 we expected the visuospatial task to tap more central processing components. Manipulating the working memory load was effective in increasing task difficulty but it affected both groups in the same way. However, it appeared from this study that older participants in particular were using a verbal labelling strategy in the visuospatial working memory component of the task. To eliminate this possibility, a further experiment was carried out using a mental rotation n-Back task. However, the demands of this task were such that older adults' performance was at chance in the more difficult conditions and therefore further work with simpler visuospatial task combinations is indicated.

In the experimental chapters we provided evidence that task domain moderates dual task costs in older adults. In order to investigate this further a meta-analysis was carried out on previous dual task ageing studies. The aims of a meta- analysis were first to investigate the magnitude of the overall effect size and to see whether this effect size was a good representation of the effects across studies. We have already stated that there are mixed results in the literature and the magnitude of the age effect seems dependent on multiple causes. In this thesis we identified task domain as an important moderator variable, such that tasks which are well preserved in normal ageing are less susceptible to the effects of concurrent processing demands. Particularly, when tasks draw on effortful, consciously controlled or central processes rather than automatic processes, dual tasking age effects emerge. Therefore, we formed groups classified according to whether the task were likely to draw on effortful consciously controlled central processes compared to automatic processes which are known to be preserved in normal ageing (e.g. Jacoby, 1991). In addition, a further group was partitioned based on whether the dual task had a large motor component. A number of studies have suggested that as well as age differences in dual task performance emerging as a result of problems at a cognitive level, older adults may have problems when the dual task involves motor planning (e.g. Ponds et al., 1988). Consistent with previous research, a strong overall effect size demonstrated that older adults found dual tasking problematic. There was variation in the size of the effects across studies and small effects were found for those tasks that were overlearned or relied on automatic processing (e.g. language processing and implicit memory) compared to large effects found for those tasks which involved primarily motor or controlled processing. In addition, the experiments presented in this thesis were entered into the meta-analysis and did not stand as outliers. Therefore, this thesis' findings were consistent with previous research.

8.3 Memory Retrieval and Concurrent Processing Demands

Previous research has given mixed results concerning whether older adults are more penalised on dual tasks. Somberg & Salthouse (1982) found that after taking into account baseline differences in performance, older adults are no more penalised than their younger counterparts. However, the first indication that task domain may moderate dual task costs was observed in a subsequent study by Salthouse et al. (1984). They used a similar procedure to that employed by Somberg & Salthouse (1982) except the later study involved two memory span tasks compared to two perceptual discrimination tasks. When dual tasking was examined on two memory tasks, there was a clear age effect. This prompted the authors to suggest that what is needed is a closer examination of task domain. A meta-analysis by Kieley (1991) also pointed to those tasks that involved a memory component influenced the magnitude of the age effect in dual task studies. Therefore, the initial focus of this thesis was whether age differences in dual task performance would be observed when dual tasks involved memory retrieval. This is an important line of enquiry as we are constantly encoding and retrieving information in situations where competing activities may capture our attention (Park et al., 1989).

The results of experiment 3.1 and 3.2 provided evidence that there are a number of processes involved in memory retrieval, each of which are differentially affected by ageing and concurrent processing demands. Consider first episodic memory retrieval. In experiments 3.1 and 3.2 a large age difference in dual task performance was found for cued recall (d = 1.52) and recognition (d = 0.71). Cued recall performance was particularly impaired since performance relied more on self-initiated processes to effectively recall an item. It is these effortful processes that are impaired in normal ageing (Anderson et al., 1998; Craik, 1986). We suggest that the effortful retrieval operations involved in episodic memory cannot easily be carried out with concurrent processing demands but perhaps younger adults are better able to use strategies to co-ordinate and manage the demands of the competing activities. It is these control functions that are lacking for older adults.

In section 1.2.6 it was suggested that older adults' performance is impaired on episodic memory retrieval tasks especially when task demands are increased. Task performance is partially dependent on difficulty but age differences in dual task costs are unrelated to difficulty or complexity. Adding a concurrent activity results in disproportionate dual task costs but increasing difficulty further does not exaggerate the age effect. Furthermore, more difficult or complex dual tasks (as indexed by younger adults' mean dual task costs) do not necessarily result in the greatest age differences in dual task performance.

For semantic memory retrieval it has been argued that the processes involved are largely automatic and carried out without awareness and therefore competing activities are unlikely to cause much interference for the young or the old. For semantic memory retrieval in both the n-Back task (experiment 3.1) and the recognition task (experiment 3.2), older adults' costs of dual tasking were equivalent. Referring to Figure 8.1 it can be seen that increasing load had little effect for both age groups and certainly did not bring about an age effect. With semantic memory we find that the material is overlearned and therefore its retrieval is perhaps relatively automatic. In the category exemplar generation tasks when a cue is presented, semantic activation of candidate exemplars might occur and retrieval follows in a relatively automatic manner. This enables more attention to be devoted to the concurrent activity. The semantic processing domain is relatively independent and resilient to the effects of ageing.

Automaticity and familiarity influence effective memory performance and tasks that tap such processes may be less reliant on effortful retrieval processes. Consequently, older adults may be able to compensate for their inability to use effortful retrieval processes by drawing on the processes involved in familiarity and automaticity. By drawing on these processes which are preserved in normal ageing there may be less need to draw on executive functions such as management and task co-ordination that they find demanding.

The distinction between automatic and controlled processes in memory is consistent with previous research. Jennings & Jacoby (1993) used the process dissociation procedure to separately examine both consciously controlled and automatic processes in memory. Both age and divided attention had detrimental effects on consciously controlled memory processes compared to more automatic processes. Under this view both age and divided attended attention prevent the efficient use of consciously controlled processing. In experiment 3.1 the episodic memory version of the task involved the effortful retrieval of words that had previously been learned. Although the task was cued recall and some environmental support was provided, older adults were required to engage in consciously controlled processing involved in generating retrieval strategies, organising of retrieval search and the like. In fact, these functions may be the responsibility of the frontal lobes (e.g. Mayes & Daum, 1997). Furthermore, the retrieval of contextual information is required in episodic retrieval tasks and again declines in frontal lobe functioning like that observed in normal ageing have been linked to the processes involved (Cabeza et al., 2000). It was suggested in Section 1.1 that ageing brings about a decline in frontal lobe functioning. Therefore, the processes involved in episodic retrieval and the possible involvement of executive processes in task co-ordination would tend to exaggerate the age effect. Competition for such processing mechanisms would be heightened for older adults. However, the burden of task co-ordination for older adults is reduced if there is less need to draw on controlled or executive processes involved in memory retrieval.

The influence of familiarity of the material and less need to draw on effortful retrieval of context benefits older adults on dual tasks that involve semantic or perhaps implicit memory (see section 1.2.5). Familiarity can also moderate dual task cost in older adults within the episodic domain. Craik (1986) described the distinction between those tasks that draw on self-initiated processes and those that draw on environmental cues to aid performance. With supportive retrieval environments older adults may be able to compensate for their poorer retrieval performance. In free recall in particular, older adults are found to perform more poorly than younger adults, particularly in the context of a dual task (e.g. Anderson et al., 1998). Free recall requires largely effortful control processes and self-initiated retrieval operations. The burden can be minimised if external cues are provided so there is less need to draw on those effortful processes. In our episodic dual tasks (experiments 3.1 and 3.2) we found that manipulating the amount of self initiated processes (recognition versus cued recall) affects older adults' dual task performance. The age effect was greater in the cued recall task compared to the recognition version of the task (*d* = 1.52 and *d* = 0.71, respectively). These effects are similar to those found by Anderson et al. (1998, see Table 7.2). Again we see how familiarity and less reliance on effortful retrieval make an impact on dual task performance. Particularly, less reliance on possessing mechanism impaired in normal ageing reduces age differences in dual task costs.

Support for the idea that concurrent processing demands are disruptive when self-initiated processes are required comes from the work on prospective memory. Prospective memory tasks usually occur in the presence of some background activity and older adults have been found to be impaired when the attentional demands are high (Einstein et al., 1997). However, much like episodic memory retrieval, when the tasks require self-initiated processes, older adults are particularly impaired. Providing external cues to retrieval are found to be beneficial and older adults seem to be as capable as their younger counterparts. For instance, in time based prospective memory tasks self-initiated retrieval is required. This is opposed to event-based retrieval tasks where performance is driven by external cues. The use of such cues relieves the burden on effortful retrieval processes, and for prospective memory tasks allows attention to be dedicated to the simultaneous performance of the background activity.

When dual tasks involve memory retrieval there are a number of factors that influence performance. For semantic memory retrieval the material and the processes involved are so overlearned that they are carried out in a relatively automatic manner. In the strictest sense automatic processing would imply processing without cognitive effort. For experiments 3.1 and 3.2 baseline reaction times and error rates were larger for the semantic task. Therefore, if baseline reaction times and error rates are any indication of the demands of the task, the semantic task was the more demanding. However, adding a concurrent activity had little effect for both age groups. Adding a load certainly does not just add to the difficulty of the task as increasing load did not exaggerate the age effect. In the episodic version of the tasks the cost for both groups was relatively small, but we find an age effect. Comparing this to the cost of dual tasking in the language domain we find large costs for older adults but no effect of age. So what creates this pattern of results? Certainly, task difficulty or complexity cannot account for this pattern of results. Furthermore, as the dual tasks in this series of experiments were quite effortful, are the processes involved in semantic memory retrieval truly automatic?

Another account suggests that older adults may find task co-ordination difficult when the tasks are similar. According to the multiple resource theory (e.g. Wickens et al., 1984), since similar tasks perhaps tap the same processing resources, a greater dual task deficit may be observed when similar tasks strain the capacity of a particular resource pool. Furthermore, similar tasks may require more effortful control processes to keep the tasks functional distinct (Kinsbourne, 1980). Perhaps older adults' performance was particularly impaired in the episodic version of the task (experiment 3.1) since the n-Back task in a sense had an episodic component that is, having to think n-Back to retrieve a cue. In the semantic task the retrieval of an item n–back (episodic) and retrieving an item (semantic) are functionally distinct and there would be less executive control required to manage the competing demands. This would fit well the functional cerebral distance principle (Kinsbourne, 1980). This would predict that greater interference for older adults would emerge if the component tasks tapped the same processing domain since older adults would find it difficult to avoid 'cross talk'. This cross talk was also evident in the recognition version of the task, which certainly cannot be explained in terms of task difficulty or complexity. The costs for the young were 0.01 and 007 for the low load and high load conditions respectively, but older adults still found task coordination problematic. If old age brings about a decline in selective inhibition older adults would find it difficult to prevent interference from even the simplest tasks. This is in agreement with our findings and it may be a more appropriate way to conceptualise age differences in dual task costs, as they are largely unrelated to effort or the demands of the component tasks.

8.4 Expertise and Skilled Performance

The observation that semantic memory is well preserved in normal ageing fits well with two other domains that were examined in this thesis. The processes involved in both language and mental arithmetic abilities are so well overlearned that introducing a concurrent activity is unlikely to be particularly problematic for the young or the old. Such activities are acquired early and older adults can be considered experts.

In fact, Tsang & Shaner (1998) proposed a model of dual task performance that included not only age as a moderator variable but expertise. According to their model of time-sharing ability, performance involves the interaction between age, structural similarity, expertise and processing resource. They argue against a multiple resource deficit model accounting for all the age differences in dual task performance. Under this model both structural similarity and capacity limitations affect the magnitude of the dual tasking age effect. In terms of structural similarity, age differences in performance can be minimised by using different response modalities. In terms of mental resources, more difficult versions of the tasks did cause greater interference for older adults. However, expertise did prove to be a significant influence on dual task performance. This was in terms of time-sharing expertise rather than expertise on the component tasks that have been discussed.

The influence of expertise in a domain is clearly shown in language abilities.

There are a number of reasons why we might expect older adults to perform poorly on dual tasks when language abilities are required. However, previous research and the findings of experiment 4.1 demonstrated that expertise in a domain might compensate for any general declines in cognitive performance. Two important points can be drawn from the language processing literature. First, introducing a concurrent task invariably leads to poorer performance, but there tends to be no interaction with age arguing against a general deficit in dual tasking. Second, increasing task difficulty by either a manipulation within task or by introducing a concurrent activity does not necessarily bring about the same effect (Tun & Wingfield, 1993).

When examining the dual task costs for both younger and older adults it was observed that introducing a concurrent task does result in considerable impairment to language processing for both age groups. In the language processing task, for younger adults the costs were 0.57 and 0.67 for the low load and high load, respectively. Therefore, having to verify sentences concurrently with a working memory load is demanding but older adults are as capable. Although the dual task can be considered demanding the processes are not impaired in normal ageing and this is why an age effect does not emerge. A task difficulty account of disproportionate dual task costs would have predicted an age effect to emerge. Again, effort was not related to dual task costs.

Taking the first point, language processing is of such ecological importance that the operations are carried out in a relatively automatic manner (Kausler, 1985), although some functions such as language production do show impairment (Burke & Mackay, 1997). It can be argued that since the processes involved are relatively automatic, performance on language processing tasks are carried out with ease by the young and the old. Furthermore, the language domain is relatively encapsulated and concurrent activities are unlikely to interfere. A further point is that older adults are able to use context to compensate for any general declines in cognitive performance. This is seen when we contrast dual tasks involving sentence verification and dichotic listening (e.g. Tun & Wingfield, 1993). These factors would tend to reduce the requirement to draw on central control processes required for task co-ordination.

Taking the second point, age effects may emerge within the language domain as we observed that the tasks were quite complex, as indexed by younger adults' dual task costs. This complexity could have been increased further by perhaps manipulating the type of sentences used in the experiment. This type of manipulation may ultimately lead to age differences in performance. Increasing difficulty by the introduction of a secondary task is quite different. Unless the secondary task taps the same processing resources, older adults are as capable as little interference occurs. It could be argued that less executive control is required to keep the processes functionally distinct.

Mental arithmetic is also a domain that largely relies on semantic memory. Mental arithmetic like language abilities are acquired at an early age; therefore, adding a concurrent task may not cause dual task interference. Retrieval of the arithmetic facts will perhaps occur in a relatively automatic manner leaving enough processing resource to manage the concurrent activity. Under these circumstances, older adults are no more penalised than the young. Therefore, when an individual is skilled in a particular task there is minimal interference from concurrent processing demands either because such demands tap separate resources or there is less need to draw on management and co-ordination functions. Being skilled at a task enables efficient processing and where normally interference from a concurrent activity is problematic, this is not the case. Much like the findings presented for language processing, the mental arithmetic task in experiment 5.1 proved to be quite demanding in the dual task conditions. Younger adults' dual task costs were 0.50 and 0.55 for the reaction times in the low and high load conditions, respectively. The load manipulation was effective but when we consider older adults costs' they were equivalent.

Along with the findings of chapter 2 and 3 (episodic versus semantic retrieval), from chapter 4 (language processing) it is clear that although there is evidence that older adults do perform more poorly on dual tasks in some situations, it is important to consider the mediating effects of skill, expertise or perhaps familiarity. In section 8.5 we consider another domain where possibly older adults are unable to compensate for general declines in performance by drawing on these factors. That is, we consider the visuospatial domain.

8.5 Novelty and Visuospatial Abilities

In the final experimental chapter we turned to the visuospatial domain and considered older adults' performance under dual task conditions. Unlike verbal skills that are well maintained in normal ageing, performance domains such as visuospatial or possibly problem solving, show decline. We were concerned with whether introducing concurrent processing demands was particularly problematic for older adults in these domains.

An examination of the visuospatial domain was of interest in this thesis because in everyday activities visuospatial tasks usually involve a dual tasking requirement. In section 6.2.3 we discussed how complex visuospatial tasks could be modelled in the laboratory by using visuospatial tasks that involve dual tasking. Owsley et al. (1991) in particular found a strong relationship between visuospatial ability, dual task performance and driving accident frequency in old age. They suggested that older adults are particularly impaired on visuospatial tasks with a dual task requirement because such activities are novel.

In experiment 6.2 a mental rotation task was used to consider age differences in dual task costs when visual spatial abilities are required. Unfortunately, it was found that the demands of the task were such that performance was at chance for many participants, particularly for the more difficult conditions. The mental rotation task was not in itself problematic. In the single task condition the reaction times and error rates were relatively small. However, when a concurrent working memory load was introduced errors increased substantially and older adults were particularly impaired. The material in the working memory task was novel, which made it difficult for both groups to memorise. Furthermore, interference or 'cross talk' between the concurrent tasks would be expected to be considerable since both tasks tapped visuospatial ability. Older adults would be expected to be less able to avoid interferences in these circumstances as more executive controlled would be required to manage the tasks which may be competing for the same processing resources.

Jenkins et al. (2000) argued against the idea that visuospatial abilities are particularly sensitive to slowing as they found age effects on both speeded and unspeeded tasks. It may be that older adults have gained greater expertise on verbal tasks and therefore visuospatial abilities are subject to impairment resulting from more general cognitive declines. Of particular interest, they suggest that poorer performance may simply be the result of the novelty of visuospatial tasks and older adults may perhaps gain greater expertise in the verbal domain over their life time. Novelty certainly has an impact on older adults' performance and is related to frontal lobe functioning (e.g. Rabbitt, 1997). In novel tasks there is likely to be more monitoring of ongoing processes in order to effectively complete a particular activity. In addition, Jenkins et al. (2000) suggest that laboratory visuospatial tasks are particularly novel compared to verbal equivalents. We may have expected this in experiment 6.2.

In the previous section we suggested that in certain circumstances dual task costs could be reduced if older adults were able to tap processing mechanisms that are not impaired in normal ageing. For instance, the influence of environment support may be applied to the visuospatial domain to attenuate age difference in performance. In experiment 6.1 we observed how memory of spatial locations could be maximised by using verbal cues to retrieve. Although not an aim of this experiment, it was found that providing supportive encoding conditions for the visuospatial information minimised any interference on the concurrent visuospatial activity. In this experiment the costs were high much like that found in experiments 4 and 5, but no age effect emerged. Typically, in spatial memory tasks participants are provided with an array of items at different locations and after they are removed, they must indicate the location of the items. Such a task is likely to require a great deal of effortful self-initiated processes. Providing additional cues to the location of the items may benefit older adults' performance. For example, Sharps & Gollin (1987) found age differences were reduced on a spatial memory task when the visual distinctiveness of the items was increased.

The influence of novelty is obviously an important consideration in the dual task literature. In tasks that are familiar or use skilled processes like language abilities, the use of such processes lessens the need to draw on control processes which are impaired in ageing. However, for novel tasks older adults are unable to draw on such processes and are particularly impaired. This is consistent with Tun & Wingfield (1995) who found that older adults reported to have particularly problems with dual tasks involving the monitoring of novel information. Furthermore, Korteling (1994) found that dual tasking was problematic for older adults when novelty was involved. This was the case even when the difficulties of the tasks were equivalent, arguing against the slowing complexity hypothesis. This is consistent with our argument that older adults have an executive deficit, as managing novelty is a trademark function of any proposed executive system (e.g. Norman & Shallice, 1980).

8.6 Mechanisms Underlying Dual Task Performance

Early research has suggested that the finding that older adults are particularly impaired on dual task is consistent with the slowing complexity hypothesis. Somberg & Salthouse (1982) were the first to suggest that older adults' poorer performance on dual tasks was simply a result of cognitive slowing. This thesis suggested that the slowing complexity hypothesis does not go far enough in explaining all instances of age differences in dual task performance.

According to the slowing complexity hypothesis older adults should be proportionally slower than younger adults as the complexity of the tasks increase no matter whether under single or dual task conditions. Somberg & Salthouse (1982) suggested the use of proportional dual task costs to analyse age differences in dual task performance. Unlike these investigators we found evidence for disproportionate dual task costs. The selective deficits found demonstrated that there is not a generalised decline in time-sharing performance, which is the result of perhaps generalised slowing. In experiments 3.1 and 3.2 we found that when we examined the effects of concurrent processing demands on retrieval, performance was only affected in the episodic version of the task. We found particularly in experiments 3.1 that task difficulty did not account for the different pattern of results across tasks. Increasing the difficulty of the concurrent working memory tasks only influences dual task costs in the episodic version the task. This is consistent with Tun & Wingfield (1993) who suggested that increasing the difficulty within a task and divided attention do not necessarily bring about the same effect.

The slowing complexity hypothesis does not explain why larger age differences have been found for less complex than more complex tasks (Korteling, 1994; McDowd & Craik, 1988). Consistent with previous research large age differences were found in the less complex or less demanding episodic task than the semantic, language processing and mental arithmetic tasks. Korteling (1994) found equivalent performance for younger adults on a secondary task when automatic and novel versions of a motor task had to be performed. However older adults found the novel version of the task problematic. The authors argued against the slowing complexity hypothesis since complexity as indexed by younger adults' performance would have predicted no age differences between the two tasks. In that study automaticity worked against older adults as in the novel condition not only were they required to acquire a new skill but they were also required to inhibit an overlearned behaviour (see section 1.2.1). Difficulty or complexity is not the sole factor influencing task performance. It is more related to the functions that are impaired in normal ageing.

Much like the slowing complexity hypothesis the idea that with increased age comes a reduction in processing resource falls short of explaining why only in certain circumstance older adults perform more poorly on dual tasks. Age differences in performance may result from a global reduction in cognitive capacity. It could be argued that the results of this thesis fit well with such a proposition. Crossley & Hiscock (1992) suggest that those tasks likely to reveal an age effect are those that involve speed, novelty and complexity, whereas tasks that are overlearnt, well practiced or perhaps involve familiar material show age equivalence. This would be in agreement with our observation of impaired dual task performance when effortful episodic retrieval is required (experiments 2.1, 3.1 and 3.2). We may also expect cognitive capacity to influence performance in the visuospatial domain as such tasks are novel in nature and primarily rely on self-initiated processes (experiments 6.1 and 6.2). When tasks draw on few resources such as in our semantic retrieval tasks, language and mental arithmetic tasks no age effects emerge. This would also be consistent with the meta-analysis presented in this thesis. In this analysis studies were partitioned into broad groups according to whether tasks involved largely automatic, controlled or motor processing. Effect sizes of d = 0.43, 0.86 and 0.76 were found for automatic, controlled and motor processing groups respectively. This demonstrated that age differences in dual task performance might be related to whether a task demands more cognitive resources.

This reduced attentional resource account does not fully explain our data. For instance, when we contrasted episodic and semantic memory retrieval in experiments 3.1 and 3.2, overall there was no disproportionate cost of dual tasking for 'automatic' semantic retrieval tasks. This is consistent with the cognitive capacity account. However, for the more 'effortful' episodic retrieval tasks, disproportionate dual task costs were observed but this was not exaggerated when the complexity of the task was further increased. In addition, in experiment 3.1, if the response times and error rate data were any indication of the demands of the episodic and semantic retrieval tasks, the semantic task was in fact the more difficult. Increasing the complexity of the semantic task also made no impact on performance. In the more 'automatic' tasks of sentence verification and mental arithmetic, although no overall age effect was observed, one might have expected age differences to emerge as the difficulty of the task increased. However, increasing difficulty affected both groups in the same way.

Referring to figure 8.1 it can be seen that younger adults' dual task costs were particularly high in the sentence verification and mental arithmetic tasks. Adding a working memory load is an effective manipulation of task difficulty. Working memory load interfered significantly with performance of the sentence verification and mental arithmetic tasks. From these data the processes involved in the two tasks are not in the strictest sense automatic or carried out without cognitive effort, otherwise one would have expected no interference in the dual task conditions. In both experiments 4.1 and 5.1 complex dual tasks were employed but older adults were not differentially affected, arguing against both the slowing complexity hypothesis and reduced attentional resource accounts of cognitive ageing. We need to ask the question what produces the costs and what produces the age difference in costs as an examination of figure 8.1 suggests the complexity, difficulty or demands of the task (indexed by younger adults' dual task costs) is unrelated to whether we observe age differences in dual task performance.

The multiple resource theory could help to explaining the different pattern of results across studies. Perhaps, similar tasks in terms of modality or domain may cause the greatest dual task interference. In experiment 6.2 this was particularly evident. Participants were required to keep in mind quite complex visual stimuli while performing a mental rotation task. The similarities in the processes involved and the high attentional demands were such that older adults' performance was at chance. Furthermore, in the episodic retrieval tasks presented in this thesis there may have been greater overlap in the processes involved in episodic retrieval of a cue (n-Back) or retrieval of a cue recently presented (experiment 3.2). However, for semantic retrieval there would be no such overlap. Navon (1984) argued against the multiple resource view since we could continue to describe independent resource pools to account for all instance of dual task interference. However, as already discussed in such circumstances cross talk or interference may occur if tasks compete for the same processing mechanisms. Under these conditions older adults may require greater executive control to manage the competing activities.

There are similarities between the speed of processing and capacity account of age differences in cognitive performance. In fact, they may reflect the same mechanisms.

Crossley & Hiscock (1992) did point out that cognitive resource might reflect concepts such as attentional capacity, working memory or speed of processing. Besides, in section 1.2.2 we pointed out that such theories lack predictive and explanatory power (e.g. Navon, 1984) and it might be more appropriate to consider mechanisms such as executive control and the strategies employed to effectively perform dual tasking.

Early research on dual task co-ordination suggested that older adults may carry out such tasks in a serial manner (e.g. Singleton, 1955). Older adults are perhaps inefficient when tasks require controlled processing. When carrying out concurrent activities it is necessary to develop strategies to effectively schedule and co-ordinate task demands. Such control mechanisms are effective in younger adults and they perform concurrent tasks in a more parallel manner. This would be consistent with discussion in chapter 1 relating to the frontal ageing hypothesis. This hypothesis suggests that increased age is accompanied by a decline in executive functions that are largely dependent on the frontal lobes. Both behavioural and neurophysiological data pointed to an executive deficit in old age. In this thesis we observed disproportionate dual task costs for some task combinations which point to a specific problem in task co-ordination. It seems additional processing operations are required to manage and co-ordinate dual tasks. This would be consistent with research into task switching where older adults are found to be less efficient in the rapid switching between tasks (Hawkins, Kramer, & Capaldi, 1992).

Older adults may have impairment in the central executive component of the working memory model. Although Baddeley and his colleagues (e.g. Baddeley et al., 1986) have failed to observe a dual task deficit in normal ageing and reported a central executive impairment only in Alzheimer's disease, this conclusion may be inaccurate. It could possibly be the particular combination of tasks used in their study may not have been sensitive enough to detect a possibly subtler deficit in central executive functioning. Certainly, other work using other methods of assessing central executive functioning have found age effects (e.g. Van der Linden et al., 1998).

A related issue is that older adults have been reported to have problems with inhibition. Hasher & Zacks (1988) suggested that there is an age reduction in the ability to inhibit irrelevant stimuli that compete for attentional resources. The authors suggest that in routine, highly practised activities there is no need to attend to what might be irrelevant contextual information. However, in novel situations, for instance when we are retrieving recently acquired information (e.g. experiments 2.1, 3.1 and 3.2) there is more of a need for inhibitory mechanisms to avoid interference between tasks.

An interesting finding in the ageing and training literature task specific training benefits are often found (e.g. Kramer et al., 1995). This finding argues against processing speed and capacity models and also suggests that a dual task is not just a more complex single task. Kramer et al. (1995) found that training was more beneficial in the dual task conditions. Furthermore, when participants were switched to novel tasks, the benefits were again seen in the dual task conditions. So although training may lead to automatisation of the component tasks, the benefits go beyond this. Practice leads to more efficient use of the processes used in actual timesharing and these skills can be transferred to novel situations. There are clearly additional processing mechanisms involved in task co-ordination skills. Further evidence from this study for a specific rather than general deficit is that the slopes comparing younger and older adults' performances were greater for the dual tasks. Therefore, the dual tasks were not just a complex single task; additional operations may be required for monitoring and co-ordinating the component tasks.

In summary, the evidence points to an executive deficit in old age being responsible for older adults' poorer performance in dual tasks. It was found that in some domains of cognition, disproportionate dual task costs were observed. It was seen that greater dual task costs were found for less complex tasks, and task combinations that may produce a great deal of interference or cross talk. Furthermore, it was observed in domains of cognition which are well preserved in normal ageing older adults may for instance use familiarity to lessen the burden on central controlled mechanisms involved in dual task co-ordination. Since previous research has suggested that older adults have an executive deficit, we argue that the results of this thesis are best explained in terms of a decline in executive functioning in ageing that results in less efficient task coordination or perhaps less efficient inhibitory processes which are necessary to prevent cross-talk.

8.7 Methodological Considerations

Past research has employed different methods of analysing dual task performance. Proportional dual task costs or ratio scores and difference scores have been commonly used. In addition, multiple regression analysis has been carried out looking at the relationship between age and dual task performance after controlling for baseline differences in performance. This method is the most similar to the proportional dual task costs analysis (Guttentag, 1989). In order to be consistent with the large majority of previous research we used the proportional difference, dual task costs measure. The different methods used involve assumptions about the relationship between single and dual task performance and the measurement scale that might be the more appropriate in considering dual task performance. We were concerned with whether older adults had a disproportionate dual task deficit and therefore the proportionate dual task costs were the chosen method in this thesis.

Since the focus was on proportionate dual task costs we could first consider whether the findings of this thesis were consistent with a global model of cognitive ageing. For instance, an account based on generalised slowing would suggest that any manipulation of task difficulty, no matter what the task, would produce proportional slowing in older adults. However, disproportionate dual task costs were found so other explanations for older adults' poorer performance could be pursued.

Trade-off effects were also identified as possible problems when considering dual task performance. In experiment 2.1 we carried out a correlation analysis between tasks to see whether age differences in trade offs could account for the data. Although no evidence was found to suggest individual differences in task trade offs we did conclude based on the observation of the raw data that older adults were unable to coordinate the two tasks so tended to concentrate on the primary task so their performance on the secondary task was at chance.

There are a number of ways that task trade off effects could be minimised. The most elaborate way of dealing with this is to construct attentional operating characteristics for each participant (e.g. Norman & Bobrow, 1975). We opted for a new paradigm that considered dual task costs within the context of a single task. In the n – back procedure the secondary task was integrated into the primary task and became a necessary part of that task. It was considered a dual task in that two simultaneous activities had to be performed. For instance while performing the primary memory retrieval task (experiment 3.1) participants were required to concurrently perform a working memory task involving the temporary storage and updating information in memory. Considering the costs of dual tasking within the context of a single task also eliminated the need to consider possible interference when two responses had to be made. Therefore, our focus was on the more central aspects of dual task interference. Daneman & Carpenter (1980) used a similar procedure to investigate dual task performance when language processing was involved and employed a similar working memory paradigm. In this procedure, participants were required to verify a series of sentences and also keep in mind the final word of each sentence. A serial recall test was given at the end of the sentence verification task. The main advantage of adopting this new n-Back paradigm throughout this study was that the standard procedure enabled a clear comparison between experiments.

8.8 Future Research

In experiments 2.1, 3.1 and 3.2 we considered memory retrieval and the factors that contribute to performance within a dual task. We focused on effortful episodic retrieval versus relatively automatic semantic retrieval. Within the episodic domain we also suggested that familiarity and supportive retrieval conditions benefit older adults. Furthermore, we identified that retrieval of contextual information is particularly problematic for older adults. Further investigations within the episodic domain are warranted. For instance, there is considerable debate in the literature as to whether content or contextual memory produces the greater age effect and this could be explored within the n-Back paradigm.

When we considered the effects of age and concurrent processing demands on language processing it became apparent that manipulating difficulty within task and by adding concurrent processing demands do not necessarily bring about the same effect. Further research could explore in more detail the complexity effects in dual tasks where skilled performance is involved. For instance, in our sentence verification n-Back task difficulty could be increased by manipulating the grammatical form of the sentences. It would be interesting to see whether increasing the complexity further would bring about an age effect or whether as we have suggested task difficulty or complexity is unrelated to age effects in dual task costs.

In experiment 6.2 it was observed that the demands of the visuospatial dual task was such that older adults' performance was at 'floor' level. We hypothesised that visuospatial processing, particularly in a dual task activity is impaired in normal ageing. This is largely due to the novelty of such tasks and less reliance on lifelong learning. Unfortunately, the stimuli used in experiment 6.2 were extremely difficult to keep in mind so perhaps further work is warranted using less complex stimuli and perhaps using a different paradigm. Furthermore, it would be interesting to manipulate the amount of self-initiated processing involved in the visuospatial task to see whether the age effect could be minimised within this domain by allowing older adults to capitalise on processes that are not impaired in ageing.

8.9 Conclusions

This thesis set out to further investigate the conditions where older adults have problems co-ordinating multiple tasks. Our aims were to build on previous research by avoiding methodological difficulties and by considering older adults' performance across a range of task domains. In terms of absolute levels of performance, evidence was provided that older adults have a general deficit in dual tasking. However, this difference may be the result of underlying age differences in single task performance.

When we consider proportional dual task costs, task domain was found to be an important moderator variable of dual task performance rather than task difficulty. It is suggested that global models of cognitive ageing such as slowing of information processing rate and reduced attentional capacity do not go far enough in explaining all instances of dual task performance. Particularly, this research found that task difficulty or complexity is not related to whether age differences in dual task performance are observed. It might be more appropriate to consider age related differences in dual task performance in terms of a specific deficit in controlling and managing multiple tasks, and those tasks that are well learned or use skilled processing produce small dual task interference effects compared to those tasks tapping controlled processing.

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Appendices

A. Experiment 2.1 Stimuli

Episodic Paired Associates

List 1
army – shape, voice – house, teacher – region, blood – area, water – college, paper – staff, march – cold, plant – teeth, woman – space, weight – letter

List 2
child – group, radio – chief, million – story, light – heart, black – hell, summer – view, peace – window, party – dance, base – white, poetry – morning

List 3
supply – king, world – quiet, picture – capital, friend – help, season- future, walk – edge, design – people, horse – watch, deep – news, earth –west

List 4
park – trip, body – evening, writing – miss, island – youth, family – touch, blue – fast, name – growth, title – opening, city – country, home – mother

List 5
market – date, health – number, letter – corner, river – nature, society – train, patient – neck, figure – pretty, night – year, dinner – hair, lady – fire

List 6
winter – square, history – love, bridge – play, present – volume, doctor – range, mouth – rock, eight – long, show – wide, music – captain, coffee – poet

Category and Category Names

Animals – horse, deer, fox
Birds – canary, dove, parrot
Body Parts – nose, ear, toe
Clothing –dress, coat, sweater
Country – Germany, Egypt, Mexico
Drinks- gin, wine, brandy
Fish – tuna, salmon, shark
Flowers – orchid, pansy, daffodil
Food Seasoning – paprika, sugar, garlic
Fruit – orange, peach, banana
Furniture – bed, desk, lamp
House parts – door, wall, floor
Insect – mosquito, spider, beetle
Instrument – trumpet, drums, flute
Material – silk, linen, velvet
Metal – steel, aluminum, tin
Professions – professor, dentist, teacher
Vegetables – potato, bean, tomato
Weapons – sword, rifle, cannon
Weather – tornado, fog, thunder

B. Experiment 2.1 Instructions

Instructions

In the following experiment you will be required to perform a number of tasks. Each task will be performed either on its own, or concurrently with another task. You will be given instructions and a practice session before the start of each task. If you are unsure of what is required please inform the experimenter before the start of each task, and further instructions will be provided.

Digit Tasks

There are two versions of the digit task that you must perform. In one version a digit will appear at regular intervals on the computer screen. You are required to keep in mind the digits until the computer prompts you for a response. The prompt is a number displayed with a red background. You must decide whether this digit is the same as any of the previous numbers. Please press yes or no on the response box as quickly and as accurately as possible. After the red back ground disappears you must once again keep in mind digits that follow, until the next digit with a red background appears.

In the other digit task you must add each digit that is presented on the computer screen until a number with a red background appears. At this point you must decide whether the number corresponds to the total of the numbers you have been adding. Please press yes or no on the response box as quickly and as accurately as possible.

The illustrations attached should make the instructions clear. Please ask if you are unsure and don't forget you will be given practice.

Memory Tasks

In this part of the experiment you will be required to perform two types of memory tasks. In the first task you will be required to learn lists of words which you will recall at a later date. Initially you will be presented with pairs of words, at regular intervals on the computer screen. When they appear read aloud each pair. After the last word has been presented there will be a short delay. Following this you will be presented with the first word of each pair, at regular intervals. You are required to respond as quickly and as accurately as possible with the second word in the pair.

In the second memory task you will be presented with a category name on the computer screen. Underneath, a partly completed name of a member of that category will be presented. The * represents deleted letters of the name. You are required to respond as quickly and as accurately as possible with the completed category member.

The illustrations attached should make the instructions clear. Please ask if you are unsure and don't forget you will be given a practice.

Dual Tasks

In this part of the experiment you will be required to perform either of the digit tasks with either of the memory tasks. Please asK if you are unsure of what is required.

C. Experiment 3.1 Stimuli

Episodic Paired Associates

List 1

live - religion, wrote – colour, dinner – heavy, black – length, picture – blue, property – half, front – cold, friend – miss, mark – wall, family – science, corner – music, felt – year

List 2
heat – center, take – deep, lady – square, view – case, horse – break, council – look, size – material, children – period, range – hair, paper – still, company – call, piece – pain

List 3
dance – audience, drink – account, move – white, film – marriage, hotel – patient, right – pass, file – town, pressure – record, team – learn, shot – reading, evening – chief, working – close

List 4
father – green, spoke – lead, straight – plant, speak – group, staff – face, heart – death, happy – woman, life – people, teacher – corps, long – spring, battle – course, land – degree

List 5
wife – research, alone – playing, weight – trip, meeting –bill, touch – capital, industry – cover, rise – level, child – sound, build – position, ship – test, military – unit, news – reach

List 6
bank – party, space – session, person – thing, product – money, hear – world, show – river, office – fall, city – youth, open – hold, fight – poet, game – house, school – answer

List 7
subject –find, four – story, trial – water, present – bright, clear – date, girl – letter, note – short, clothes – train, officer – million, husband – design, matter – concern, door – type

List 8
Surface – country, west – hour, nine – lord, fell – building, machine – event, sign – club, congress – member, station – room, plan – hall, jack- five, scene – rest, hard – college

List 9
play – march, human – winter, table – general, running – series, back – island, attach – sight, growth – hand, business – pool, court – nation, write – shape, post – well, figure - name

Category and Category Names

Animals – dog, cat, elephant, lion, tiger, horse

Birds – robin, blackbird, sparrow, eagle, thrush, crow

Plants – rose, daffodil, tulip, cactus, grass, geranium

Instruments – guitar, violin, piano, flute, drum, cello

Trees – oak, beech, ash, elm, sycamore, chestnut

Vegetables – carrot, cabbage, pea, cauliflower, bean, potato

Fruits – apple, orange, pear, banana, grape, peach

Crimes – murder, rape, theft, assault, fraud

Drinks – vodka, whiskey, beer, water, lemonade, orange

Clothes – socks, trousers, shirt, coat, shoes, skirt

Vehicle – car, lorry, bus, bicycle, motorbike, train

Weapons – knife, gun, sword, rifle, spear, pistol

Tools – hammer, saw, screwdriver, chisel, spanner, pliers

Colours – green, blue, red, yellow, black, orange

Occupations – teacher, doctor, nurse, dentist, lawyer, policeman

Organs – heart, lung, liver, kidney, brain, stomach

Furniture – chair, table, bed, wardrobe, stool, dressing table

Illnesses – flu, measles, cancer, cold, chicken pox, mumps

Utensils – knife, fork, spoon, saucepan, frying pan, pot

Elements – hydrogen, oxygen, sodium, potassium, nitrogen, magnesium

Sports – rugby, tennis, football, hockey, swimming, badminton

D. Experiment 3.1 Instructions

Episodic Task

Task One

In this task, a number of word pairs will be presented on the computer screen at regular intervals (e.g. APPLE – CAR). You are required to memorise the word pairs for later recall. In order to make the task easier, when each pair is presented on the computer screen try to imagine an association between the two words. This will make it easier to recall the words later. In the example above, you could imagine an apple sat on the driver's seat of a car.

After the last word has been presented, the experimenter will read the first word of each pair. You will be required to respond vocally with the second word of the pair in your own time. After the last word pair the experimenter may decided to present the word pairs again and you will be asked to recall the second word of each pair a second time.

In the final stage of the task the first word of the pair will be presented on the computer screen for a number of seconds. You must respond vocally with the second word of the pair as quickly and as accurately as possible. Your responses will be recorded. An incorrect response will be recorded if you respond after the first word of the pair disappears from the computer screen.

Task Two

This task is very similar to task one but it is more difficult. Again, word pairs will be presented on the computer screen. You will be required to memorise the word pairs. Like in task one you may be given a number of opportunities to memorise the words.

In the final stage of the task, the first word of the pair will be presented on the computer screen. At this point, please wait until a prompt appears below the word. The prompt will be either **, 1 Back* or *2 Back*. In this task as well as recalling the associated word you will be required to keep in mind the last two words presented on the screen. In other words, when the word appears on the computer screen rehearse this in your mind and wait for the next word. Keep this word in mind also. When the prompt appears do not respond if the *** prompt appears. If the *1 Back* prompt appears remember the last word that you kept in mind and respond with the word associated with it. If the *2 Back* prompt appears remember the previous word that you have kept in mind and try to recall the word associated with it. When the prompt appears respond vocally as quickly and as accurately as possible. An incorrect response will be recorded if you respond after the prompt has disappeared from the computer screen.

Task Three

This task is identical to task two except on this occasion you will be required to keep in mind the last three words. The prompt may be either **, 1 Back, 2 Back* or *3 Back*.

Semantic Task

Task One

In this task a category name (e.g. Fruit) and a partially completed category member (e.g. A****) will be presented on the computer screen for a number of seconds. You must respond vocally with the appropriate category member (in this example apple) as quickly and as accurately as possible. Your responses will be recorded. An incorrect response will be recorded if you respond after the category and partially completed category member has disappeared from the computer screen.

Task Two

This task is very similar to task one. Firstly, a category name will be presented on the computer screen for a number of seconds. This category name will then disappear and be replaced by a partially completed category member and a prompt underneath. This is the test stage and you will be required to make a response. After a number of seconds the partially completed category member and prompt will disappear and be replaced by another category name. Again, this will disappear after a number of seconds and be replaced by another partially completed category member and prompt. This sequence of events will continue for a short period of time.

In the test stage if a '1-Back' prompt appears you will be required to think back to the very last category name that disappeared from the computer screen and complete the partially completed category member currently on the screen. If the '2-Back' prompt appears you will be required to think of the category name that appeared on the computer screen two positions back. You must then use this information to complete the current partially complete category member displayed on the computer screen. At the test stage you may be given a '*' prompt which means on this occasion you do not have to make any response.

Therefore, in order to complete this task you must keep in mind the very last two category names that appeared on the computer screen and rehearse them in your mind. When it comes to the test stage a prompt indicates which of the two category names you are rehearsing must be used to complete the partially completed category member.

Task Three

This task is identical to task two except on this occasion you will be required to keep in mind the last three category names. The prompt may be either **, 1 Back, 2 Back* or *3 Back.*

E. Experiment 3.2 Stimuli

Word Lists

Experimental List 1

live, wrote, colour, dinner, heavy, black, length, picture, blue, half, front, cold, friend, miss, mark, wall, family, private, science, corner, music, felt, year, heat, centre

Experimental List 2

talk, deep, lady, square, view, case, horse, break, council, look, size, period, range, hair, paper, still, company, call, piece, pain, dance, black, account, move

Experimental List 3

white, film, hotel, patient, right, pass, file, town, record, team, learn, shot, reading, evening, chief, working, close, father, green, spoke, lead, plant, speak, group

Practice List 1

staff, face, heart, death, happy, woman, life, people, teacher, long, spring, battle

Practice List 2

course, land, degree, wife, alone, playing, weight, trip, meeting, bill, touch, capital

Practice List 3

cover, rise, level, child, sound, build, ship, test, unit, news, reach, bank

Category and Category Names

Animals – horse, tiger, lion

Birds – eagle, robin, thrush, crow

Clothes – socks, skirt, coat, shirt, shoes

Colours – green, black, blue, yellow, orange

Crimes – rape, arson, fraud, assault, theft

Drinks – beer, whiskey, water, orange

Elements – sodium, oxygen

Fruits – apple, pear, peach, banana, grape, orange

Furniture – chair, table, stool

Illnesses – mumps, cancer, cold

Instruments – guitar, violin, drum, flute, cello

Occupations – nurse, lawyer, doctor, dentist

Organs – liver, kidney, heart, lung

Plants – rose, cactus, tulip, grass

Sports – tennis, hockey, rugby

Tools – pliers, chisel

Utensils – spoon, fork

Vegetables – carrot, potato, bean

Vehicles – train, lorry, bicycle

Weapons – knife, pistol, rifle, spear, sword

F. Experiment 3.2 Instructions

Instruction

Please read the following instructions that describe the first set of tasks that you will have to complete. If you are unsure of what is required please ask the experimenter for help. There will be a practice session before each task.

Task One

In this task a category member and a category name will be flashed on the computer screen at regular intervals (e.g. Cannon – Weapon?). You must decide whether the category member belongs to the category and respond on the computer keyboard as quickly and as accurately as possible using the 'Y' (yes) and "N" (no) keys.

Task Two

In this task firstly two category members will be presented on the computer screen for a number of seconds (e.g. Car – Red). After these have disappeared from the screen a category will be presented on the computer screen for a number of seconds (e.g. Vehicle?). You must decide whether any of the previous two category members that appeared on the screen belong to the category currently shown on the computer screen. After a number of seconds another two category members will appear on the screen.

Task Three

In this task four category members will be presented on the computer screen for a number of seconds (e.g. Purple – Axe – Bus – Driver). After these have disappeared from the screen a category will be presented on the computer screen for a number of seconds (e.g. Colour?). You must decide whether any of the previous two category members that appeared on the screen belong to the category currently shown on the computer screen.

Instructions

In these tasks you will firstly be trained on sets of words. Each set will have four words in it. Sets will be flashed on the computer screen at regular intervals (e.g. Set 1: Cow – Place – Mat – Coin). After the last set has flashed on the computer screen you will be asked by the experimenter to name each word in each set. The sets may then be re-presented on the computer screen until you are able to correctly recall all the sets.

Task One

In this task a word from one of the sets and the set name will be presented on the computer screen at regular intervals (e.g. Place – Set 1?). You are required to decide whether this word belongs to the set and respond as quickly and as accurately as possible on the computer keyboard.

Task Two

In this task two words will be presented on the computer screen for a number of seconds (e.g. Horse – Coin). After these have disappeared a name of a set (e.g. Set 1?) will appear on the computer screen for a number of seconds. You must decide whether any of the previous words belong to the set currently shown on the computer screen and respond as quickly and as accurately as possible on the computer keyboard.

Task Three

In this task four words will be presented on the computer screen (e.g. While – Joint – Poem – Tree). After these have disappeared a name of a set (e.g. Set 1?) will appear on the computer screen for a number of seconds. You must decide whether any of the previous words belong to the set currently shown on the computer screen and respond as quickly and as accurately as possible on the computer keyboard.

G. Experiment 4.1 Stimuli

List 1

The drink was extremely cold, The girl struck the born, The children ate the cake, The lady was very pretty, The dentist opened his mouth, The man touched the gone, The mother and father cried, The youth hit the person, The river flooded the under, The stranger tried to help, The cat climbed the went, The horse jumped the simple, The bird ate the harder, The soldier shot the open.

List 2

The corridors were very long, The tourist found the early, The burglar stole the true, He travelled on the small, The barrel was very heavy, The toxic fumes were strong, Many of the animals stayed, The boy was always yawning, Some of the fans shouted, The teacher cleaned the board, The fence was painted black, The man kicked the ball, The women emptied the give, The teacher wrote the letter.

List 3

The animals followed the much, The leopard killed the tried, The accused decided to answer, The man helped the over, The story was not true, The girl saw the some, The climber did not fall, The girls found the tried, The ape climbed the above, The tenant was told to move, The man helped a typing, The small dog always barked, The girl paid the bill, The welder fixed a none.

List 4

The cat chased the alone, The teacher told a turned, The doctor told the mother, The writer loved a reach, The girl inspected a jogging, The pupil read the book, The water was almost clear, The tramp always slept call, The new building was large, The young girl was pretty, The man found a write, The lion ate the speak, The builder caught the gave, The dog chased the infant.

List 5

The train was never early, The camper made a looking, The vicar entered the church, The child found his family, The policeman caught the never, The girl was very young, The boy was found playing, The tiger ate a much, The joiner carried a great, The porter carried the case, The two men always shouted, The doctor found the hear, The gypsy carried the darker, The sailor found the island.

List 6

The zebra jumped the think, The judge heard him speak, The pool was fairly deep, The two girls never walked, The dentist drilled the through, The rat ate the some, The secretary was always typing, The people found the kind, The painter studied the enough, The priest spoke to final, The child frightened the horse, The lecturer entered the wide, The footballer entered the none, The brother and sister spoke.

List 7

The puppy ate the made, The brick wall was level, The athlete jumped the reading, The boxer fought a most, The fish swam in meet, The inspector hit the true, The journalist asked the gone, The typist left the office, The vodka was very strong, The man emptied the tried, The mouse ran very them, Many of the people cried, The smoker asked the some.
His friend bought the drink.

List 8

The nurse bandaged the hand, The young man liked running, The cricketer injured his limb, Only one letter was kept, He received too much, The lady drove her staying, The exam was very easy, The soldiers could not march, The small child liked eating, The surgeon cut the write.
The witness saw the raised, The enemy fired the feel, The priest wrote a them, The man could not write.

List 9

The ladders were too short, The nurse ran very move, The student studied the wrote, The cowboy shot the going, He could find the wrote, The dog frightened the child, The room was too dark, The boy read the heavy, The golfer found the club, The police officer was serious, The design was the best, The postman delivered the think, The lady emptied the heavy, The driver smashed a feel.

H. Experiment 4.1 Instructions

Task One

In this task, a number of partially completed sentences (e.g. The man ate the) with a word underneath (e.g. very) will be presented on the computer screen at regular intervals. You are required to add the word to the end of the sentence and decide whether the sentence makes sense and respond 'yes' or 'no' on the computer keyboard as quickly and as accurately as possible.

Task Two

This task is very similar to task one. Firstly, a word will be presented on the computer screen for a number of seconds. This word will then disappear and be replaced by a partially completed sentence with a prompt underneath. This is the test stage and you will be required to make a response. After a number of seconds the partially completed sentence and prompt will disappear and be replaceD by another word. Again, this will disappear after a number of seconds and be replaced by another partially completed sentence member and prompt. This sequence of events will continue for a short period of time.

In the test stage if a '1-Back' prompt appears you will be required to think back to the very last word that disappeared from the computer screen. If the '2-Back' prompt appears you will be required to think of the word that appeared on the computer screen two positions back. You must then add the word to the current sentence on the computer screen and decide whether the sentence makes sense and respond appropriately.. At the test stage you may be given a '*' prompt which means on this occasion you do not have to make any response.

Therefore, in order to complete this task you must keep in mind the very last two words that appeared on the computer screen and rehearse them in your mind. When it comes to the test stage a prompt indicates which of the two words you have been rehearsing must be used to complete the partially completed sentence.

Task Three

This task is identical to task two except on this occasion you will be required to keep in mind the last three words. The prompt may be either **, 1 Back, 2 Back* or *3 Back.*

I. Experiment 5.1 Stimuli

List 1

4-2+3=5, 2+3+1=5, 7+1-4=4, 4-1+4=6, 7+2-4=5, 2+3+1=3, 2+1-1=1, 4+3+1=8, 3-2+5=8, 3+2-1=4, 7+2-4=5, 7+2-3=7, 5-2+6=4, 1+4-3=2

List 2

2+3+1=6, 3+2-1=3, 2+5-3=4, 8-3+1=6, 8-5+1=7, 5-1+4=6, 3+2-3=3, 4+3-1=6, 6-4+3=4, 5+1+1=6, 1+4-3=2, 4+3-1=5, 5-1-3=1, 8-3+1=5

List 3

6+3-1=8, 6+4-5=4, 5+3-4=5, 4+1-2=4, 9-5+1=5, 6+2-3=5, 3+1+3=7, 6+4-9=1, 8-5+1=2, 6+4-6=1, 4+1+3=9, 6+4-6=4, 6-1+3=8, 6-1+3=7

List 4

5+2-4=1, 2+3+2=7, 5+3-3=5, 5+2-1=4, 6-1+1= 3, 5+4-1=4, 3+1+3=7, 6+2-3=5, 6-4+3=4, 6-4+3=5, 3+4-5=2, 9-5+1=2, 6-5+5=1, 3+2+1=5

List 5

6-4+3=5, 4+1+3=8, 2+3+2=6, 6+3-3=5, 4+3-1=6, 1+9-7=3, 4+1-4=2, 3+2-3=1, 6+2-3=5, 3+1+3=7, 4+4-3=4, 6-5+2=1, 2+3-1=3, 9-5+1=5

List 6

4+3+1=7, 2+1-2=1, 5+3-3=5, 6+2-3=4, 6+4-6=3, 8-5+1=4, 2+3+1=6, 4+1-2=2, 7+1-4=4, 7+2-4=2, 6+4-9=1, 4+5-3=2, 4+3+1= 9, 6+2-1=7

List 7

8-5+1=5, 5+4-1=8, 4+1-2=2, 7+2-3=4, 3+2+1=6, 8-5+1=5, 2+3-4=1, 5+2-4=2, 3+4+7=8, 3+1+3=7, 6+2-3=9, 7+2-4=5, 5+3-4=1, 3+4-2=5

List 8

3+3+1=7, 2+3+1=7, 6-5+5=4, 9-5+1=5, 6+4-6=4, 7+1-4=3, 6-4+3=4, 2+3+2=7, 6-1+1=5, 3+3-4=1, 4+1-3=2, 6-5+5=6, 8-3+1=6, 6+2-3=4

List 9

8-5+1=4, 7+2-4=3, 6+3-3=6, 3+1+4=9, 9-5+1=5, 4+3+1=7, 6+2-3=5, 7-1+2=8, 6+3-1=1, 6-5+5=6, 7+1-3=5, 6-4+3=6, 6+4-6=3, 6+2-3=4

J. Experiment 5.1 Instructions

Task One

In this task, a number of simple mental arithmetic problems will be presented on the computer screen at regular intervals. Some of the problems will be correct (e.g.1+3+2=6) and some not (e.g. 2-1+3=6). You must verify as quickly an as accurately as possible whether the answer to the problem is correct by pressing 'y' or 'n' on the computer keyboard.

Task Two

This task is very similar to task one. Firstly, a number will be presented on the computer screen for a number of seconds. This number will then disappear and be replaced by an arithmetic problem with a prompt underneath. This is the test stage and you will be required to make a response. After a number of seconds the arithmetic problem and prompt will disappear and be replaced by another number. Again, this will disappear after a number of seconds and be replaced by another arithmetic problem and prompt. This sequence of events will continue for a short period of time.

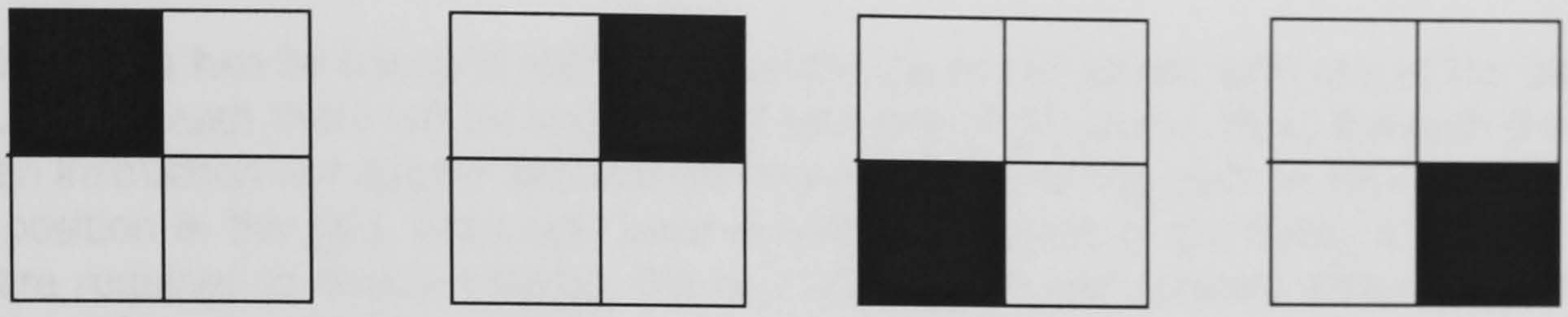
In the test stage if a '1-Back' prompt appears you will be required to think back to the very last number that disappeared from the computer screen. If the '2-Back' prompt appears you will be required to think of the number that appeared on the computer screen two positions back. You must then decide whether this number is the answer to the problem on the computer screen. At the test stage you may be given a '*' prompt which means on this occasion you do not have to make any response.

Therefore, in order to complete this task you must keep in mind the very last two numbers that appeared on the computer screen and rehearse them in your mind. When it comes to the test stage a prompt indicates which of the two numbers you have been rehearsing must be used to complete the partially completed sentence.

Task Three

This task is identical to task two except on this occasion you will be required to keep in mind the last three numbers. The prompt may be either **, 1 Back, 2 Back* or *3 Back.*

K. Experiment 6.1 Stimuli



L. Experiment 6.1 Instructions

Task One

In this task, a two by two grid will appear at the top of the screen with one of the blocks filled. Underneath there will be another grid with one of the blocks filled. Beneath the top grid an instruction will appear and you are required to move the block in your mind to the new position in the grid. Once you have moved the position of the block in the top grid you are required to decide whether the two grids match and respond either 'y' or 'n' as quickly and as accurately as possible on the computer keyboard.

Task Two

This task is very similar to task one. Firstly, a grid will be presented in the lower portion of the computer screen for a number of seconds. This grid will then disappear and be replaced by a grid and instruction at the top of the computer screen and a prompt below. This is the test stage and you will be required to make a response. After a number of seconds the grid, instruction and prompt will disappear and be replaced by another grid. Again, this will disappear after a number of seconds and be replaced by another grid, instruction and prompt. This sequence of events will continue for a short period of time.

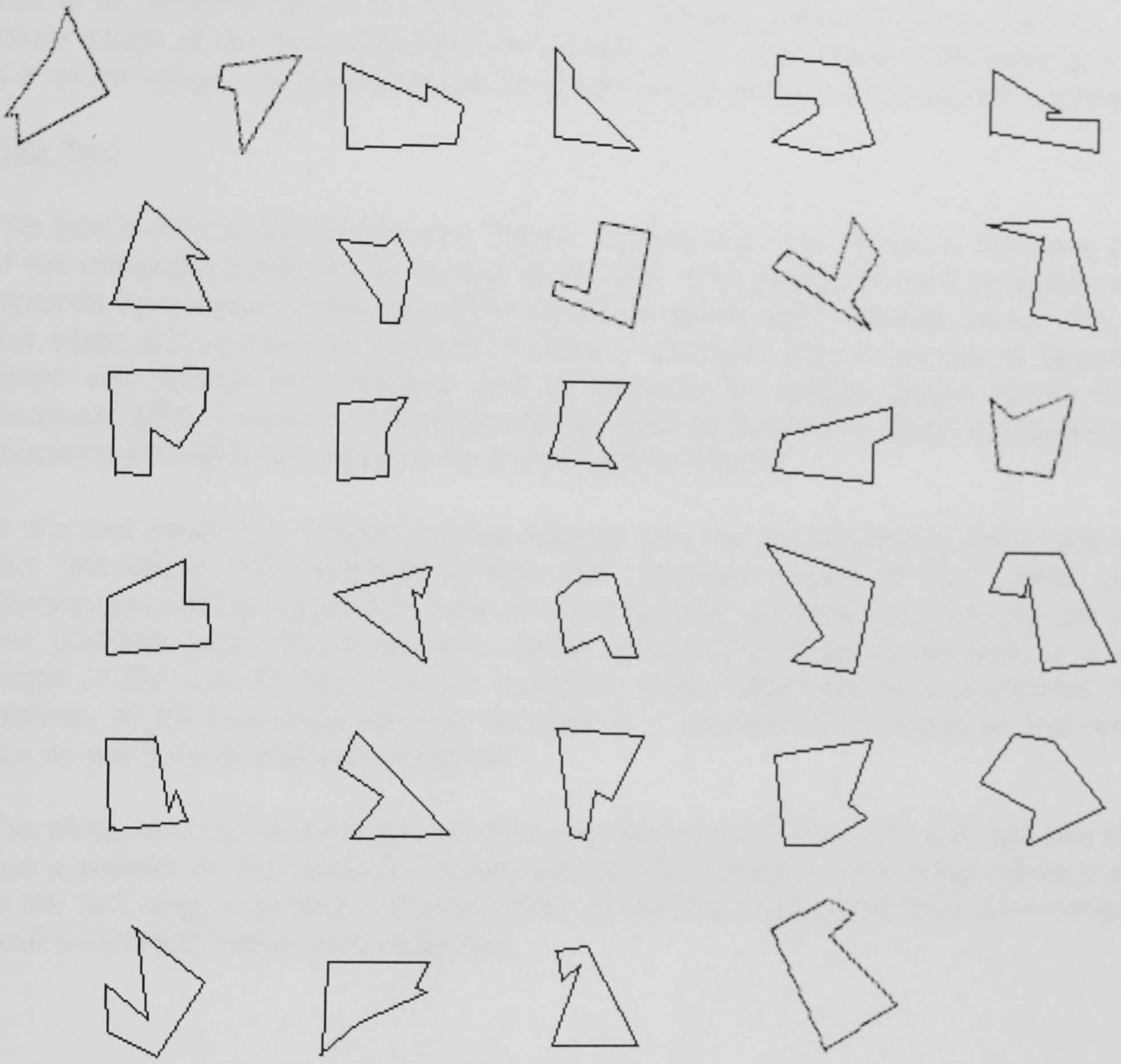
In the test stage if a '1-Back' prompt appears you will be required to think back to the very last grid that disappeared from the computer screen. If the '2-Back' prompt appears you will be required to think of the grid that appeared on the computer screen two positions back. You must then decide whether this grid is identical to the current grid on the computer screen after you have moved the block in your mind as the instruction indicates. At the test stage you may be given a '*' prompt which means on this occasion you do not have to make any response.

Therefore, in order to complete this task you must keep in mind the very last two grids that appeared on the computer screen and rehearse them in your mind. When it comes to the test stage a prompt indicates which of the two grids you have been rehearsing must be used to make the comparison.

Task Three

This task is identical to task two except on this occasion you will be required to keep in mind the last three grids. The prompt may be either **, 1 Back, 2 Back* or *3 Back.*

M. Experiment 6.2 Stimuli



Each of the above shapes were used in a variety of orientations and also as mirror images.

N. Experiment 6.2 Instructions

Task One

In this task, a shape will appear at the top of the screen with a second underneath. Your task is to mentally rotate the first shape and decide whether it either matches or is a mirror image of the second shape. Please respond 'y' if the shape is the same and 'n' if it is a mirror image, as quickly and as accurately as possible on the computer keyboard.

Task Two

This task is very similar to task one. Firstly, a shape will be presented in the lower portion of the computer screen for a number of seconds. This shape will then disappear and be replaced by a shape at the top of the computer screen and a prompt below. This is the test stage and you will be required to make a response. After a number of seconds the shape and prompt will disappear and be replaced by another shape. Again, this will disappear after a number of seconds and be replaced by another shape and prompt. This sequence of events will continue for a short period of time.

In the test stage if a '1-Back' prompt appears you will be required to think back to the very last shape that disappeared from the computer screen. If the '2-Back' prompt appears you will be required to think of the shape that appeared on the computer screen two positions back. You must then decide whether this shape is identical or a mirror image of the current shape on the computer screen after you have performed mental rotation. At the test stage you may be given a '*' prompt which means on this occasion you do not have to make any response.

Therefore, in order to complete this task you must keep in mind the very last two shapes that appeared on the computer screen and rehearse them in your mind. When it comes to the test stage a prompt indicates which of the two shapes you have been rehearsing must be used to make the comparison.