Effects of Ageing on

Visual Attention and Perception

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Abstract

A bilateral letter version of the spatial cueing technique introduced by Posner (1980) was employed across five experiments. Four experiments also used a perceptual cue-discrimination task. In Experiment 1 the effects of ageing on visual attention and perception were examined using a simple version of the paradigm with one valid and one invalid letter (X versus T). Perceptual cue discrimination and visual orienting at both brief (150 ms) and long (500 ms) stimulus onset asynchronies (SOAs) were intact for both age-groups. In Experiment 2 however, when the same tasks were used but with an increase in complexity to four valid and four invalid letters, whilst both groups were able to accurately perform the Perception Task, older adults did not benefit from the cues when performing the Attention Task. Based on research supporting an increase in attentional set-size with categorisation of stimuli, Experiment 3 was conducted using vowels as the valid letters (A E I O). Older adults were able to successfully perform both tasks. This was interesting as the degree of visual/perceptual complexity between Experiment 2 and 3 was similar. In Experiment 4 the nature of participants' awareness of the cue-target contingencies was examined using the Experiment 1 Attention Task, however, implicit instructions were used and a post-experiment questionnaire was administered to probe awareness. Any cue-target learning that occurred in either age-group was found to be explicit. In Experiment 5 electrophysiological methods were used to compare performance on the Attention and Perception tasks (using SOAs of zero & 700 ms) to explore further the dorsal/ventral distinction and age-related effects on it. The behavioural data showed strong effects of cue validity and high levels of accuracy for both age-groups as well as slower overall response times for the older adults. P1 amplitudes were greater on validly-cued trials for both groups on the Attention Task but the effect occurred later for younger adults. Within an early time window a strong dorsal/ventral distinction was present for both groups and this was maximal in the parietal lobe in the Attention Task, and in the temporal lobe in the Perception Task, which supported a dual-pathway model of vision.

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Chapter 1: Introduction

"The New Zealand population is undergoing a major demographic transformation and is facing an epidemic in ageing" (The HOPE Foundation for Research on Ageing, 2010).

In 1966 just 12% of the population was 64 years or older. By 2040 it is estimated that this figure will have climbed to 24%. As the 'baby boomer' generation enters retirement the proportion of older adults will increase substantially and over the next 20 years, it is estimated that those over 85 years of age will quadruple. As an increasing proportion of our population retires, there will be major societal implications in areas such as the economy, demographics, town planning, infrastructure, and of course health care. It is a clear and well-recognised fact that there is an increasing need for research into all areas of ageing, and that this will continue to be the case for the foreseeable future (The HOPE Foundation for Research on Ageing, 2010).

Cognition and ageing

The research area of cognitive ageing is concerned with the scientific study of cognitive processes at varying levels of the adult life-span and refers to how our mental capacities change as we age. Some of these capacities can deteriorate; some can remain the same and a few can even improve with age (Bosworth & Hertzog, 2009). In cognitive ageing research the most widely-known effect of ageing is the increased slowing of behaviour (e.g. Cerella, 1985b; Salthouse, 1988a). Kausler (1991) provides a full review of the effects of ageing at different stages of information processing. The review focuses

specifically on how ageing affects sensation, perception, attention, learning, memory, concept acquisition, problem solving and reasoning, and explains how all stages are affected to greater or lesser amounts by ageing.

Cognitive reserve is a concept used to describe the theory that our individual differences in task processing, can provide differences in the reserves that we have available to protect against brain pathology and the effects of ageing (Stern, 2006). Whilst it is generally believed that genetics, as well as environmental and brain stimulation influence an individual's cognitive reserve, a range of conflicting results have been found as to whether educational attainment has any effect on normal age-related cognitive decline. Education level is believed to provide an indirect measure of cognitive reserve and is influenced by both innate and environmental factors (Van Dijk, Van Gerven, Boxtel, Van der Elst & Jolles, 2008).

Due to the varied findings surrounding the relationship between education level and age-related cognitive decline, Van Dijk and colleagues (2008) conducted a large scale longitudinal study using a broad range of tests chosen to cover the cognitive areas that are known to show decline across the adult lifespan (such as mental speed), and those that show later-life decline (such as verbal fluency). Tests measured long-term memory, interference control, attentional shifting, semantic and phonemic fluency and mental speed. Consistent with Christiansen et al. (2001) and Gerstorf, Herlitz and Smith (2006), results failed to indicate any protective effects of higher education on cognitive change over time with normal ageing. Interestingly, health factors were found to influence

cognitive change over time. A greater decline in mental speed was found with poorer physical health, and a greater decline in both attentional shifting and long-term memory was found with poorer mental health.

Working memory and ageing

Working memory stores information temporarily in the brain and uses it to perform cognitive tasks. A large amount of research exists on cognitive ageing and working memory. Much of this research suggests that the disparity between the working memory performance of younger and older participants increases as task complexity increases. For example, Dobbs and Rule (1989) looked at a variety of working memory tasks that differed in storage and processing requirements. With storage requirement only tasks, age did not predict performance, but when tasks combined both storage and processing (more complex tasks) age became a strong predictor of performance. Similar results were shown by Gick, Craik and Morris (1988) who varied the grammatical complexity of sentences in a reading-span task and found that increased sentence complexity reduced the accuracy of working memory more for older adults than for younger adults. A series of three experiments conducted by Babcock and Salthouse (1990) found that age-related differences in working memory appeared to be determined by differences in the capacity of both storage and processing efficiency. These findings have since been supported by other studies (e.g. Hartman, Dumas & Neilson, 2001; Shimamura & Jurica, 1994).

Research has also focused on differences in materials (e.g. verbal versus non-verbal) in relation to ageing and working memory. Findings suggest that verbal working memory is

better preserved with ageing than nonverbal working memory (e.g. Park et al., 2002; Reuter-Lorenz, Jonides & Smith, 2000 provides a review). In general, it appears that nonverbal working memory is impaired with ageing (Jenkins, Myerson, Joerding & Hale, 2000; Myerson, Hale, Rhee & Jenkins, 1999). A study by Leonards, Ibanez and Giannakopoulos (2002) looked at the effect of ageing on working memory for letters, faces and doors and found that age-related decline was significantly greater for faces and doors than it was for letters.

Another area of working memory which has been well-researched is the area of interference. Many studies particularly in early cognitive ageing research have shown that older adults perform more poorly when they divide their attention (e.g. Broadbent & Gregory, 1965; Broadbent & Heron, 1962; Inglis & Caird, 1963; Welford, 1958). Based on the literature, Reuter-Lorenz and Sylvester (2004) proposed that the processes which are involved in mediating interference resolution, namely executive attention, contextual coding, and inhibitory control, all decline with ageing. One reason why the working memory of older adults may be more prone to interference could be related to the difficulty that they experience with selective attention. Connelly, Hasher and Zacks (1991) found that older adults experienced more difficulty ignoring irrelevant text in reading comprehension whilst May, Hasher and Kane (1999) found clear effects of ageing using a reading-span task with a descending order manipulation to adjust for age differentials. In a large sample of 250 participants, younger adults were found to have a significantly greater memory span than older adults. West (1999) found that the performance of older adults was more impaired by distractor stimuli than younger adults.

Task-irrelevant information was found to disrupt the efficiency of working memory processes in older adults by increasing memory-based errors, indicating a detrimental effect of ageing on the ability to encode and retain information.

Several studies have also found that older adults show greater retroactive interference effects; that is, their retention of previously encoded information is more disrupted by new information, compared to younger adults. Chao and Knight (1997) showed that older participants were less able to inhibit processing of distractor events than younger adults on an auditory memory task, and similar results were found by Hedden and Park (2001) using word-pair lists. Proactive interference has been found to be more robust with regards to ageing effects. This describes when traces of past memories inhibit ones full potential to retain new information or memories (Still, 1969). Hedden and Park (2001) provide a review of studies showing a variety of minimal to non-existent effects of ageing on proactive interference in working memory.

Research by Fernandes, Craik, Bialystok and Kreuger (2007) which required younger and older adults to study auditorily presented word lists and later recall the words, found that ageing was associated with lower recall scores in all conditions. When a distracting task was concurrently performed during encoding, memory was more greatly affected than when it was performed during retrieval. In their review on divided attention and ageing, Ishimatsu and Miura (2003) explain how the flexibility of attentional allocation deteriorates with age and that younger and older adults differ in their attentional allocation strategies.

Light, Prull and Kennison (2000) found mixed results across three priming experiments where they examined the effects of divided attention and ageing on priming in exemplar generation and category verification. In the first experiment, slightly more priming in category verification was found for older adults, whereas in the second experiment reliable priming was found for younger adults and no priming was found for older adults. In the third experiment, no reliable age differences were found. Light and Prull's (1995) participants were required to recall words presented visually under full attention along with those presented under divided attention (Experiment 1). They were also required to differentiate between old words previously presented visually, and state whether the words had been presented visually or auditorily (Experiment 2). As expected, dividing attention decreased overall recall and recognition performance. However there was no evidence for an increased effect with ageing.

Vision and ageing

The leading causes of blindness and reduced vision are age-related macular degeneration, cataracts, diabetic retinopathy, open-angle glaucoma and refractive errors. Ageing is a major risk factor to the development of these conditions and 83% of the world-wide diagnosed cases are in people who are at least 50 years old (Cavallotti & Cerulli, 2008). Fortunately, many of these eye problems can often be corrected through surgery or even with glasses. Although the specific rates of deterioration of visual capacities are still largely unknown, non-pathological age-related changes occur in most structures in the primary visual pathway (Spear, 1993 provides a review). Whilst rod numbers seem to decrease with ageing, cone numbers remain stable at the photoreceptor level (Curcio,

Millican, Allen & Kalina, 2001). Density in retinal ganglion cells also decreases with ageing particularly outside the macular region (Harman, Abrahams, Moore & Hoskins, 2000).

One of the most common health problems experienced by older adults is presbyopia which affects almost all people over 50 years. It is a chronic disorder which specifically causes problems with near vision due to changes in accommodation of the eye (Praveen, Sannapaneni, Bindiganavale, Gullapalli & Ravi, 2006). Accommodation describes a change in the shape of the lens of the human eye so that close objects can be brought into focus. This ability begins to decrease during late childhood then at midlife, it begins to affect daily activities and becomes known as 'symptomatic presbyopia'. It is thought that these changes in accommodation could be related to changes in the ciliary muscles, lens, capsule of the lens, and/or changes in the vitreous which occur as we age, although little is known for certain about the causes (Praveen et al., 2006). Fortunately, whilst surgery can be used to improve accommodation, presbyopia can usually be treated with contact lenses or reading glasses thus it is unlikely to have any influence on the present research.

In an applied sense, the role of peripheral vision in ageing is particularly relevant to mobility and other physical aspects of living; an area in which older adults commonly experience difficulties. Posture is maintained through the use of peripheral vision and peripheral information helps us navigate through our environment (Leibowitz, Post, Brandt & Dichgans, 1982). Research by Berencsi, Ishihara and Imanaka (2005) looked at whether central and peripheral vision had differing influences over postural control. The

results of three experiments showed that body sway was reduced in conditions where peripheral visual information was available compared to conditions with only central visual information. Thus it appeared to be peripheral rather than central vision that helped adults maintain a stable standing posture.

Driving is another applied area where peripheral vision is particularly important. West et al. (2010) looked at older adults' failure rates for stopping at red lights and how these related to vision and cognition. A strong association was found between failure to stop at red traffic lights and a narrowing of the attentional visual field (the peripheral area where objects can be perceived whilst attention is centrally fixated). The application of this research points towards placing traffic lights lower in the visual field to improve their visibility to older adults.

In another related study by McGregor and Chapparo (2005), a self-reported questionnaire was used to probe older adults on the visual difficulties that they experienced whilst driving and performing other daily tasks. Results indicated that older adults required more time to perform visual tasks than they had previously required and that they experienced problems with static and dynamic acuity, peripheral vision, illumination and contrast sensitivity. During driving, they reported experiencing problems with glare, peripheral vision and night driving which led the authors to propose that changes should be made to redesign road signs for safer use.

Perception and ageing

Milner and Goodale (2006) describe perception as the conscious experience of seeing, and elaborate on this as being our visual experience of the stimulus array that we are viewing. As Faubert (2002) explains, we interact with our environment throughout our life, as we respond to how we perceive it. Although accurate perception requires extremely complex processing, our ability to do this becomes so automatic that we do not notice the complexity involved. As we age, changes in our perceptual abilities are slow and unnoticeable due to the automatic and reflexive nature of perception. Whilst some previous research has shown that perceptual abilities remain intact with ageing, other research has found deterioration in some perceptual functions.

An interesting early paper focused on sensory processing was presented by Cerella (1985a). Cerella examined whether extrafoveal perception deteriorated with advancing age and found evidence in support of reduced peripheral vision in older adults. Results showed that as letter targets moved off the fovea, the age deficit in letter recognition time increased. Older adults also had greater difficulty seeing the outside characters in a grouped display and their restricted field of vision was thought to be protecting them from environmental distractors.

Sensation and perception are frequently viewed as being a unitary pair and are often not distinguished from one another. A long history of research exists as to whether these two can in fact be distinguished adequately and if so, how this should be done. However, for clarity it will be useful here to tease sensation and perception out, in order to examine

what the present thesis is most interested in, in terms of perception and ageing. The study of sensation or sensory processes is concerned with the first contact between the organism and the environment e.g. how we process the brightness of the target. Perception however, is concerned with our conscious experience of objects and their relationships to one another and is a greater focus in the present thesis. The primary point of interest in terms of the Perception Task used throughout this thesis is whether an object can be identified or 'discriminated' from other objects.

A series of studies into the effects of ageing on perceptual processing and working memory capacity for visual stimuli were presented in a paper by Faubert (2002). The studies focused on luminance, colour, motion, texture, and symmetry processing as well as the ability to retain size and spatial frequency information. Faubert proposed that whilst a number of perceptual abilities diminish with age, the extent of the deterioration is related to the complexity of the neural circuitry that is involved in processing the task. Even with a cognitively simple task, when the computational load increases in complexity, deficits in perceptual processing become more likely.

Levine et al. (2000) presented a study using Positron Emission Tomography (PET) that looked at age-related differences in visual perception. Differences were assessed by showing two classes of visual textures to younger and older adults and examining the differences in cortical activation during form perception. Whilst for the younger adults, the occipitotemporal pathway was activated during form perception as predicted by Goodale and Milner's view of perception as a ventral process (Goodale & Milner, 1992),

the older adults showed additional activation outside this pathway. Activated regions included the medial, middle and superior frontal lobe, and the anterior cingulate gyrus of the left hemisphere. These results suggest that a reorganisation of cortical activation occurs with ageing. It would appear that these age-related differences in brain activation could be a result of changes in early visual processes with ageing, such as those needed for visual perception.

As in the present thesis, letter-discrimination has also been used to study visual perceptual processes and how they are influenced by ageing. As explained by Thapar, Ratcliff and McKoon (2003) letter identification is a useful area to study as it provides a simplified version of the processes that are involved in processing alphanumeric characters. Also, as it is such a simple task, it can be useful in examining how common stimuli are processed categorically, where letters can be grouped into categories such as vowels and consonants.

Wright and Elias (1979) looked at whether older adults had more difficulty ignoring irrelevant distractor stimuli than younger adults using a visual task with distractors present. The task involved presentation of a precued central letter either alone or surrounded by distractors which either required the same response as the target letter, a different response or no response. The authors concluded that the irrelevant distractor stimuli did not elicit age-related response slowing, and that in fact, the younger adults were more detrimentally affected by this than the older adults. However, this interpretation was challenged by Cerella (1985a – see above) who felt that the findings

could be explained through the reduced ability of the older adults to *see* the distractors – thus lessening their distracting influence.

In Lambert and Holmes (2004) older and younger adult participants were required to perform both a complex perceptual cue-discrimination task as well as an attentional orienting task, both with central and peripheral cue conditions. A set of four valid "correct" letters were specified and the discrimination task involved a valid and an invalid letter being presented and participants responding to indicate the side of the valid letter. Whilst the mean accuracy level of the older adult participants was high (90%) they performed significantly less accurately overall than the younger adults (98%).

Similar results were found in a letter discrimination experiment by Thapar et al. (2003). On each trial, one of two dissimilar letters from a pair was displayed for a varied duration then masked, and participants were required to indicate the identity of the letter. Instruction was varied so that on some blocks of trials, participants were asked to respond as fast as possible whilst on others, accuracy was emphasised. Older adults were found to be both slower and less accurate overall than younger adults.

Two cortical visual processing streams

Vision arises from activity in two distinct neural pathways (Merigan & Maunsell, 1993). It was Ungerleider and Mishkin (1982) who initially discovered the existence of two separate cortical visual processing streams when they found two prominent sets of visual projections in the primate visual cortex. Whilst both streams arise in area V1, the dorsal

stream projects to the posterior parietal cortex whereas the ventral stream projects to the inferotemporal cortex.

Following Ungerleider and Mishkin's findings, Goodale and Milner (1992) proposed a model of cortical visual processing that primarily distinguished between vision for action and vision for perception as two separate pathways of visual processing; the dorsal and ventral streams. Whilst both processing streams are influenced by bottom-up input and top-down control and they both process and transmit information about object structures and locations, they do this very differently. The neural substrates of visual perception differ distinctly from those underlying the visual control of action. Thus, we identify and recognise an object using very different processes from those that we use to shape our hand to pick it up.

The ventral visual pathway involves the occipital and temporal lobes of the cortex. This pathway has been associated with conscious perception and plays a major role in perceptual object identification. The ventral stream takes visual inputs and transforms them into perceptual representations of objects and their relationships to each other (Milner & Goodale, 2006). Conversely, the dorsal visual pathway involves the occipital and parietal lobes of the cortex. It is associated with visually guiding actions directed towards objects. It does this by noting visual information about an object and transforming it into coordinates (Milner & Goodale, 2006). The dorsal stream has been linked with spatial vision (Mishkin, Ungerleider & Macko, 1983), the control of visually

guided actions (Milner & Goodale, 2006), and attentional movements (Lambert & Shin, 2010).

The dorsal/ventral distinction has been examined using a range of behavioural tasks (e.g. Desmurget et al., 1999; Rossetti, Pisella & Pelisson, 2000; Tanne, Boussaoud, BoyerZeller & Rouiller, 1995) and has been well-researched with younger adults.
Tasks that have been used to study this distinction include both visual tasks such as visual search tasks and also tasks that are more physically-oriented (see later in this section). Lehky and Sereno (2007) used a visual fixation task to compare shape encoding in high-level ventral and dorsal areas in primates. Shape selectivities of individual neurons were found to be greater in the ventral area. Responses to different shapes were also more dissimilar in the ventral area which indicated a greater capability for object discrimination and generalisation.

Veerman, Brenner and Smeets (2008) examined hand movements towards targets that varied from other objects based on certain attributes. On some trials, the target changed location with another object once the hand started moving towards it. The time that it took to correct the movement was 50 ms slower when the attributes of the target and replacement object differed by colour, shape or texture, versus when they differed based on luminance, orientation or size. Results indicated that whilst the dorsal pathway processed 'where' attributes in a relatively fast and direct way, longer processing times occurred in the ventral pathway as the parietal cortex mediated responses after the initial processing of 'what' attributes.

Similarly, Lee and van Donkelaar (2002) also demonstrated this distinction in younger adults by monitoring the speed of pointing movements towards a central circle in the Ebbinghaus illusion whilst using transcranial magnetic stimulation (TMS) to disrupt either dorsal or ventral stream processing. Results suggested that the ventral stream contributed to pointing movements based on relative object size information through projections to prefrontal areas, whilst pointing movements were not found to be directly influenced by the dorsal stream.

Interestingly (as a slight aside), this dorsal/ventral visual distinction is represented similarly in the auditory system, where auditory information processing shows a dichotomy between the spatial/dorsal ('where') stream and the nonspatial/ventral ('what') stream (e.g. Alain, Arnott, Hevenor, Graham & Grady, 1998). Chen, Zhang and Zhou (2006) compared the performance of congenitally blind adults with that of sighted adults and provided striking auditory evidence in support of the dorsal/ventral dissociation. Spatial and nonspatial peripheral auditory attention tasks were performed that manipulated location-based and frequency-based inhibition of return (IOR) concurrently. Blind participants performed faster in the spatial attention tasks and slower in the nonspatial attention tasks indicating that lack of early vision enhances the auditory dorsal pathway but impairs the auditory ventral pathway during peripheral auditory attention.

In terms of ageing effects, behavioural research has found that whilst older adults show a substantial decline in bottom-up visual processing (Madden & Whiting, 2004) top-down visual processing appears to be relatively well-preserved with ageing (Madden, Whiting,

Cabeza & Huettel, 2004). Madden (2007) suggests that that any age-related decline in bottom-up processing could be related to the decreased activation of cortical regions in the occipital lobe with ageing, as these regions mediate visual processing.

The contrast between bottom-up and top-down processes is well-demonstrated using visual search tasks. These tasks involve the participant attempting to find a target item in a display of 'distractor' items whilst response times and accuracy are measured. In a highly efficient search the target will differ from the distractors based on colour, shape and size, and will look as though it is 'popping out' of the display. Searching for targets in this situation is based on bottom-up attentional processing with salient differences between the target and distractors. In a less efficient search, the target and distractors will share some features so that target detection time increases as display size increases. In this situation, top-down processing will be used based on the observers' expectations and knowledge of differences between the target and distractors (Madden, 2007).

Whiting, Madden and Babcock (2007) performed two experiments that examined the influence of top-down information on adult age-differences in the ability to use spatial cues to search for single targets. In Experiment 1 both age-groups effectively used target-related top-down information when cues were mainly uninformative (25% valid). When they were more informative however (75% valid), older adults were less efficient at using the cues.

In Experiment 2 when top-down information was related to target features (when all trials in a block were of a constant trial type e.g. target orientation was varied), older adults performed well and used the top-down information efficiently. However, when only bottom-up information was available capture effects for older adults were larger than for younger adults. This was seen during 'mixed block' trials when target stimuli differed by orientation and colour within a block and thus top-down prior information was not available for each trial. This demonstrated increased attentional capture by bottom-up information with ageing.

Neuroimaging and Attention

The majority of research into the brain mechanisms of attention has used PET and functional magnetic resonance imaging (fMRI), which measure the activation of cerebral gray matter whilst the participant performs cognitive tasks. One important MRI study in this area investigated patient D.F. who had severe visual form agnosia and provided strong evidence for the existence of two separate systems of perception and action (Milner et al., 1991). D.F.'s ventral occipital lesions meant that whilst she could process visual input in order to guide actions, she could not visually discriminate between objects (James, Culham, Humphrey, Milner & Goodale, 2003). However, her visuomotor skills were found to be intact due to visual processing in the dorsal stream (Goodale, Milner, Jakobson & Carey, 1991).

Neuroimaging studies based on research by Corbetta and Schulman (2002) who distinguished between the ventral and dorsal components of the frontoparietal attention

network, have found evidence for increasing dorsal activation with ageing. This is consistent with the increasing emphasis placed on top-down processes (mediated by the dorsal region) with ageing (Cabeza, 2002; McIntosh et al., 1999). In McIntosh et al. (1999) PET was used to examine brain activation, whilst older and younger adults judged differences between two stimuli during a memory load manipulation. Whilst behavioural performance was equivalent for each age-group, PET revealed weaker functional interconnections for older adults between the brain regions that supported performance (occipital, temporal and inferior prefrontal cortices), indicating that these regions were operating less efficiently as a network. Other additional areas were also activated in older adults (medial, temporal and dorsolateral prefrontal cortices) most likely as a compensation mechanism for the reduced effectiveness of the network.

Another neuroimaging study examining top-down attentional processes was conducted by Madden et al. (2007). Two conditions were used in a visual search task where it was either likely that a colour singleton would predict the target location, or unlikely. Through fMRI it was seen that in the 'likely predict' condition only, whilst older adults showed frontal and occipital lobe activation during visual search, younger adults showed only occipital lobe activation. It appeared that this increased frontoparietal activation in older adults represented increased top-down attentional control which again suggested the use of compensatory mechanisms in response to a decline in bottom-up processing with ageing.

In an electroencephalography (EEG) study by Phillips and Takeda (2010) older adults were required to search for a target in two conditions. Either distractors shared no features with the target or they each shared a colour or orientation feature. In the former condition search time did not increase with display size whilst in the latter condition it did. Greater bottom-up control of attention was found when there were no shared features between the target and distractors. In combination with the results from a similar earlier study by Phillips and Takeda (2009) on younger adults, findings indicated that older adults were more likely to use bottom-up attentional control than younger adults, due to their increased susceptibility to bottom-up attentional capture (Kramer, Hahn, Irwin & Theeuwes, 2000).

Thus, the literature in this area does seem to embody a paradox. Whilst some studies have found that older adults have impaired bottom-up processing and retain top-down processing which they rely on as compensation for the bottom-up deficit, other studies have shown that older adults are more susceptible to bottom-up attentional capture (see above for examples). This could be related to problems experienced with distractibility that are known to increase with ageing (e.g. Scialfa & Joff, 1997).

Visual attention and ageing

The area of visual attention is concerned with our limited capacity for visual processing at any one time. We often have a large quantity of visual information available at the retina and can only process a small amount of this at once. This selectivity of information processing is a central aspect of attentional behaviour. Visual attentional

skills involve those such as: filtering out distractions in order to select objects of interest; shifting attention by shifting our information processing resources; dividing attention between locations and sustaining attention over time. Impairments in visual attention can increase the amount of time older adults take to complete daily activities. For example, common daily activities such as reading medicine bottles and finding objects in crowded drawers or cupboards can be more difficult when visual attention is degraded and impairments in tasks which use divided attention can make other tasks more difficult e.g. avoiding hazards when driving (Owsley & McGwin, 2004).

It is widely known that the speed of attentional processing decreases with ageing (Cerella, 1985b; Salthouse, 1982, 1985). The majority of ageing studies have found an association between slower overall response times and ageing (e.g. Hartley, Kieley & Slabach, 1990; Folk & Hoyer, 1992; Curran, Hills, Patterson & Strauss, 2001; Yamaguchi, Tsuchiya, Kobayashi, 1995; Lambert & Holmes, 2004). Hartley (1992) suggested that this association was unrelated to deficits in attention and instead was primarily due to the slowing of the response-related processes that are associated with ageing.

The deterioration in response times during attention-based tasks and also response accuracy with ageing has been well demonstrated using visual search paradigms (see earlier in 'two cortical visual processing streams'). Interestingly, the speed of visual search performance improves similarly for older and younger adults when both are given prior information on the defining features of a target (e.g. Whiting, Madden, Pierce &

Allen, 2005). In this study, there was no evidence for age-related deterioration of attention when the target clearly differed from the set of homogenous distractors.

Studying the relationship between ageing and attention has a lot of applied relevance, for example, Owsley and McGwin (2004) examined the relationship between visual attention/processing speed and mobility in older adults. Visual attention was assessed using the useful field of vision test and the association between this and each mobility measure was examined. This test provided a measure of visual attention under time-limiting conditions. Performance deficits on this task have been linked to mobility problems that occur in areas such as driving and visual search (which is important in performing everyday household tasks). Participants were asked to identify the radial direction of a target in their periphery whilst simultaneously discriminating between two targets in central vision. Results showed that a deficit in visual attention was associated with poorer performance mobility, after other influences on mobility had been adjusted for, such as age, visual and cognitive status and medical conditions. The importance of this relationship is obvious as mobility is one of the most common problems experienced by older adults. Mobility is also linked to physical and psychological wellbeing, as well as the ability to live alone and maintain overall independence.

Nagamatsu, Liu-Ambrose, Carolan and Handy (2009) used EEG and examined two aspects of visual-spatial attention (attentional control and facilitation) in two groups of older adults (fallers and non-fallers). Non-fallers were classified as those who had not experienced any falls six months prior to testing. Participants were required to respond with the left or right hand to indicate as quickly and accurately as possible the location of

the target whilst remaining fixated on the central cross. Both groups were able to direct their attention effectively towards the cued location, as indicated by the increased P1 component in the right visual field, for attended targets. P1 is used to describe the first positive component in a waveform with a peak around 100 ms. Fallers however, showed impairments in the ability of attention to modulate visual sensory processing. Thus, for left visual field targets, increased P1 amplitude for attended targets was present for non-fallers but not for fallers. This impairment in spatial attention-related facilitation in fallers is consistent with the finding that fallers have a narrowed fixation of attentional focus as suggested by Liu-Ambrose, Nagamatsu, Leghari and Handy (2008).

Attentional orienting and ageing

Orienting is used to describe the selection of information from sensory input (Fan, McCandliss, Sommer, Raz & Posner, 2002). Typical orienting of attention in daily life involves shifting our attention to the location of interest in an 'overt' manner. Thus we will move our eyes, head or even whole body, so that our fovea is aligned with the object. A 'covert' shift of visual attention (Posner, 1980) is when the attentional response system shifts the focus of attention to the peripheral or parafoveal visual field, in the absence of an overt movement.

Experimentally, covert visual attention is frequently assessed through performance on spatial cueing paradigms originally developed by Posner and colleagues (Posner, 1980; Posner & Cohen, 1984). All of the attention experiments in the present thesis have used variations on a peripheral bilateral letter version of this paradigm (Lambert & Holmes,

2004). In this task participants are instructed initially to focus their attention on a central point such as a cross. They are then provided with precues and asked to try to use the cues to speed responding and aid them in covertly orienting their attention to the target. The term 'validity effect' is used to describe the difference between response times on valid and invalid trials (see below). These validity effects along with accuracy levels have consistently shown that participants are faster and more accurate at detecting targets at a cued location 'valid trial' when compared to an uncued location 'invalid trial' (e.g. Danckert & Maruff, 1997; Yantis & Jonides, 1990). As the visuospatial focus of attention is shifted to the cued location, sensory processing of the target is facilitated (Hawkins et al., 1990). Earlier research has suggested that there are different processes involved in visual orienting in response to central and peripheral cues. Central cues (also known as endogenous cues) have been said to elicit orienting of attention that appears to be slow and under voluntary control. Visual orienting in response to peripheral (exogenous) cues however has been shown to be rapid, reflexive and somewhat automatic (Müller & Rabbitt, 1989; Jonides, 1981; Yantis & Jonides, 1990; Danckert & Maruff, 1997; Klein, 2004).

This dichotomy was well demonstrated in a study by Jonides (1981) which compared the effects of central and peripheral spatial cues on visual attention and gave participants a memory span task to complete whilst they performed a visual search task. A central arrow indicated the likely target location in the central condition and a peripheral arrow indicated the likely location in peripheral conditions. Results showed that when working memory load increased, attentional orienting to central cues decreased, whilst orienting to

peripheral cues remained unchanged. Orienting in response to central cues was slower and operated under conscious control, whilst orienting to peripheral cues involved rapid and reflexive processes (Müller & Rabbitt, 1989; Cheal & Lyon, 1991).

However, over the last decade, evidence has been reported on central cues such as arrows, direction words and letters, generating automatic (or at least non-conscious) shifts of attention. Both centrally-presented social cues (Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen, 1999; Langton & Bruce, 1999) and symbolic directional cues (Ristic, Friesen, & Kingstone (2002) with eye cues, and Tipples (2002) with uninformative arrows), have been shown to trigger what appears to be reflexive orienting of spatial attention to the cued location. Hommel, Pratt, Colzato and Godijn (2001) found that central symbolic arrow and word cues with no predictive value elicited rapid and substantial cueing effects, which suggested that endogenous cues can operate automatically. The experiments consisted of a simple detection task, IOR task and two choice decision tasks and involved non-predictive arrows and direction words which were presented centrally. The authors proposed that the reflexive nature of orienting was related to the over-learned representations of the meaning of the symbols used, rather than their central or peripheral locations. Similarly, Ristic et al. (2002) performed three experiments which used centrally-presented non-predictive gaze and arrow cues and found reflexive orienting in adults, preschoolers and split-brain patients. Thus it is worth noting that the previously established dichotomy between exogenous peripheral orienting and endogenous central orienting of attention may not be as robust as it once appeared.

Some research has shown that age-related differences exist in the orienting of attention to central cues, particularly with symbolic cues such as arrows that point to the likely location of the target, although findings have been mixed. Greenwood, Parasuraman and Haxby (1993) found that normal ageing did influence shifts of attention in response to central cues in a letter-discrimination task at cue-target intervals longer than 200 ms and Folk and Hoyer (1992, Experiment 2) found that performance was detrimentally effected by ageing with centrally-presented arrow cues. Hoyer and Familiant (1987) found that response times on a visual search task were faster for older adults when the target was presented at least 750 ms after the cue, whilst for younger adults this stimulus onset asynchrony (SOA – delay between the cue and target onsets) only needed to be 350 ms. Lambert and Holmes (2004) looked at how ageing influenced the orienting of attention in response to complex spatial cues (both central and peripheral). Older adults were found to be unable to orient efficiently in response to central arbitrary symbolic letter-cues even when they had shown high perceptual accuracy on a cue-discrimination task.

Many studies however, have found no evidence for a decline in orienting to central cues with ageing (e.g. Nissen & Corkin, 1985; Lincourt, Folk & Hoyer, 1997). Tellinghuisen, Zimba and Robin (1996) found that older and younger adults showed similar response patterns to central precuing in a procedure where an arrow preceded the target as an attentional precue. An endogenous visuospatial precuing task with four levels of resource demand was used to examine whether previous studies had failed to find age-related differences in responding due to low levels of resource demand. Task complexity varied, depending on line-orientation, lexical decision making and target luminance. Although it

was predicted that age differences would occur under conditions with increased resource demand (when targets were dim in the lexical task) no age-related differences were found. A series of three experiments by Hartley et al. (1990) which investigated the use of cues by older and younger adults showed a similar time course of processing and use of cues for both age-groups. Older adults showed cueing effects that were at least as large as younger adults across the three experiments.

Following their Experiment 2 results, Folk and Hoyer (1992, Experiment 3) found that shifts of attention by central cues were preserved in older adults. The latter experiment used a different display which enabled participants to encode the spatial orientation of the central cue more easily than in the previous experiment. These findings led the authors to propose that age-related decline was more likely to occur when cue-encoding demands were high (Hoyer & Familiant, 1987) but not in low cue-encoding demand situations (Hartley et al, 1990; Nissen & Corkin, 1985).

Previous research has shown little effect of ageing on responding to peripheral cues and the process has appeared to be relatively well-preserved in older adults. The attentional effects of peripheral cues have been found to be at least as large for older adults when compared to younger adults (e.g., Greenwood et al, 1993; Hartley et al, 1990, Robinson & Kertzman, 1990). Lorenzo-López et al. (2002) found that both older and younger adults were able to discriminate targets following valid cues more quickly than those following invalid cues and that efficiency in shifting attention in response to peripheral cues remained intact with ageing. Folk and Hoyer (1992; Experiment 1) also found that

attentional shifts based on peripheral cues were unaffected by ageing and that for both younger and older adults, invalid peripheral cues had significant costs on performance. Experiment 2 showed a decline in the ability to shift attention in response to symbolic central cues with ageing. However, the results of Experiment 3 revealed that it was the efficiency of encoding the cues that had declined with ageing, whilst the efficiency of the attentional shift had not been affected.

Tales, Muir, Bayer and Snowden (2002) compared sample groups of mild to moderate Alzheimer's disease patients, normal older adults, and normal younger adults. A spatial-cueing paradigm was used to assess the ability of the three groups to use cue information to guide their attention to the likely location of a target. Although attentional slowing was found in the Alzheimer's group, no slowing was found for the older adult control group where the peripheral attentional system of the normal older adults appeared to be intact. Baxter and Voytko (1996) found similar results in animal populations where older monkeys were able to orient their attention as efficiently in response to peripheral cues as younger monkeys. Again, no evidence for slower response times was found with ageing.

A minority of studies have shown ageing effects in response to peripheral cues. Faust and Balota (1997) used similar sample groups to Tales et al. (2002) to assess visual attention using a simple detection task. Experiment 1 assessed peripheral cueing effects using the cueing paradigm, with an SOA that varied between 100 ms and 800 ms. In Experiment 2, half the trials remained the same, but these were interspersed with 'double-cue' trials. On these, a second cue was presented before the target in order to see whether

IOR would occur. Both younger and older adults showed the expected validity effect for single-cue trials and showed IOR for double-cue trials. A greater effect of cue validity was found for the older adults on both experiments but no group effects were found on the double-cue trials. Changes in the posterior attentional system (which influences visuospatial attention) seemed to have occurred with ageing, in both healthy older adults and those with Alzheimer's disease.

Masking and ageing

There are a number of variables that affect our ability to discriminate between objects in complex visual scenes. Most of us are familiar with the experience of trying to see the road when driving through fog or mist. Our detection and recognition of the target road are often impaired as the fog provides a form of visual environmental camouflage. Typically, our perceptual errors increase and our responding slows, which can have serious consequences on an activity such as driving. Whilst previous research has examined masking of targets, only a small amount of this has involved older adults even though an increased difficulty in viewing conditions is more likely to seriously impact this group due to their degraded visual systems (Speranza, Moraglia & Schneider, 2001).

The influence of visual masks on older adults is of particular interest, as this age-group experiences many visual changes that increase their susceptibility to visual clutter, for example, a reduced field of vision (Kline & Scialfa, 1997). Driving is one example where there are large amounts of visual clutter in the environment and the inability of older adults to continue driving can result in a loss of independence. Ho, Scialfa, Caird

and Graw (2001) showed that when searching for traffic signs embedded in digital images of driving scenes, errors were more common among older adults and search efficiency decreased with increasing clutter and with ageing. Older adults have consistently exhibited visual search deficits, especially in situations of high similarity between targets and distractors (e.g. Scialfa & Joff, 1997).

In research on visual distraction, the term visual masking is used to describe a decrease in the visibility of one stimulus due to the presentation of another. This presentation can be either close-by, or even have the same temporal and spatial proximity (Atchley & Hoffman, 2004). Enns and Di Lollo (1997) used a form of masking similar to that used in the present thesis. In the four-dot masking conditions, four dots surrounded the target on each of its four corners. It was investigated whether in the absence of contact with the target, the distractor dots could still decrease target discriminability. Masking in the form of decreased accuracy was found when the targets appeared in unpredictable locations, but not when they were presented at a location near to fixation. As spatiotemporal resolution was low for targets in unattended locations it was possible that these targets were more likely to be open to substitution by masks when attention was directed towards them. Thus, although the dots may not typically have served as masks, they did in fact mask the target because visual attention was spread across a large spatial region.

The same visual masking task was used by Atchley and Hoffman (2004) with older adults. When masks appeared at the same time as the target older adults showed masking effects whilst younger adults did not. Additionally, when attention was spread across a

larger region whilst the accuracy of younger adults remained the same, older adults showed decreased response accuracy. Older adults appeared to be using attention more than younger adults to compensate for a degraded visual representation and this became more difficult when attention was spread out. In Experiment 3 by reducing the target contrast 'simulated ageing' was performed on the eyes of younger adults who then demonstrated similar masking effects to the older adults. This indicated that the problem of masking for older adults lay in a decrease in the spatiotemporal characteristics of the target, related to the ageing eye.

Although the following study did not look specifically at visual masks, it is of interest in a broader sense as visual masks provide a form of visual noise. Speranza et al. (2001) looked at the effects of ageing on visual stimuli embedded in visual noise in the form of texture. It was found that older adults were more greatly influenced by visual noise. Larger age differences in detection performance were found in Experiments 2-4 where visual background noise was present, compared to Experiment 1 where it was not. This was consistent with other research (e.g. Speranza, Moraglia & Schneider, 1995; Pardhan, Gilchrist, Elliot & Beh, 1996).

In Shih (2009) older and younger adults were required to search for two digit targets amongst letter distractors in a rapid serial visual presentation task (RSVP). The salience of T1 (the earlier target) and T2 (the later target) were varied independently by presenting the digits in either a salient 'brighter' colour (red or green) or the distractor colour (black). Attentional blink refers to a loss of performance on T2 due to processing of T1 in

RSVP tasks. For both the targets the attentional blink of the older adults was longer than the younger adults – showing degraded performance with ageing. When visual stimuli were rapidly presented one after the other on the screen, detection of the second target was more impaired for older adults if it appeared 200-500 ms after the first target (Raymond, Shapiro & Arnell, 1992). Older adults showed a greater effect of masking from the brighter stimulus than younger adults.

Implicit learning and ageing

The sheer amount of information that we learn about our environment and the relationships between objects in it, is vast and often far greater than that which enters our conscious awareness. When we learn something 'explicitly' we are aware of what we have learned and can explain and describe it. However, 'implicit' learning occurs largely subconsciously. Thus, although we may have learned about relationships between objects and developed knowledge about them which we can use, when asked to describe what we have learned we are unable to do so (Reber, 1993).

Howard and colleagues have performed many studies on implicit learning and ageing, although these have primarily used sequence learning. Howard and Howard Jr. (2001) looked at the effects of instruction on implicit pattern learning using an alternating serial reaction time task (SRTT), where predictable and random patterns alternated in a visual display. They found that intentional instructions impaired implicit pattern learning in older but not in younger adults. Howard, Howard Jr., Dennis, LaVine and Valentino (2008) found that implicit learning of an invariant association remained intact in older

adults. The task involved the learning of letter strings where a given letter remained constantly in the same position. Howard, Howard Jr., Dennis and Kelly (2008) performed four experiments using the triplet-learning task to investigate sequence learning. In this task, participants are required only to respond to the last target event in a series of three-event sequences/cues. Target predictability was varied by manipulating the frequency and relationships among the three cues. Whilst both age-groups learned the sequences, older adults showed less learning and relied mainly on information from the second cue, whereas younger adults used both the first and second cues.

Several studies have used implicit contextual cueing paradigms to study implicit processes in visual search tasks. Implicit contextual cueing refers to whether participants are able to learn the association between contextual environmental information and a specific target. Howard, Howard Jr., Dennis, Yankovich and Vaidya (2004) looked at the effects of ageing on implicit spatial contextual learning and found that contextual cueing (using repeated spatial configurations to aid target search) remained intact with normal ageing, whilst higher-order serial learning (using subtle regularities in sequences) was impaired. Another recent contextual cueing study by van Asselen and Castelo-Branco (2009) looked at the role of peripheral vision in implicit contextual cueing. A covert visual search task was employed to test whether peripheral vision could underlie implicit contextual cuing. Subjects were asked to indicate the orientation of the target whilst remaining fixated on the central cross. When the stimulus configuration was new, longer response times were found. Learning was found to be stored over time in memory as evidenced by repeated testing conducted ten days later. Thus it appeared that during

implicit contextual learning covert shifts of attention allowed contextual information to be first perceived and then stored through means of peripheral vision.

Whilst some experiments have been conducted into the implicit orienting of attention using cueing paradigms, none of these have involved an older adult group. A group of three experiments by McCormick (1997) used a cueing paradigm to assess the automaticity of exogenous orienting and found that brief presentations of stimuli captured attention automatically without explicit awareness. Three experiments by Lambert, Naikar, McLachlan and Aitken (1999) with younger adults also found exogenous attentional orienting occurred in the absence of explicit awareness using a bilateral letter-cueing paradigm. The orienting effect appeared to occur independently of perceptual awareness of the cue and also of the cue-target relationship. Bartolomeo, Decaix and Sieroff (2007) found that endogenous orienting with peripheral cues could occur independently of explicit awareness, whilst Risko and Stolz (2010) found evidence for the cueing effect reflecting implicit rather than explicit learning. More details are provided on these implicit cueing experiments in Chapter 4.

Derived attention

The notion of derived attention was proposed by William James in 1890. James (1890, 1983) proposed that attention could be either immediate or derived. Immediate was when the topic or stimulus was interesting in its own right and derived was when its interest was based on an association with something else immediately interesting. James believed that whilst voluntary attention was derived, reflexive attention could be either immediate

or derived. Whilst the majority of cueing studies have focused on reflexive orienting based on immediate attention (e.g. Müller & Rabbitt, 1989, who used the popular procedure of luminance changes to peripheral cue stimuli), few have addressed the notion of derived attention, even though it is intuitive that learning and experience would influence the degree of attentional capture of objects in our environment. Lambert and Roser (2001) used a bilateral letter cueing paradigm to test James' proposal of derived attention, by looking at the effects of peripheral colour changes on attention and found that even when participants were unaware of the contingencies between the cue and the target, they still oriented their attention more quickly towards the colour that had been associated with the target during a brief training period.

Although many studies have looked at the effects of ageing on endogenous and exogenous orienting using standard cueing paradigms, Lambert and Holmes (2004) is the only ageing study that has looked at derived attention using the bilateral letter cueing paradigm. Lambert and Holmes tested the 'cue encoding' hypothesis (Folk & Hoyer, 1992) which proposed that age-related decline would be more likely in situations where cue-encoding demand was high and less likely when cue-encoding demand was low. Two 'complex' tasks, one a visual orienting task and the other a cue discrimination task were performed by younger and older adults. The term 'complex' was used to refer to the four valid and four invalid letter cues, chosen randomly for each participant from a pool of eight letters: R W D N T S A H. In the visual orienting task when cues provided predictive information as to the likely location of a target, younger adults appropriately used these cues to shift their attention. Older adults failed to do this and they also

performed more poorly on the cue discrimination task, where participants were required to determine whether letters presented to the right and left were valid or invalid. Whilst it was hypothesised that any age-related decline in spatial orienting would be related to a decline in the performance of cue discrimination, attentional deficits occurred even when older participants' ability to perceive the cues was unimpaired. This suggested that in some situations older adults may fail to shift visual attention appropriately, even when perceptual ability, as assessed by conventional discrimination tasks, may appear intact. The authors proposed that in learning how to perform new perceptuomotor skills, ageing had negatively influenced the ability to form new links between the different components of a task, which helped to explain why older adults often experience problems in performing new complex tasks.

The present research

The overall aim of this thesis was to investigate the effects of ageing on visual attention and perception using a bilateral letter cueing paradigm similar to that of Lambert and Holmes (2004). Of particular interest was how responding would be influenced by variations in cue complexity and how implicit and explicit processes would contribute to orienting. This was to be investigated extensively using both behavioural (response time and accuracy) measures and electrophysiological methods.

The experiments in this thesis will build on those of Lambert and Holmes (2004). The majority of previous research in this area has found no effect of normal ageing in the automatic shifting of attention in response to peripheral cues. However, most of these

studies have used simple cueing situations (e.g. Folk and Hoyer, 1992; Greenwood et al., 1993) which are less representative of the real world than more complex ones and few of these studies have used the bilateral letter cueing paradigm.

In the present thesis, Experiment 1 investigated the effects of ageing on attentional and perceptual systems using two simple computer-based visual tasks, one looking at visual perception (using a speeded cue-discrimination response) and the other using a bilateral letter version of the cueing paradigm. Both included trials with visual 'distractors' added to further investigate the influence of increased complexity on these processes. Experiment 2 examined how ageing influenced the ability to perform the Attention and Perception tasks with a further increase in complexity, through the introduction of a multiple-cue situation. Experiment 3 examined the influence of stimulus categorisation on the ability of older and younger adults to perform the Attention and Perception tasks in a complex, multi-cue situation. Experiment 4 examined the effects of ageing and the contributions of implicit and explicit processes to attentional orienting in a simple cueing task. Finally in Experiment 5, as well as gathering behavioural data EEG was used to compare the event-related potentials (ERPs) elicited during performance of the simple versions of both the Attention and Perception tasks for older and younger adults. Standardised Low Resolution Electromagnetic Tomography (sLORETA - Pascual-Marqui, 2002; Fuchs, Kastner, Wagner, Hawes & Ebersole, 2002; Jurcak, Tsuzuki & Dan, 2007) was also used to compare areas of neural activation within and between tasks and also between age-groups.

Chapter 2: The Bilateral Letter Cueing Paradigm

Introduction

Although there have been many studies that have looked at the effects of ageing on endogenous and exogenous orienting using standard cueing paradigms (e.g., Greenwood et al., 1993; Hartley et al., 1990, Robinson & Kertzman, 1990) Lambert and Holmes (2004) is the only study that has investigated the effects of ageing on derived attention using the bilateral letter cueing paradigm.

Lambert and Holmes looked at how ageing influenced perceptual cue-discrimination, and orienting of attention in response to complex spatial cues presented both centrally and peripherally. All participants performed two tasks. In the Visual Orienting task on each trial they were required to shift their attention in response to one of four valid bilateral letter cues (where the target asterisk would appear on the same side as the valid letter 80% of the time) and then respond to the target. For each participant a different set of four valid and invalid cues were chosen randomly from a pool of eight letters: R W D N T S A H. On each valid trial, a valid letter would appear in the visual field preceding the asterisk and an invalid letter would appear on the opposite side. On invalid trials an invalid letter would appear in the visual field preceding the asterisk and a valid letter would appear on the opposite side. In the Cue Discrimination task, participants were required to discriminate the valid letter from the invalid one (one on each side) and respond to the valid letter as quickly as possible.

Findings indicated that older adults were unable to orient efficiently in response to either central or peripheral letter cues. This was true even for participants who had shown high levels of perceptual accuracy on the Cue Discrimination task. The authors proposed that the older adults may have been suffering from an age-related decline in the ability to develop new functional links between different components of a task, whilst learning new perceptuomotor skills. That is, they experienced difficulty in forging links between cue-encoding processes and visual orienting.

This dissociation between perception and attention in older adults is examined more closely in the present chapter and theoretical explanations for it are considered. These experiments aimed to compare the efficiency of *orienting in response to peripheral cues* (visual attention), with the accuracy of *responding to peripheral cues directly* (cue discrimination - visual perception), in older and younger adults. Specifically, Experiment 1 asked whether older adults' failure to orient attention in response to letter cues in Lambert and Holmes (2004) was due to a general decline in derived attention with ageing, or whether their failure to orient was mediated by the complexity of the spatial cues employed in the earlier study.

Folk and Hoyer (1992) proposed that whilst there are age differences in the efficiency with which symbolic cues are encoded, the efficiency of the actual shifting/orienting process is preserved with ageing. They suggested that age-related decline is more likely to occur in high cue-encoding demand situations than in low cue-encoding demand situations. In the present chapter, this will be referred to as the 'cue-encoding

hypothesis'. In this thesis, this hypothesis refers specifically to encoding the letters as attentional cues and does not refer to perceptual encoding, as reflected in the performance of the Perception Task.

A further aim for these experiments was to explore age-related changes in visual masking effects. Visual masking occurs when the target stimulus appears less visible, due to the presentation of 'masking' stimuli, either simultaneously or close in time or space (Atchley & Hoffman, 2004). In Experiments 1 and 2, peripheral precues were masked on half of the trials by surrounding them with four 'S' stimuli to increase the perceptual encoding demand, in order to investigate whether these 'masks' would influence the ability to orient and whether the effect of the masks was influenced by ageing.

Each participant performed two tasks. These tasks were of the same length and were created to be as similar to eachother as possible. The main difference was the response that was required by the participant. In the Perception Task, participants responded directly to the valid letter, whereas in the Attention Task, they were required to respond to the target asterisk directly, and to use the valid letters to help direct their attention. Thus both tasks used the same letters, but the Perception Task measured perception directly whilst the Attention Task measured the ability to use letters to shift attention appropriately. This enabled the results from both tasks to be compared within subjects, in an attempt to investigate whether these processes and pathways were declining similarly with ageing.

In Experiment 1 a simple cue-encoding demand situation was used with one valid letter cue and one invalid letter cue. Valid cues signified where the target stimulus was likely to appear and invalid cues signalled where it was unlikely to appear. In Experiment 2, visual complexity was increased to four valid and four invalid letters. Of specific interest was whether responding on the two tasks would be influenced by ageing and whether a similar effect of ageing would be found in both the Attention and Perception tasks, and across both experiments. For both tasks and in both experiments, slower response times were expected for older adults resulting from an age-related decline in cognitive functioning (e.g. general slowing of processing; Cerella, 1985b; Salthouse, 1988a) consistent with prior research (e.g. Hartley, 1992).

Experiment 1

Lambert and Holmes (2004) found that older adults failed to orient their attention appropriately in response to bilateral letter cues, using a method that involved the measurement of simple response times where all responses were made on the same key. In Experiment 1, the first hypothesis of interest was whether this failure to orient occurred because the process of derived attention itself had declined with ageing. That is, do older adults exhibit a general impairment in the ability to orient attention in response to cue letters? A second and alternative hypothesis is that older adults were unable to orient appropriately due to the cue-encoding demands of the task, which were relatively high: the cue letter-set included four valid and four invalid letters. Note that this second hypothesis includes the possibility that the ability to orient attention was influenced by the *perceptual* demands of discriminating between the four valid and four invalid letter

cues (a large cue set) whereby cue letters become associated with likely and unlikely locations. If the first hypothesis is true, older adults will fail to orient appropriately in response to letter cues in Experiment 1, even when cue-encoding demands are reduced, by using a smaller cue-letter set with one valid and one invalid letter ('X' and 'T'). However, if the second hypothesis is true, older adults will orient appropriately in Experiment 1 with a simpler set of attentional cues.

Method

Participants

All participants were screened for major visual and other health problems through preliminary discussion prior to participation. Participants were unable to participate unless their vision could be corrected to normal vision (self-reported), with the use of contact lenses or glasses. All older adults could be described as active in their community and lived independently. All participants received a $10 voucher for participating in one 30 minute testing session. The research was approved by the University of Auckland Human Participants Ethics Committee.

The younger adults consisted of 18 participants (13 females) between the ages of 20 and 31 years (mean = 23.9, SD = 3.07) with a mean of 16.7 years of formal education (SD = 1.6). The older adults consisted of 17 participants (9 females) between the ages of 60 and 75 years (mean = 65.4, SD = 4.7) with a mean of 15.9 years of formal education (SD = 1.55). Nine older adults were in full-time employment, 6 were in part-time employment

and the remaining 2 worked part-time in voluntary positions. 15 younger adults and 16 older adults were right-handed.

Apparatus

The experiments were run using an IBM compatible laptop computer connected to an LCD monitor, with a graphics resolution of 1280 x 1024 pixels. The testing programme was written using E-Prime software. Testing for all participants was carried out in a room with either no windows, or curtains that were drawn, in which standard illumination was provided by a single light attached to the ceiling. For the younger adults, testing was conducted in a testing room in the Department of Psychology at the University of Auckland. For the older adults, testing was conducted in a suitable testing room of the participants' choice (in most cases in their own home). All testing sessions used the same computer monitor, and had similar room illumination. A chin-rest was used to maintain viewing distance at approximately 57 cm.

Display and stimuli

The stimuli were presented in black against a white background. The fixation display was a central cross subtending approximately 0.6° x 0.6°. In the Attention Task the target stimulus was an asterisk that subtended 0.5° x 0.5° and appeared either to the left or right of the central cross. The inner edge of the target asterisk was approximately 8° from the central cross. This same stimulus served as feedback in the Perception Task. The cue stimuli (either an 'X' or a 'T') were approximately 0.6° (height) x 0.5° (width). The lower edge of each letter was presented 0.3° above fixation. The same stimuli were used

for the Perception Task where the letter rather than the asterisk, was the target. The inner edge of the cue/target letter was approximately 7.9° from the central cross. On half of the trials for both tasks, four masks (‘S’ stimuli) subtended approximately 0.6° (height) x 0.5° (width). Relative to the valid and invalid letter, the masks were positioned as if around a clock face spaced 45°, 135°, 225° and 315° from 12 o’clock. The distance between the masks and the valid and invalid letter subtended approximately 0.2°. All letters were presented in upper-case in the font style Arial for all participants.

Procedure

Half of the participants received the Attention Task first followed by the Perception Task, whilst the other half received the reverse. Half of the participants received a version where the ‘X’ was the valid letter and ‘T’ was the invalid letter (of which they were informed) whilst the other half received the reverse.

Participants were required to respond using the left key (‘z’) if the target was on the left and the right key (‘/’) if it was on the right. They were instructed to keep their fingers positioned on these keys throughout the experiment, whilst each block of trials was underway, and to respond as quickly as possible while avoiding errors. They were encouraged to take breaks if needed in between blocks.

Throughout the experiments in this thesis eye-movements were not monitored. Thus it is possible that the results may reflect not only covert shifts of attention, but also overt changes in eye position. Two considerations suggest that an interpretation of the findings

in terms of covert, rather than overt orienting is more appropriate. Firstly, it has been known since the early work of Posner and colleagues (Posner, Nissen & Ogden, 1978; Posner, Snyder & Davidson, 1980) that when participants respond to clear, luminance defined targets presented in an otherwise empty field, eye movements are rarely made. Posner et al. (1978) reported that in this situation participants made eye movements of more than 1° on less than 4% of trials and that the pattern of attentional effects elicited by the cue was unchanged when these trials were excluded. A second reason for doubting that eye movements played a critical role in these experiments arises from earlier findings using the bilateral cueing paradigm. Lambert and Duddy (2002) observed a clear advantage in response time for targets presented at the valid location, even when the delay between cue and target onset was extremely brief – 100 ms or less. Since it takes about 150 ms or longer to prepare and initiate an eye movement, this suggests that the response time effects evoked by bilateral letter cues of the kind used here and by Lambert and Duddy (2002) were mediated by shifts of covert, rather than overt attention.

Participants were instructed to fixate on the central cross throughout the experiment and the importance of this fixation was emphasised prior to beginning the practice trial block. One second prior to presentation of the letters, the central cross disappeared for 100 ms. This made the cross look as though it were blinking at the beginning of every trial to draw the attention of the participant to the fixation cross and to remind them to focus there at the beginning of each trial.

Each testing session began with participants performing a block of 24 practice trials so that they were familiar with the task. During this time responses were monitored by the investigator to ensure task comprehension. Trial type varied pseudorandomly throughout the experiment.

Attention Task

Participants were instructed to respond to the target 'asterisk' as quickly as possible. The cue letters were then presented for 100 ms and were followed by a blank screen after which the target stimulus was presented to create one of two cue-target stimulus onset asynchronies (SOA). The SOA alternated randomly between 150 ms and 500 ms throughout the experiment. This enabled the speed of orienting in response to spatial pre-cues to be assessed. The target stimulus (asterisk) disappeared when the key was pressed and the central cross blinked to signal the start of the next trial after 750 ms had elapsed.

Participants were told that the asterisk would appear on the same side as the valid cue 80% of the time, and that they should try and use the letter cue to prepare for the target asterisk occurring on the same side as the valid letter, and opposite to the invalid letter. They were instructed to pay attention covertly, by directing attention to the expected location of the target, whilst their eyes remained fixated on the central cross. Participants were also informed that on random trials mask 'S' stimuli would appear around the cue letters and that they should respond in the same manner as when these were not present.

Following a short break after completion of the practice trials, participants performed two blocks of 80 trials. Within each block there were 64 valid trials (where the target appeared on the same side as the valid letter cue), and 16 invalid trials (where the target appeared on the same side as the invalid letter cue); there were 40 masked trials and 40 unmasked trials; there were 40 trials at each of the two SOAs; there were 40 trials with the target in the right visual field and 40 trials with the target on the left.

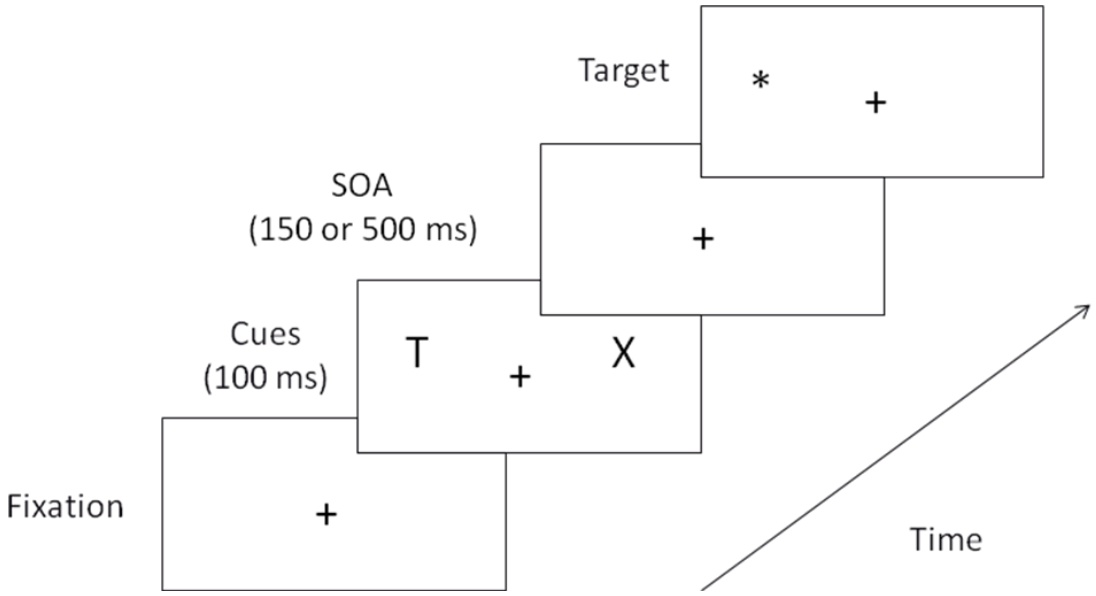


Figure 1: A representative trial sequence from Experiment 1 (Attention Task) on an unmasked valid trial with 'T' as the valid cue. (Not to scale. SOA = stimulus onset asynchrony – timed from cue onset to target onset).

Perception Task

Participants were instructed to respond to the target letter as quickly and accurately as possible. They were told that the asterisk would then appear to indicate the correct location of the target letter. This provided participants with feedback on the accuracy of

their response, and also ensured that stimulus conditions were similar between the Attention and Perception tasks. The central cross then blinked to signal the start of the next trial after 750 ms had elapsed.

Participants were informed that on random trials mask 'S' stimuli would appear around the cue letters and that they should respond in the same manner as when these were not present, as rapidly as possible, even if they were unsure of the location of the target. Participants performed two blocks of 80 trials, after completion of the practice block and a short pause. Within each block there were 40 masked trials and 40 unmasked trials. There were 40 trials with the target in the right visual field and 40 trials with the target in the left visual field.

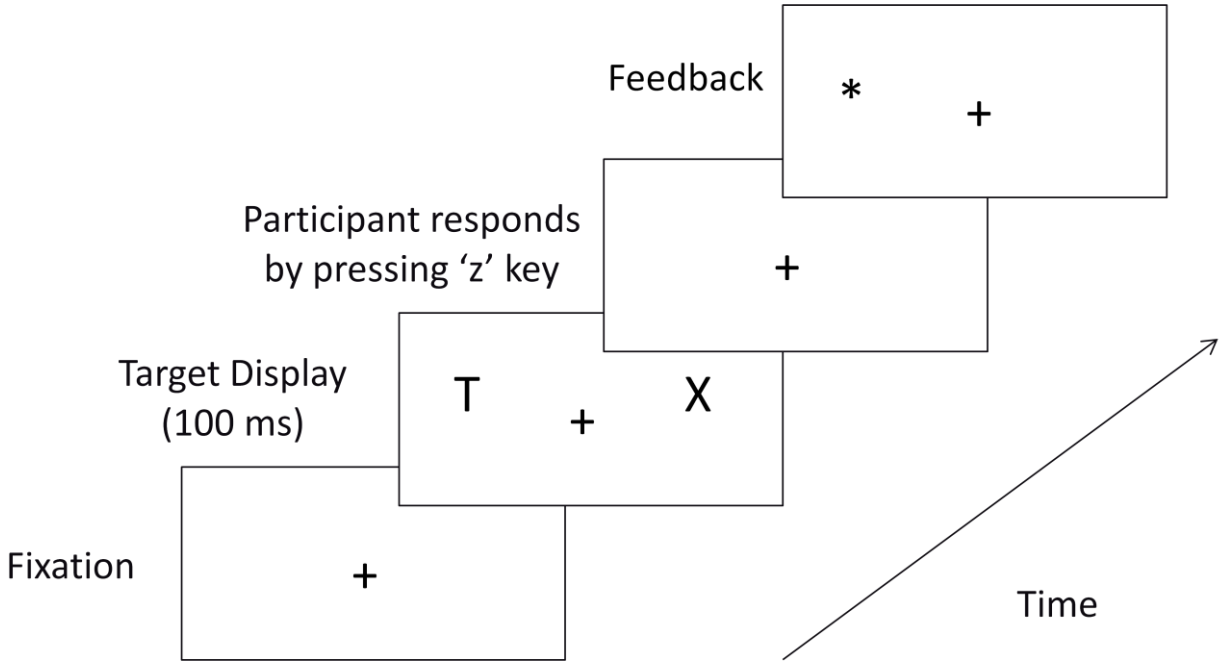


Figure 2: A representative trial sequence from Experiment 1 (Perception Task) on an unmasked trial with 'T' as the target letter.

Results

Analysis

Trial response errors were excluded in both tasks. These consisted of anticipations where response times were less than or equal to 100 ms, delayed responses where response times were greater than or equal to 1000 ms and response errors where the wrong key was pressed. An alpha level of .05 was used for all statistical tests, and all significance tests were 2-tailed. The inclusion criterion was for anticipation errors, delayed responses and response errors to be less than 8% and all participants met this criterion.

In the Attention Task, anticipations were 1% for both younger and older adults, and delayed responses were 2% for the younger adults and 2.1% for the older adults. Response errors were 2.9% for the younger adults and 2% for the older adults[1]. In the Perception Task, anticipations were 1% and delays were 2.1% for the older adults. For the younger adults anticipations were 1.5% and delays were 2.4%. An accuracy analysis for the Perception Task is provided below.

Attention Task

A four-factor analysis of variance (ANOVA) was conducted on the mean response time for each participant in each condition separately for the older and younger adults, to see if there were any order effects related to whether a participant had performed the Perception or Attention Task first. The independent groups factor was Order (Perception First vs. Attention First) and the repeated measures factors were SOA (150 ms vs. 500 ms), Cue

[1] Response errors were compared between age-groups using an independent samples t-test and were found to be non-significant ($p > .05$).

Validity (Valid vs. Invalid) and Masking (Masked vs. Unmasked). As no significant effects or interactions involving the factor Order were found for either age-group, this factor was dropped from subsequent analyses.

Figure 3 shows the response time results for the Attention Task for each age-group. An ANOVA was conducted on the mean response times for each participant in each condition. The independent groups factor was Age Group (Older vs. Younger), and the repeated measures factors were SOA (150 ms vs. 500 ms), Cue Validity (Valid vs. Invalid) and Masking (Masked vs. Unmasked). The main effect of SOA was significant, $F(1, 33) = 88.32$, $p < .001$, showing that mean response times were faster at the longer SOA (see Figure 3). The main effect of Age Group was also significant, $F(1, 33) = 18.52$, $p < .001$, which showed that mean response times were longer for older (424 ms) than younger (351 ms) adults. The interaction between SOA and Age Group, $F(1, 33) = 4.80$, $p = .036$, was significant showing a greater mean decrease in response times at the long SOA for older adults (79 ms, Figure 3a) than for younger adults (50 ms, Figure 3b). Finally, the main effect of Cue Validity, $F(1, 33) = 35.72$, $p < .001$ and the interaction between Cue Validity and Masking, $F(1, 33) = 16.4$, $p < .001$, were both significant. The former (Figure 3a, b) showed that mean response times were significantly faster when cues were valid (369 ms) compared to invalid (406 ms), whilst the latter showed that the mean difference in response times between valid and invalid trials was larger when the cue letters were unmasked, compared to when they were masked[2]. The absence of an interaction between Age Group and Cue Validity; $F(1, 33) = 1.179$, p = n.s. was also of relevance, where both older and younger adults showed faster mean response

[2] A strong effect of cue validity also existed on masked trials: $F(1, 33) = 13.3$, $p = .001$.

times on valid trials. There was no interaction present between SOA and Cue Validity, $F(1, 33) = .253$, p = n.s. That is, at both SOAs participants showed faster mean response times on valid trials (402 ms and 336 ms respectively) than invalid trials (437 ms and 375 ms respectively).

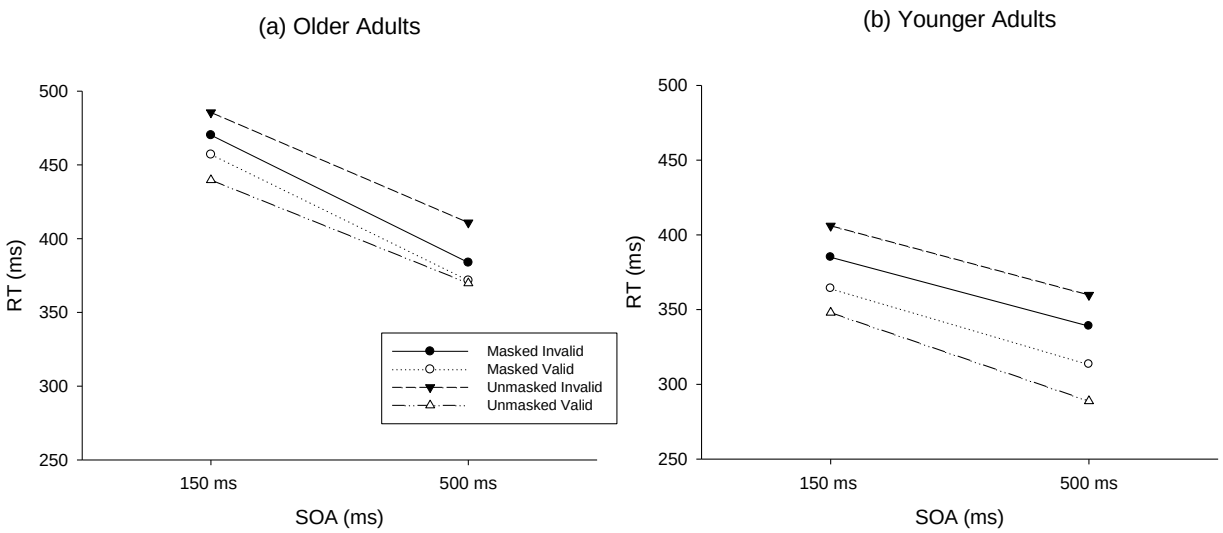


Figure 3: Results of the Attention Task for Experiment 1: Mean response times (RT) in ms as a function of stimulus onset asynchrony (SOA) for (a) older and (b) younger adults.

Perception Task

Figure 4 shows mean percentage correct in responding on the Perception Task for older and younger adults. An ANOVA was conducted on the mean accuracy levels using Age Group as the independent groups' factor, and Masking as the repeated measures factor. No significant effect of Age Group on accuracy levels was found; $F(1, 33) = 1.798$, p = n.s. The effect of Masking was found to be significant; $F(1, 33) = 46.26$, $p < .001$, which showed significantly higher mean accuracy levels on unmasked trials (98% correct)

compared to masked trials (81% correct). No interaction was found between Masking and Age Group, $F(1, 33) = 2.59$, p = n.s.

Paired samples t-tests were then conducted to more closely investigate differences in accuracy within each age-group. Mean accuracy levels were significantly higher for younger adults on unmasked trials (98%) compared to masked trials (85%); $t(17) = 5.45$, $p < .001$. This was also the case for older adults; $t(16) = 4.69$, $p < .001$, (unmasked accuracy = 98%, masked accuracy = 77%).

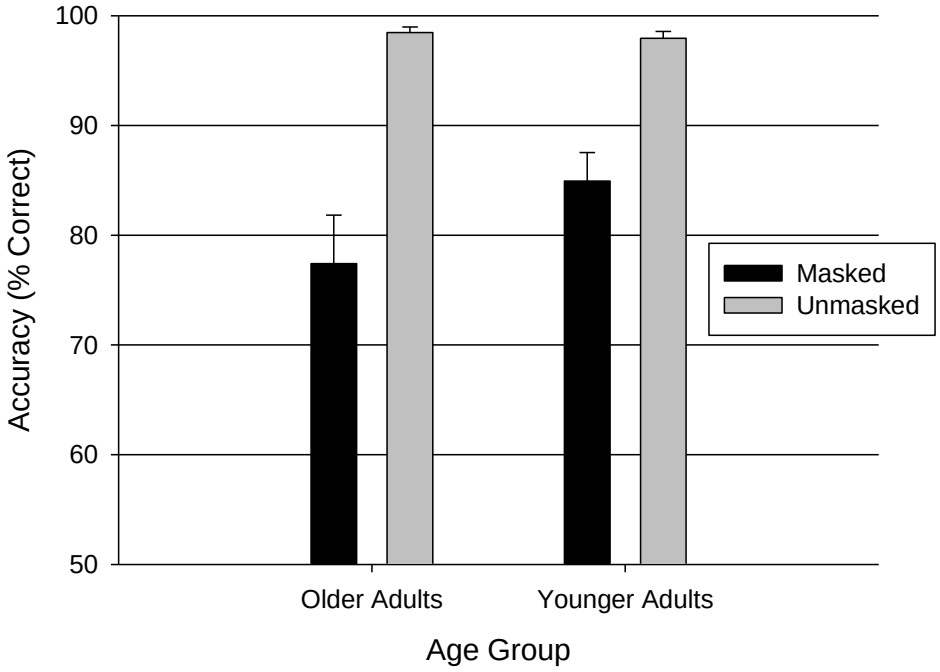


Figure 4: Accuracy results on the Perception Task for Experiment 1: Mean accuracy (% Correct) as a function of cue type (unmasked vs. masked) for older and younger adults.

An ANOVA was also conducted on mean response times (Figure 5) using Age Group as the independent groups factor, and Masking as a repeated measures factor. The main

effect of Age Group was significant; $F(1, 33) = 17.591$, $p < .001$, where the mean response time of younger adults (477 ms) was significantly faster than that of older adults (631 ms). A significant effect of Masking was found, $F(1, 33) = 90.1$, $p < .001$, which showed that mean response times were longer when stimuli was masked (625 ms) compared to unmasked (483 ms). A significant interaction was found between Masking and Age Group, $F(1, 33) = 6.8$, $p = .013$. Older adults showed a significantly greater increase in mean response time from masked to unmasked trials (mean difference = 181 ms) than younger adults (mean difference = 103 ms).

Paired t-tests were then conducted to further examine the effects of Masking on the response times for each age-group individually. Younger adults showed significantly slower mean response times for masked trials (528 ms) compared to unmasked trials (426 ms); $t(17) = 7.24$, $p < .001$. A similar effect was found for older adults; $t(16) = 6.74$, $p < .001$, (masked mean RT = 721 ms, unmasked mean RT = 541 ms).

Independent samples t-tests were conducted to look for overall differences in response times between older and younger adults. On masked trials the mean response time for older adults (721 ms) was significantly slower, $t(33) = 4.151$, $p < .001$, than for younger adults (528 ms). This was the similar for unmasked trials, $t(18) = 2.816$, $p = .011$, (older adults mean = 680 ms, younger adults mean = 483 ms).

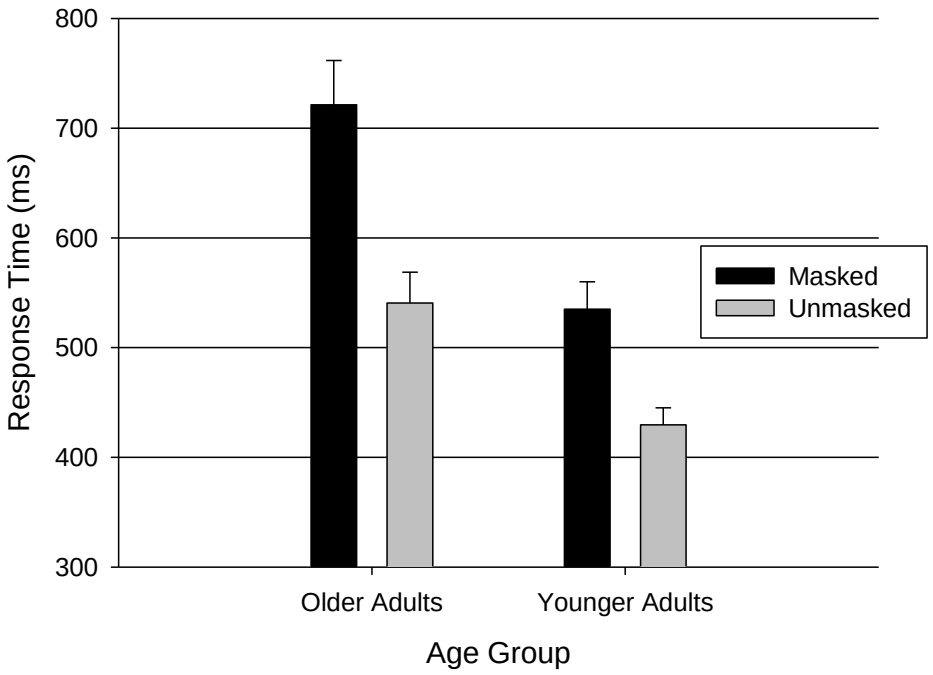


Figure 5: Response time results on the Perception Task for Experiment 1: Mean response times (ms) as a function of cue type (unmasked vs. masked) for older and younger adults.

Discussion

The results of Experiment 1 showed that older adults oriented successfully in the simple cue-encoding demand situation. Thus it would appear that the process of derived attention remains intact in normal older adults, providing support for my second hypothesis – that older adults were unable to orient in Lambert and Holmes (2004) due to the high cue-encoding demands of the task. The inability of older adults to orient in Lambert and Holmes (2004) might have been explained using the theory that older adults had a deficit in their ability to encode cues when four different letters could serve as valid or invalid cues. However, the group of older adults in Lambert and Holmes who showed no impairment on the complex Cue Discrimination Task (similar to my Perception Task),

were unable to perform the orienting task thus this explanation remains no longer plausible.

The masking manipulation showed that adding mask objects to the display impaired performance on the Perception Task, as expected. Masks also impaired participants' ability to orient in response to the cue letters: validity effects were significantly reduced in the masked condition compared to the unmasked condition. Furthermore, older and younger adults showed similar reductions in the magnitude of validity effects on trials where the cue letters were masked. This is an interesting observation in relation to the cue-encoding hypothesis that was outlined earlier. When the perceptual difficulty of encoding the cues was increased, visual orienting as indexed by the magnitude of the validity effect, decreased in a similar manner for older and younger adults. One possible explanation for this reduction in orienting with masking is that orienting during masked trials is occurring in a more implicit manner. Previous research (e.g. Lambert et al., 1999) has shown a decreased but nevertheless consistent effect of cue validity with unconsious orienting thus this explanation does appear plausible and is further explored in Chapter 4. As indicated earlier, the failure of older adults to orient in the study of Lambert and Holmes (2004) may have arisen either because of a deficit in cue-encoding – a problem in discriminating between the four valid and the four invalid letters; or because of a deficit in the ability to associate a complex set of cue letters with likely and unlikely target locations. My observation that increasing the perceptual difficulty of discriminating between cue letters via masking had similar effects on the performance of both age-groups may be taken as evidence in favour of the latter interpretation. Thus,

perceptual cue-encoding appears to remain intact with ageing. This is supported by the evidence that accuracy levels of the older adults' performance on the Perception Task remained unimpaired.

The central finding of Experiment 1, that derived attention in response to simple letter cues is intact in older adults, suggests that the failure of orienting observed by Lambert and Holmes (2004) may have been due to the complexity of the cue- encoding required for the Attention Task in that experiment, rather than due to a failure of derived attention *per se*. Experiment 1 did however include several features that could potentially confound the comparison between these results and those of Lambert and Holmes (2004). Firstly, the response requirement differed between the experiments. In the present experiment, choice response times were measured where a different key was used to signal a left or right response. In the previous study, simple response times were measured where all responses were made on the same key (the spacebar). Thus participants were not required to differentiate which side the target appeared on, only whether or not it was present. The present experiment also used black letters on a white background, whilst Lambert and Holmes used white letters on a black background. Finally, the inner edges of my target stimuli were further into the periphery (8°) as opposed to 5.2° from the central cross in the previous study. Whilst none of these differences undermine the conclusion that the process of derived attention is intact in older adults, they do weaken the assertion that cue-encoding is the critical factor driving the opposing findings of the present study and those of Lambert and Holmes (2004).

Older adults showed slower response times throughout both tasks in Experiment 1 (see Figures 3 & 5), consistent with prior research (e.g. Rabbitt & Vyas, 1980; Robinson & Kertzman, 1990).

Experiment 2

Although there is no *a priori* reason to believe that any of the differences between Experiment 1 and Lambert and Holmes (2004) would be responsible for the variation in results between the studies, it is possible that they could have influenced the performance of older adults on Experiment 1. Experiment 2 was carried out, to discover whether cue-encoding was indeed a critical factor affecting the success of orienting by older adults in the derived attention paradigm, or whether one of the other design features that differed between the experiments (such as response requirement) was the critical factor influencing orienting by older adults. Experiment 2 was identical to Experiment 1 in all respects, except for the cue-encoding demands. If cue-encoding is the critical factor then older adults should fail to orient appropriately in this complex situation.

Method

Participants

The younger adults comprised 10 participants (8 females) between the ages of 20 and 30 years (mean= 24.1, SD = 3.18) with a mean of 17.2 years of formal education (SD = 1.23). The older adults were 10 participants (7 females) aged 57-70 (mean= 64, SD = 4.50) with a mean of 16.8 years of formal education (SD = 1.62). None of the participants had participated in Experiment 1. Out of the older adults 4 worked full-time,

3 worked part-time and 3 were in voluntary part-time positions. Nine of the younger adults and 8 of the older adults were right-handed. Refer to Experiment 1 for additional details.

Apparatus

As described in Experiment 1.

Stimuli and Procedure

This was the same as in Experiment 1 with the following changes. The cue stimuli were four valid letters and four invalid letters chosen randomly from a pool of eight (W A X T N R D H) which varied for each participant and was consistent for the Attention and Perception tasks.

Results

Analysis

For the Attention Task the rate of anticipations was acceptably low at 1.3% for older adults and 1.2% for younger adults. This was also the case for the delayed responses which were 1.7% for older adults and 3.4% for younger adults. The rate of response errors were 0.86% for older adults and 2.8% for younger adults[3]. For the Perception Task, the rate of anticipations was 0.4% for the older adults and 0.1% for the younger adults, whilst the delayed responses were 0.78% for the older adults and 2.7% for the younger adults. An accuracy analysis for the Perception Task is provided below.

[3] Response errors were compared using an independent samples t-test and were found to be significantly higher for younger adults, $t(18) = 33.4$, $p < .001$.

Attention Task

A four-factor ANOVA was conducted on the mean response time for each participant in each condition separately for the older and younger adults, to see if there were any order effects related to whether a participant had performed the Perception or Attention Task first. The between-groups factor was Order (Perception First vs. Attention First) and the repeated measures factors were SOA (150 ms vs. 500 ms), Cue Validity (Valid vs. Invalid) and Masking (Masked vs. Unmasked). As no significant effects or interactions involving the factor Order were found for either the younger or older adults, this factor was dropped from subsequent analyses.

A four-factor ANOVA was then conducted on the mean response times for each participant in each condition (see Figure 6a and 6b). As in Experiment 1 the independent groups' factor was Age Group, and the repeated measures factors were SOA, Cue Validity and Masking. There was a significant effect of Age Group; $F(1, 18) = 11.248$, $p < .001$, where the mean response times of younger adults (350 ms) were significantly faster than those of older adults (402 ms). The main effect of Masking was significant, $F(1, 18) = 7.477$, $p = .014$ which showed that mean response times to the target were faster when the cue stimuli were masked (369 ms) compared to when they were unmasked (383 ms). The main effect of SOA was significant, $F(1, 18) = 68.7$, $p < .001$, which showed faster mean response times at the longer SOA (352 ms) than at the shorter (400 ms). The main effect of Cue Validity was also significant, $F(1, 18) = 10.135$, $p = .005$, showing faster mean response times on valid trials (369 ms) compared to invalid trials (382 ms).

There was a significant interaction between Cue Validity and Age Group, $F(1, 18) = 16.583$, $p = .001$, which showed that whilst younger adults had faster mean response times on valid trials (332 ms) compared to invalid trials (361 ms); $t(9) = 21.14$, $p = .001$, older adults showed no difference in mean response times between valid (406 ms) and invalid trials (403 ms); $t(9) = .523$, p = n.s. The significant interaction between Masking and Cue Validity; $F(1, 18) = 9.82$, $p = .006$, was qualified by a three-way interaction with Age Group; $F(1, 18) = 5.578$, $p = .03$. This showed that on unmasked trials younger adults had faster mean response times when trials were valid; $t(9) = 29.4$, $p < .001$, whilst older adults showed no difference; $t(9) = .10$, p = n.s. For masked trials however, neither age-group showed any effect of cue validity (Younger adults $t(9) = .178$, p = n.s., Older adults $t(9) = 1.6$, p = n.s.).

Proportional cueing scores were calculated for each participant, using the procedure employed by Curran et al., (2001). The rationale for this analysis derives from the finding that older adults are known to respond more slowly than younger adults, when performing perceptual-cognitive tasks of the kind investigated here. Proportional cueing scores may provide a more appropriate metric for comparing the validity effects displayed by older and younger adults, by correcting for between-group differences in response time. This is achieved by expressing the difference between valid and invalid trials not as an absolute temporal value (Invalid RT – Valid RT), but as a proportion of the mean response time obtained by each participant. Thus, proportional cueing scores were calculated as:

$$Proportional\ Cueing\ Score = \frac{RT_{invalid} - RT_{valid}}{(RT_{invalid} * p_{invalid} + RT_{valid} * p_{valid})}$$

Proportional cueing scores were then entered into a three-factor ANOVA with Age Group as an independent groups factor and Masking and SOA as repeated measures factors. This analysis revealed a pattern that paralleled results of the mean response time analysis. Thus, proportional cueing scores were higher on unmasked trials (.153) compared to masked trials (.049); $F(1, 18) = 18.32$, $p < .001$. Proportional cueing scores did not vary reliably as a function of any other factor.

Performance was examined separately in the masked condition, where cue-encoding demands were high. When the masked condition was examined separately, the proportional cueing scores of older adults (.030) did not differ reliably from those of younger adults (.068), $F(1, 18) = 2.22$, n.s.

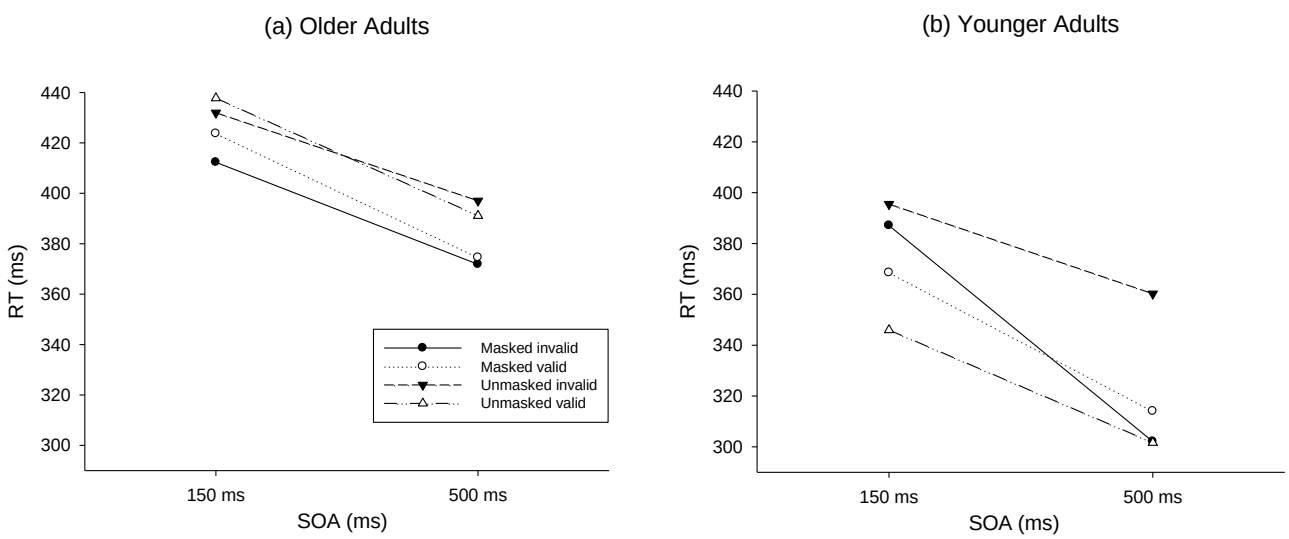


Figure 6: Results of the Attention Task for Experiment 2: Mean response times (RT) in ms as a function of stimulus onset asynchrony (SOA) for (a) older and (b) younger adults.

Perception Task

An ANOVA was conducted on mean accuracy levels using Age Group as the independent groups' factor, and Masking as a repeated-measures factor (see Figure 7). A significant effect of Masking was found, $F(1, 18) = 132.42$, $p < .001$, which showed significantly higher mean accuracy levels for unmasked trials (95% correct) compared to masked trials (58% correct)[4]. No interaction existed between Masking and Age Group, $F(1, 18) = .074$, p = n.s. There were no significant differences in mean perceptual accuracy found between older (59% vs. 95%) and younger (57% vs. 95%) adults on masked or unmasked conditions.

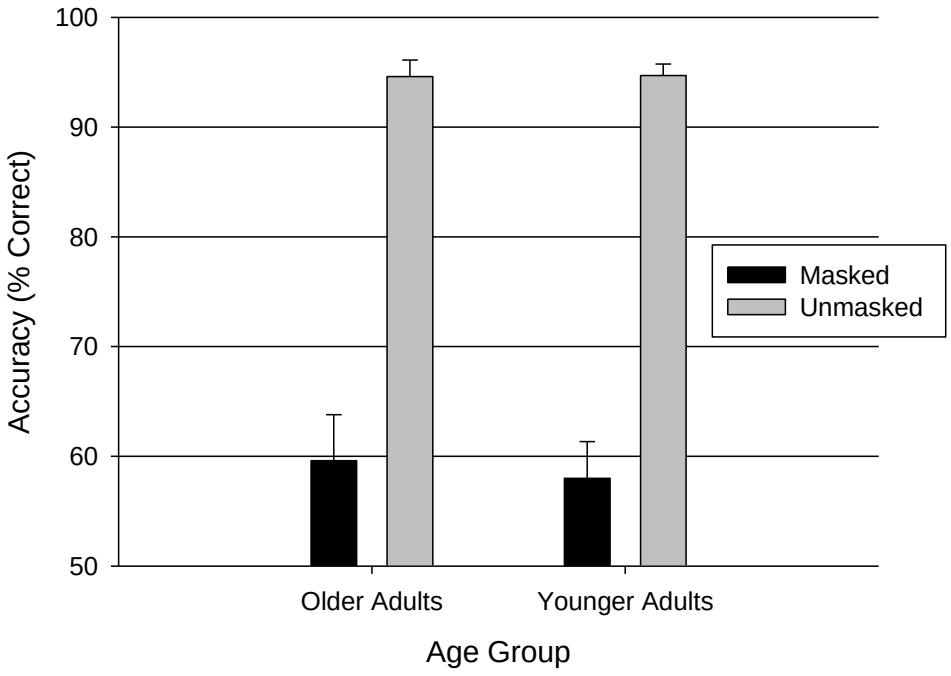


Figure 7: Accuracy results on the Perception Task for Experiment 2: Mean accuracy (% Correct) as a function of cue type (masked versus unmasked) for older and younger adults.

[4] Both age-groups were found to be performing significantly above chance on the masked trials. Older adults: $t(9) = 2.0$, $p = .049$, younger adults: $t(9) = 2.39$, $p = .028$.

An ANOVA was also conducted on mean response times (see Figure 8) using Age Group as the independent groups' factor, and Masking as a repeated measures factor. A significant effect of Masking was found, $F(1, 18) = 15.82$, $p = .001$, which showed that mean response times were longer when stimuli were masked (715 ms) compared to unmasked (581 ms). The main effect of Age Group was also significant, $F(1, 18) = 9.204$, $p = .007$, indicating slower mean response times for older adults (781 ms) compared to younger adults (516 ms). There were no significant interactions.

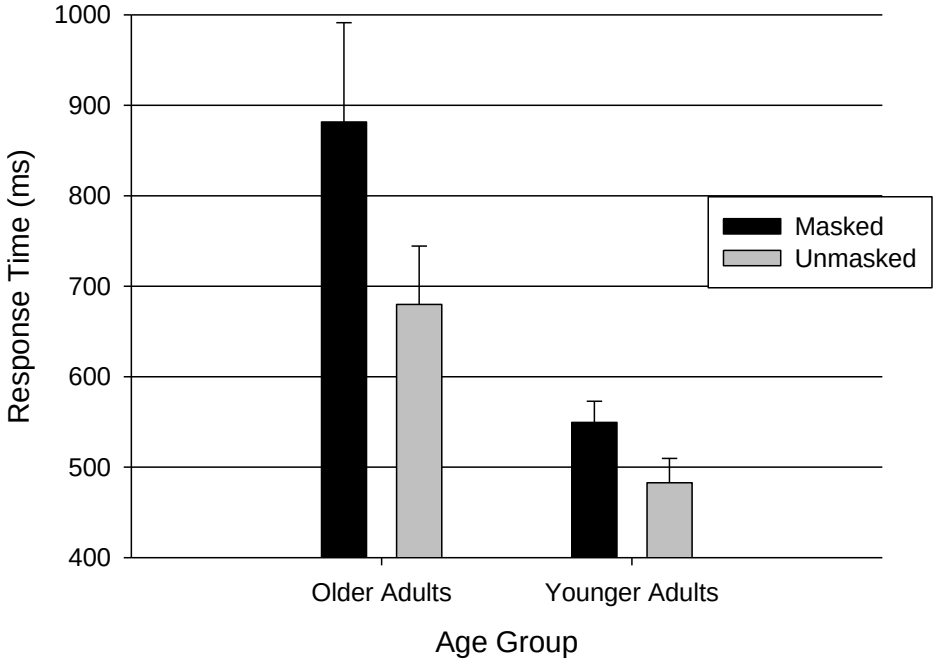


Figure 8: Response time results on the Perception Task for Experiment 2: Mean response times (ms) as a function of cue type (unmasked vs. masked) for older and younger adults.

Discussion

The results from Experiment 2 indicate that derived attention is intact in a complex cueing situation for younger adults, but that this is not the case for older adults. Ageing

had very little effect on visual perception: accuracy levels were similar for both age-groups on the Perception Task, in both masked and unmasked conditions. Response times on the Perception Task were consistently and significantly slower for older than younger adults as found repeatedly in previous ageing research (e.g. Cerella, 1985b; Salthouse, 1988a). This does not indicate further impairment in the ability to perform the task, other than speed of responding.

Added to the results of Experiment 1 this failure of older adults to orient successfully in the complex situation suggests that complexity of cue-encoding could be the critical factor affecting the success of orienting by older adults in a derived attention paradigm, and rules out the failure being attributed to other methodological factors such as experimental design features. Experiment 2 indicates that whilst visual attention appears to decline with ageing when the complexity of the cueing environment increases, visual perception remains intact. This empirical dissociation is consistent with Goodale and Milner's (1992) theoretical proposal concerning separate systems of perception and action, where visual attentional processing is carried out in the dorsal stream, whilst perceptual processing occurs in the ventral stream. Lambert and Shin (2010) demonstrated that cue-encoding was a dorsal process and showed that the dorsal pathway was linked with rapid attentional shifts. Thus ageing appears to affect dorsal-stream processing but have little influence over processing in the ventral stream. These results confirm those of Lambert and Holmes (2004) and show that they hold when a choice response is required as well as with the simple response method which was originally used.

General Discussion

The results of these two experiments demonstrate that whilst derived attention is intact in older adults, this is only the case in an environment with simple attentional cues. Visual perceptual accuracy however, appears to remain largely unaffected by ageing regardless of the complexity of the task. A number of previous studies have shown that exogenous orienting in response to peripheral cues remains relatively intact with ageing (Folk & Hoyer, 1992, Experiment 1; Hartley et al., 1990, Experiment 3; Nissen & Corkin, 1985). This is consistent with my results from Experiment 1 where 'exogenous' design features of the experiment included the peripheral location of the cue stimuli, and the rapid orienting of attention (see Lambert, Roser, Wells & Heffer, 2006; Lambert & Shin, 2010; Lambert & Duddy, 2002). Results showed that both younger and older adults oriented their attention appropriately using simple letter cues. A strong validity effect was present with longer response times for invalid cues. Thus there was no apparent effect of ageing on the ability to orient successfully (see Figure 3).

The results from the Experiment 2 Attention Task suggested that older adults showed a greater 'warning signal' effect in the masked condition than younger adults, as the masks provided a magnified warning of the target which improved their response times. As explained by Fernandez-Duque and Posner (1997) alerting is when a warning signal induces a change in internal state. A warning signal indicates the likelihood of the targets appearance, usually in the absence of information about its location (Posner, 1978; Posner & Raichle, 1994). Older adults appeared to be relying more heavily on the cue to prepare for the target. This would explain why older adults had a greater decrease in

response times at the longer SOA than younger adults, as more warning of the target appearance was available at the longer SOA.

In Experiment 2 there was dissociation between performance on the Attention Task (impaired in older adults) and performance on the Perception Task (preserved in older adults). One interpretation of these findings is to propose that normal ageing is accompanied by a relatively greater deficit in dorsal stream processing, relative to ventral stream processing. However, attentional orienting in the derived attention paradigm makes use of top-down (endogenous) components, in the sense that participants make a conscious decision to orient after perceptual encoding of the cue letter(s). In addition, the task appears to involve a relatively automatic (exogenous) orienting component. This can be inferred from the speed of orienting and perhaps also from the peripheral location of the cues. Even at the short SOA (150 ms) my results showed significant differences in the speed of responding between valid and invalid trials. These considerations suggest an alternative interpretation where the source of older adults' problems reflects an inability to set up linkages between dorsal and ventral processing in a situation of increased complexity where more stimuli are involved (and thus more linkages) as proposed by Lambert and Holmes (2004). Experiment 1 showed that both processes appeared to be intact, as older adults were able to perform both the Attention and Perception tasks successfully. Thus a pure attentional deficit explanation would appear unlikely. In Chapter 5 neuroimaging techniques are used to explore these hypotheses directly.

A further interpretation, which is not necessarily inconsistent with my hypothesis of a deficit in the ability to link dorsal and ventral processing can also be entertained. The results of Experiment 1 indicated that the process of derived attention was intact in normal older adults. In addition, their performance on the complex Perception Task in Experiment 2 indicated that they were not deficient in memorising (explicitly) a set of letter cues, and could discriminate between these letters at the exposure times and eccentricities used. In Experiment 2 older adults showed dissociation between intact perceptual discrimination of cue letters and a failure to use them as cues. A further interpretation of the reason why older adults were unable to perform the complex visual orienting task is that the problem may be akin to a dual-task deficit. That is, they are deficient in combining complex cue-discrimination with orienting. Although they are proficient at each part of the task individually, when the tasks are combined into one complex attentional orienting task, they are unable to perform adequately.

Several studies have looked at dual-task deficits and how these are influenced by ageing (e.g. Owsley & McGwin, 2004; McDowd & Shaw, 2000; Crossley & Hiscock, 1992) and have found that older adults do experience difficulties in dividing their attention. Dual-tasking is a term used to describe the degradation of performance of one or both tasks when two tasks are performed simultaneously. Verhaeghen, Steitz, Sliwinski and Cerella (2003) conducted a meta-analysis on a group of studies that examined the relationship between ageing and dual-task effects; 33 using latency as the dependent measure and 30 using accuracy. Whilst both younger and older adults suffered from the effects of dual-

task performance the effects of ageing on performance were related to response time rather than accuracy.

Dual-task interference however, is typically interpreted in terms of shared attentional resources in situations where two motor tasks are performed simultaneously (Verhaeghen & Cerella, 2002). Thus, my Attention Task does not specifically call upon dual-tasking in the traditional sense as holding a load in memory is not a motor task. For example, a typical dual-task experiment might involve reciting a stream of numbers, whilst attempting to respond to a certain character when it appears on the screen (Verhaeghen & Cerella, 2002). The results of Experiment 2 could, however, be explained in terms of older adults' inability to perform the Attention Task whilst simultaneously holding a memory load in their short-term memory, which would require the performance of multiple tasks at the same time.

Consistent with this explanation, it is possible that the older adults in Experiment 2 were actively choosing to ignore the cues as they were experiencing difficulty in orienting their attention whilst simultaneously performing complex discrimination. The significant decrease in response errors by the older adults when compared to the younger adults supports this. However, as found by Lambert and Roser (2001) using a similar paradigm, exogenous[5] orienting of attention appeared to be an implicit process, which occurred independently of explicit awareness (this idea is explored further in Chapter 4). Lambert and Roser's results suggested that at least for younger adults it may not be necessary to

[5] Previous studies using this paradigm have used the terms 'exogenous' and 'automatic' to describe the rapid speed with which orienting has been found to occur (e.g. at SOAs of zero - Lambert & Duddy, 2002).

pay full attention to the cues in order to orient successfully, as the cues appeared to function either automatically or semi-automatically. It would seem that if the cueing process functioned independently of conscious awareness as in the earlier study, older adults would still be able to orient their attention, even if their performance was significantly slower than younger adults.

As older adults tend to perform tasks more slowly than younger adults, one explanation for the results of many ageing studies is generalised slowing, where findings are suggested to be unrelated to impairments in psychological function (Salthouse, 1988a). For example, in the study of Curran et al. (2001) although older adults appeared to show stronger cue-validity effects than younger adults, this disappeared after adjusting for response times. In Experiment 2, it could be suggested that perhaps older adults were merely slower at discriminating and responding to valid letters than younger adults. However when the results from the long SOA condition (500 ms) were examined, where older adults had the most time available to respond, they still failed to use the cues to appropriately direct their attention and showed no improvement when they were given increased time. This is surprising as they had a full half-second to prepare for the target and yet they still failed to do so.

Arguably the most logical explanation for the present results is a categorical interpretation. In Experiment 2 due to the random nature of the four valid letter cues selected for each participant, it would have been impossible for the valid cues to be categorised into a group. Thus, four perceptually distinct and unrelated cues were

required to be mapped to the target asterisk (as opposed to just one in Experiment 1), increasing the level of difficulty. Previous research has shown how categorisation can influence perceptual and attentional set (e.g. Jonides & Gleitman, 1972). This explanation is explored in more detail in Chapter 3 with a categorisation-based experiment and an exploration of previous research in this area.

In summary, the results of Experiments 1 and 2 showed that older adults were able to orient their attention appropriately in response to simple bilateral letter cues which held predictive information about the likely location of the target asterisk, but were unable to do this in response to a complex set of letter cues. The deficit appeared to be unrelated to the ability to discriminate perceptually between the cue stimuli or to memorise the valid and invalid letter cues, as both the simple and complex Perception tasks were performed accurately by older adults. It appeared unlikely that the failure of the older adults to orient their attention in Experiment 2 could be attributed to slow cue-encoding, as they were unable to orient even on trials with a longer SOA - when the delay between the cue and the target was increased. A dual-task explanation also appeared unlikely as the tasks being examined were not two simultaneous motor tasks, and the automatic nature of orienting under this paradigm would have made an active attempt to ignore the cues difficult. The most likely explanation for the failure of orienting by older adults was an inability to categorise letter cues in the Attention Task due to their random nature which made grouping difficult. This meant that they were unable to use the letter categories to aid orienting in the complex cueing situation.

Chapter 3: Categorisation and Complex Cueing

Introduction

The results from Experiment 2 revealed an ageing effect of attentional orienting using a complex set of eight letter cues. Whilst younger adults had no difficulty orienting their attention in response to the bilateral letter cues, older adults were unable to do this successfully. However, both age-groups were able to perform complex cue-discrimination (the Perception Task) with a high level of accuracy. These findings were consistent with Lambert and Holmes (2004) who used similar tasks to those used in Experiment 2 and found the same ageing effect with a simple one-key response method in contrast to the choice response method used throughout this thesis. These results prompted the generation of the hypothesis that the use of categorisation may help to overcome the difficulty that older participants had with orienting using complex cues. It is possible that in the Attention Task in Experiment 2 older adults were simply ignoring the cues as they were unable to successfully orient their attention using such a large and random cue set.

Previous research has shown how categorisation can influence perceptual and attentional set. Jonides & Gleitman (1972) showed that search times were longer and more dependent on set size when targets and distractors were from the same category compared to when they were from different categories. Subjects were required to visually search for an *'O'* in displays of either letters or numbers, which varied in set size and were

instructed to perceive it as either a ‘zero’ or the letter ‘oh’. Serial search functions were found when subjects perceived the target and distractors as belonging to the same category, whilst search functions were flat when they were perceived as being from different categories. Research by Taylor & Hamm (1997) examined category effects on temporal visual search using rapid serial visual presentation (RSVP). The target was embedded in a stream of randomly drawn letters. As in Jonides and Gleitman’s (1972) study, the target was a letter and for some subjects the probe was an ‘oh’ whilst for others it was a ‘zero’. Those subjects with ‘zero’ as the probe, showed a greater deficit in probe detection, which demonstrated the positive influence of categorisation on responding.

Taylor (1978) looked specifically at the processes of identification and categorisation and whether (for example when we are presented with the visual object ‘T’) these processes occur simultaneously or sequentially. Experiments 1 and 2 (which used a matching ‘same-different’ procedure) showed that identity-based decisions are faster than category-based decisions. Experiment 2 also showed that when decisions can be based on either identity or category, response times are faster and less variable than when decisions are solely identity based. This is similar to the present experiment where each valid letter cue has its own individual letter identity e.g. ‘A’, as well as the categorical identity ‘vowel’ which is shared by all the valid letter cues.

The results of these studies demonstrate the increased level of difficulty that can result from being unable to categorise stimuli and the subsequent aid that categorisation can have on responding. If the older adults in Experiment 2 (who showed some form of

attention-related deficit) had been able to categorise the valid letters due to their being related, or similar in some way, perhaps they would have been able to successfully perform the task.

One form of selective attention that is often used in choice response time tasks is memory-driven selective attention. This is when performance can be improved if subjects are able to use stimulus-response relationships held in memory. Although findings have been varied in this area some studies have shown that both older and younger adults are able to use memory-driven selectivity. When target stimuli in a visual search task are organised in a highly familiar manner (e.g. A B C D E F) or can be classified according to category membership (e.g. letters and digits) performance of both age-groups is improved through use of the information (Madden, 1982; Thomas, Waugh & Fozard, 1978).

As explained by Thornton and Raz (2006) there are many connections shared between the brain regions associated with working memory and visuospatial attention. Thus in Experiment 2 when these two systems were simultaneously activated (in order to remember the valid letters accurately) it is likely that common processing resources were being shared. Both prefrontal and posterior parietal areas have been observed to be active during working memory tasks requiring letter retention (Bunge, Klingberg, Jacobsen & Gabrieli, 2000) and during centrally cued spatial orienting tasks (Coull & Nobre, 1998). As Thornton and Raz (2006) suggested, there are likely to be shared common cognitive resource requirements between working memory and visuospatial attention due to shared

common neuroanatomical associations. Thus, when these are activated simultaneously, interference could be observed. For older adults especially, who may have decreased working memory capacity, visuospatial attention could be degraded due to limited resources. If this is the case, the memory load of Experiment 2 could be reduced by changing the randomly chosen valid letters, into letters that are already stored in long-term memory as a category group[6]. This would reduce demand on the working memory system by enabling categorisation of the valid letter cues. I anticipate that participants will orient attention to the well-learned category group 'vowels' in Experiment 3, in a similar manner to how they oriented attention to the valid letter 'X' or 'T' in Experiment 1. That is, in contrast with Experiment 2 where participants were required to map four separate valid letter stimuli to the target asterisk, both Experiment 1 and 3 will involve more of a 'one-to-one' mapping process, of mapping either 'X or T' to the target in Experiment 1, and mapping 'vowels' to the target in Experiment 3.

Experiment 3

Experiment 3 was conducted in an attempt to provide some clarification as to why older adults were unable to orient their attention in response to a complex set of attentional cues in Experiment 2, whilst they performed the Perception Task successfully even though the latter task involved complex cue-discrimination using the same letter set. In Experiment 3, four vowels (A E I O) were used as the valid letters as there are so few vowels that they provide a more greatly over-learned category than consonants (there are 20 clear consonants). As the Perception Task had demonstrated that older adults'

[6] This idea was suggested by Jeff Hamm, University of Auckland.

memory for the complex letter set was intact, this new experiment was designed to further investigate the deficit found in Experiment 2. Specifically, I was interested in whether using a familiar category as valid cues (and thus allowing for categorisation) would enable older adults to overcome their deficit, and allow them to orient their attention using a perceptually diverse set of cues.

Method

Participants

The younger adults consisted of 14 participants (10 females) aged 21-32 years (mean = 24.4, SD = 3.0) with a mean of 17.2 years of formal education (SD = 0.89). The older adults consisted of 13 participants (10 females) aged 58-76 years (mean = 68.7, SD = 5.3) with a mean of 16.7 years of formal education (SD = 1.1). Two older adults were in full-time employment, 9 were in part-time employment and 2 worked part-time in voluntary positions. 13 of the younger adults and 12 of the older adults were right-handed. Further details are available in Experiment 1.

Apparatus

As described in Chapter 2.

Display and stimuli

The cue stimuli were four vowels (A E I O) and the four invalid letters were consonants (R V W X). Other details replicated those of Experiment 2.

Procedure

See Experiment 2 in Chapter 2.

Results

Analysis

In the Attention Task anticipations were 1.9% for younger adults and 2.4% for older adults. Delayed responses were .13% for the younger adults and 1.2% for the older adults. Response errors were 3.2% for the younger adults and 4% for the older adults. In the Perception Task, there were no anticipations for either age-group, and delayed responses were .22% for the younger adults and 2.6% for the older adults. An accuracy analysis for the Perception Task is provided below.

Attention Task

Figure 9, panels (a) and (b), shows response time results for the Attention Task, and Figure 10 panels (a) and (b) illustrates the mean differences in response times between invalid and valid trials. A four-factor analysis of variance (ANOVA) was conducted on the mean response times for each participant in each condition. The independent groups factor was Age Group (Older vs. Younger), and the repeated measures factors were SOA (150 ms vs. 500 ms), Cue Validity (Valid vs. Invalid) and Masking (Masked vs. Unmasked). The main effect of Age Group was significant, $F(1, 25) = 11.517$, $p = .002$, which showed that the mean response times of younger adults (368 ms) were significantly faster than those of older adults (501 ms). Masking was also significant, $F(1, 25) = 7.358$, $p = .012$, which showed that mean response times were faster on

masked trials (414 ms) compared to unmasked trials (456 ms). The main effect of SOA was significant, $F(1, 25) = 19.111$, $p < .001$, showing that mean response times were faster at the longer SOA (407 ms) compared to the shorter SOA (462 ms). The main effect of Cue Validity was also significant, $F(1, 25) = 16.001$, $p < .001$, which showed that mean response times were faster on valid trials (400 ms) than on invalid trials (469 ms). The interaction between Masking and Cue Validity was significant, $F(1, 25) = 7.616$, $p = .011$. This showed that on unmasked trials, there was a greater mean decrease in response times from invalid (512 ms) to valid (399 ms) trials, when compared to the mean decrease on masked trials (427 ms to 402 ms respectively).

Most importantly, the interaction between Cue Validity and Age Group was non-significant, $F(1, 25) = .122$, p = n.s., as was the three way interaction between Cue Validity, Age Group and SOA, $F(1, 25) = .978$, p = n.s. (see Figure 9).

The effects of ageing

The data were then analysed separately for the older and younger adults to further examine ageing effects. The rationale behind these analyses was to establish whether validity effects were reliable within each separate age-group. A four-factor ANOVA was conducted on the data for the older adults. The main effect of Masking was found to be significant; $F(1, 12) = 4.939$, $p = .046$, which showed that mean response times were faster on masked trials (470 ms) compared to unmasked trials (534 ms). The main effect of SOA was also significant; $F(1, 12) = 6.047$, $p = .030$ where mean response times were faster at the longer SOA (432 ms) than the shorter (471 ms). Finally the main effect of

Cue Validity was significant; $F(1, 12) = 5.502$, $p = .037$ where older adults showed faster mean response times on valid trials (439 ms) than on invalid trials (564 ms). The interaction between Masking and Cue Validity for the older adults did not approach significance; $F(1, 12) = 2.302$, p = n.s.

For the younger adults, the main effect of SOA was significant; $F(1, 13) = 39.084$, $p < .001$, where mean response times were faster at the longer SOA (344 ms) compared to the shorter (393 ms). Cue Validity was also found to be significant; $F(1, 13) = 17.632$, $p = .001$, which showed that mean response times were faster on valid trials (337 ms) when compared to invalid trials (400 ms). Finally the interaction between Masking and Cue Validity was significant; $F(1, 13) = 10.107$, $p = .007$, showing a greater mean decrease from valid (470 ms) to invalid (325 ms) trials in the unmasked condition, compared to in the masked condition (369 ms and 349 ms respectively)[7].

[7] Analysis of the masked and unmasked trials separately for each age-group revealed effects of cue validity on unmasked trials for both younger; ($F(1, 13) = 25.6$, $p < .001$) and older; ($F(1, 12) = 4.9$, $p = .042$) adults. No cue validity effects were seen for either group on masked trials (Young; ($F(1, 13) = 1.143$, p = n.s.), Old: ($F(1, 12) = 1.48$, p = n.s.)).

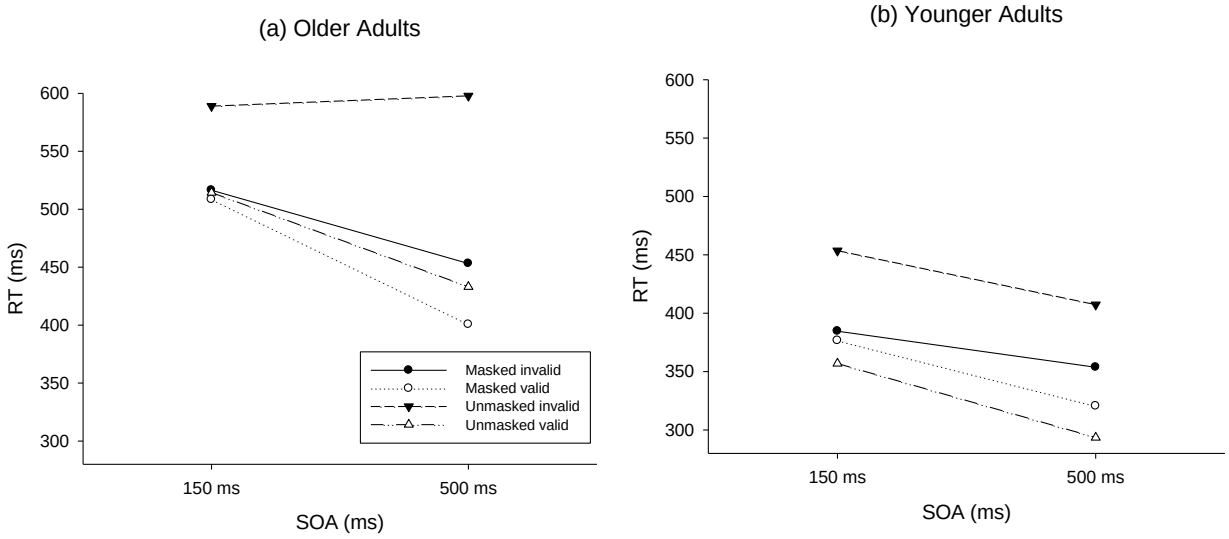


Figure 9: Results of the Attention Task for Experiment 3: Mean response times (RT) in ms as a function of stimulus onset asynchrony (SOA) for (a) older and (b) younger adults.

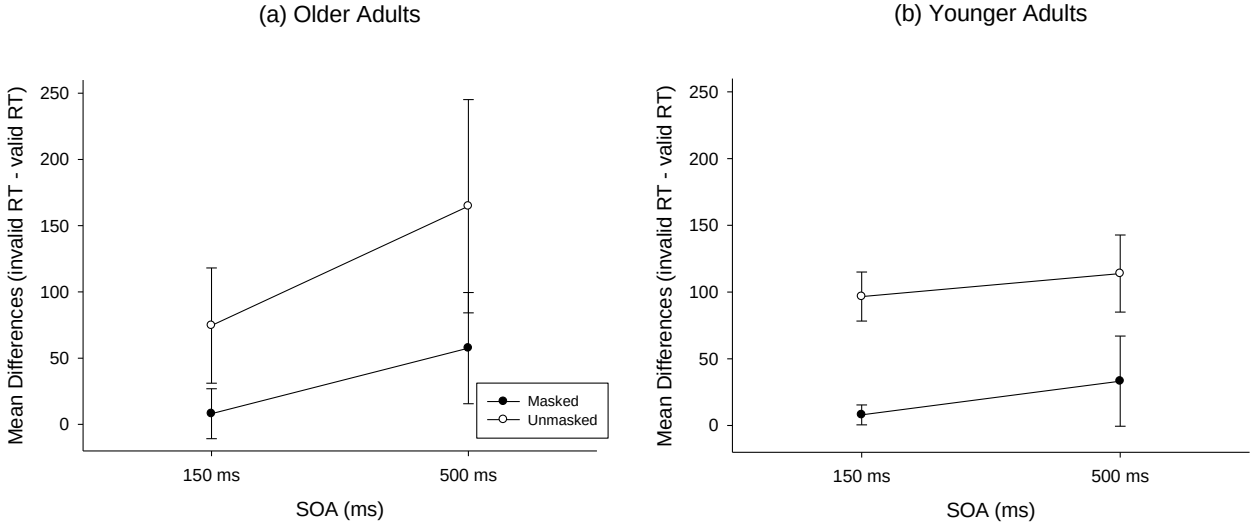


Figure 10: Results of the Attention Task for Experiment 3: Mean differences in response times (invalid – valid RT) in ms as a function of stimulus onset asynchrony (SOA) for (a) older and (b) younger adults (Nb. Error bars show standard errors of the means).

Perception Task

Figure 11 shows mean percentage correct in responding on the Perception Task for older and younger adults. An ANOVA was conducted on the mean accuracy levels using Age Group as the independent groups' factor, and Masking as the repeated measures factor. A significant effect of Masking was found, $F(1, 25) = 133.322$, $p < .001$, which showed significantly higher mean accuracy levels on unmasked trials (97% correct) compared to masked trials (62% correct). There was no effect of Age Group where mean accuracy levels were similar for older and younger adults.

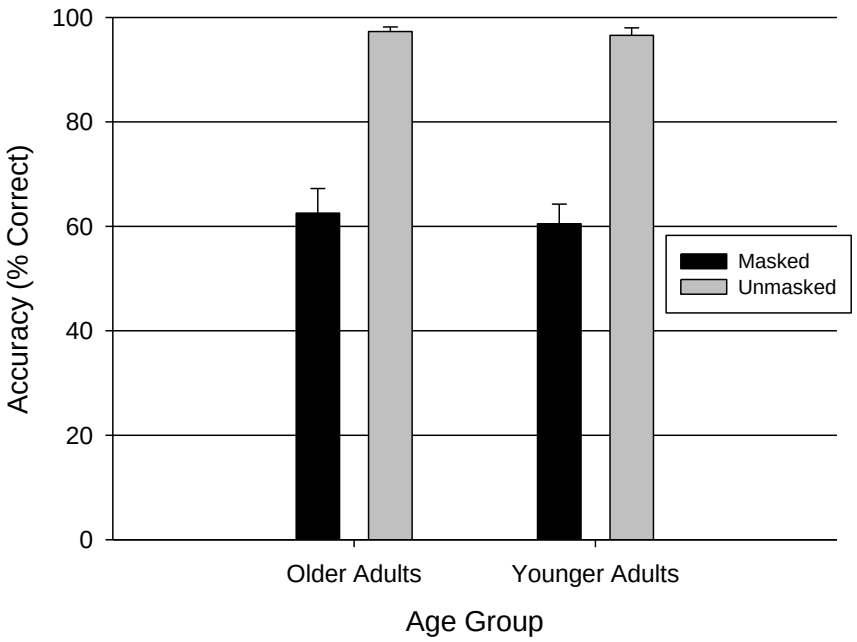


Figure 11: Accuracy results on the Perception Task for Experiment 3: Mean accuracy (% Correct) as a function of cue type (unmasked versus masked) for older and younger adults.

An ANOVA was also conducted on the mean response times (see Figure 12) using Age Group as the independent groups factor, and Masking as a repeated measures factor. The main effect of Age Group was significant, $F(1, 25) = 6.753$, $p = .015$, where the mean

response time for older adults (716 ms) was significantly slower than that for younger adults (468 ms). The main effect of masking was found to be non-significant, $F(1, 25) = 2.266$, p = n.s. (see Figure 12).

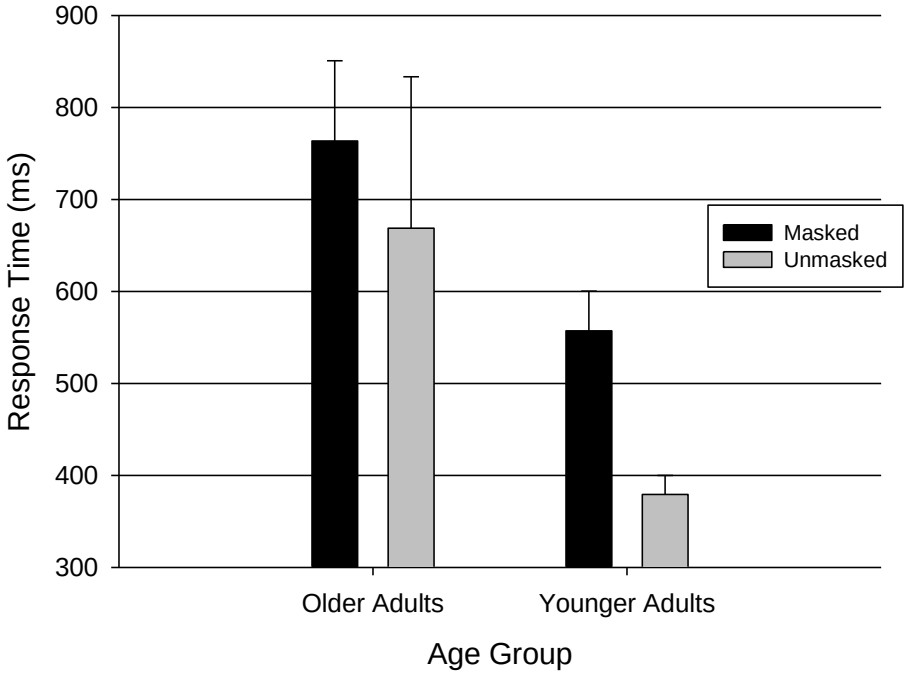


Figure 12: Response time results on the Perception Task for Experiment 3: Mean response times (ms) as a function of cue type (unmasked vs. masked) for older and younger adults.

Response time comparison - Experiment 3 with previous experiments

The response times were compared separately within each age-group to see if there were significant differences between the experiments for either the Attention or Perception tasks. The analysis for the Attention Task comparing Experiment 2 and 3 showed a significant main effect of Experiment for the older adults, $F(1, 21) = 4.686$, $p = .042$, which indicated that the mean response times for Experiment 2 (402 ms) were

significantly faster than those for Experiment 3 (501 ms). For younger adults however, there was no significant main effect of Experiment, $F(1, 22) = 1.279$, p = n.s., where mean response times were similar for both Experiment 2 (347 ms) and Experiment 3 (368 ms). This was further explored by comparing the response times on the Attention Task for Experiment 3 with those from Experiment 1. Again, a similar pattern emerged where the older adults showed significantly slower mean response times in the Experiment 3 (502 ms) when compared to Experiment 1 (424 ms); $F(1, 28) = 4.974$, $p = .034$. Younger adults also followed the same pattern as they had in the previous comparison, whereby they showed no significant difference in mean response times between Experiment 1 (351 ms) and Experiment 3 (368 ms); $F(1, 30) = .794$, p = n.s.

For the Perception Task however, neither age-group showed any effect of Experiment on response times. For the older adults; $F(1, 21) = .246$, p = n.s., the mean response time was 780 ms for Experiment 2 and 716 ms for Experiment 3. For the younger adults; $F(1, 22) = 1.430$, p = n.s., mean response times were 516 ms and 468 ms respectively. When comparing Experiment 1 and 3, again, no significant effects of Experiment were found on mean response times. For the older adults the mean response time was 631 ms for Experiment 1 and 640 ms for Experiment 3; $F(1, 28) = .020$, p = n.s., and for the younger adults these were 477 ms and 468 ms respectively; $F(1, 30) = .799$, p = n.s.

Discussion

The results from Experiment 3 indicate that older adults were able to orient their attention appropriately in response to a complex set of attentional cues. By changing the valid

letters to vowels, the stimulus-cue mappings that were required resembled more of a 'one-to-one' mapping as in Experiment 1. Thus the vowel category of valid letters became more like one stimulus, even though the identities of the four valid letters were completely distinct (A E I O). Results have shown that older adults can benefit from the cues in the Attention Task if the processing demands are made simpler, either by reducing the number of cues or by arranging them in categories.

When a highly familiar category of stimuli (vowels) is used as the valid cues, older adults' are able to use them to orient their attention. Responding in this experiment could be based on either letter identity (e.g. the letter 'A') or letter category (e.g. 'vowels'). These results are consistent with other studies which have shown that categorisation can influence perceptual and attentional sets (e.g. Jonides & Gleitman, 1972; Taylor & Hamm, 1997). Madden (1982) and Thomas et al. (1978) showed that classification of target stimuli according to category membership improves the visual search performance of both older and younger adults. In Experiment 3, the categorisation of cue stimuli into vowels has improved the performance of the older adults in that they are able to orient their attention in response to a perceptually diverse set of cue stimuli. In contrast when a random and unrelated cue set of the same size was used in Experiment 2, which required four valid letters to be mapped onto the target stimulus, older adults were unable to use the cues to orient their attention.

In contrast to Experiment 2, the cues used in Experiment 3 allowed participants to 'chunk' the four letters into one piece of information. This made the task more similar to

Experiment 1 (with one valid and one invalid letter) and results reflected this. Allen and Coyne (1989) found that when asked to organise letter sequences in memory, both older and younger adults chunked four-letter sequences into two sets of two letters and that letter organisation was similar for both age-groups. However, in a study by Flowers and Darley (1978) which looked at effects of ageing on immediate recall, a decline in chunking efficiency was found with ageing, although this decline primarily affected the immediate recall of eight-item word strings rather than six-item strings. In my Experiment 2 however, older adults were able to recall the valid letters with a high level of accuracy in the Perception Task when they were unmasked and even on masked trials they showed accuracy levels that were similar to the younger adults. It would appear therefore that memory in itself was not impaired (this is discussed in more detail in Chapter 6).

Relationship to previous experiments

Finally, can the results of this experiment help to explain those of Experiment 1 and 2? Interestingly, when the results of the Attention Task for this experiment are compared to those of the previous experiments, the response times of older adults (but not younger adults) in this experiment are significantly slower than those in Experiment 1 and 2. This was not the case for Perception Task, where both age-groups showed a consistency of response times for the three experiments. The mean age of all the older adult groups was similar (Experiment 1 mean = 65 years, Experiment 2 mean = 64 years, Experiment 3 mean = 68 years).

Although the instructions for all attention experiments were identical, for some unknown reason the older adults in Experiment 3 seemed to use a slower and more deliberate method of responding in order to ensure accurate orienting of attention. It would appear that the perceived difference in difficulty between Experiment 2 and 3 influenced whether or not older adults chose to utilise the cues. In Experiment 3 the decreased level of difficulty meant that the Attention Task possessed elements of both Experiment 1 and 2. As in Experiment 1, the use of the cues required a one-to-one stimulus mapping whereby the category 'vowels' was required to be mapped to the likely location of the target (as opposed to Experiment 2 where it was necessary to map four perceptually distinct and unrelated valid letters to the likely location of the target). However, as in Experiment 2, successful use of the cues in Experiment 3 required four perceptually distinct valid stimuli to be mapped to the likely location of the target. Results of Experiment 3 showed a clear effect of orienting for the older adults (as was seen in Experiment 1) however this is accompanied with an attentional impairment when compared to younger adults, which took the form of an increase in response times with orienting.

In summary, both younger and older adults have shown that they are able to use the cues to perform the complex Attention Task. That is, they have discriminated between the valid and invalid letter on each trial whilst orienting their attention and responding simultaneously to the valid letter. Whilst the younger adults appeared able to memorise a complete set of random letter cues and use them to orient in Experiment 2, it appeared that the inability of the older adults' to do so in the same experiment, may have been

related to their inability to map four completely distinct valid cues to the likely location of the target. The categorisation information available in Experiment 3 enabled them to overcome this. It remains unknown as to whether encouraging older adults to respond more slowly may enable them to successfully perform Experiment 2, however, this instructional change would be a major diversion from the original 'Posner's paradigm'. It is still unclear as to why older adults chose this slower strategy in Experiment 3 and how greatly this influenced their ability to orient. Perhaps older adults were unable to successfully perform when the level of difficulty was increased due to a reduction in general purpose processing resources with ageing (Crossley & Hiscock, 1992).

Chapter 4: Attentional Orienting – Explicit or Implicit?

Introduction

Implicit learning describes learning that occurs without intention or conscious awareness and is an important component in our adaption to changes in the environment throughout our life (Reber, 1976). Whilst some of the learning that we retain is explicit, a large proportion of it is implicit, as it would be neither necessary nor helpful to retain everything in our conscious awareness. It makes sense for implicit processes to be studied more extensively in relation to peripheral cueing due to the often automatic nature of the orienting of attention in response to peripheral cues (Lambert & Shin, 2010). It is somewhat surprising that there have been so few studies conducted into the effects of ageing on implicit learning and that no previous research has used a cueing paradigm to look for implicit attentional orienting in older adults.

Visual search paradigms have been more widely used than cueing paradigms to study implicit learning effects, although very little research has been done into the effects of ageing on implicit learning. As explained by Jiang and Chun (2001) who have conducted many of these implicit learning experiments using visual search with younger adults, there is a bi-directional interaction between attention and implicit learning. Whilst implicit learning of visual context guides attention towards targets, attention can influence the extent of implicit learning that occurs. One series of experiments by Jiang

and Chun (2001) examined how contextual knowledge can be acquired through implicit learning, where implicit learning of context can guide attention towards target information. The effects of selective attention on implicit learning were examined using the 'contextual cueing' paradigm. Visual search was performed and items were presented in red (attended colour) and green (ignored colour). Experiments 1, 3 and 4 showed that when the spatial configuration of items in the attended colour was consistently paired with the target location, visual search was facilitated. However, when the 'ignored item' configuration was paired with the target (Experiments 2 and 4) no contextual cueing occurred. It appeared that implicit learning only occurred when relevant predictive information about the target was attended to.

Experiment 4 in the present chapter continues to use the bilateral letter version of Posner's cueing paradigm (Posner, 1980), to examine the contribution of explicit and implicit processes to the orienting of attention. As in the experiments in previous chapters, letters replace the typical arrows as pre-cues. As in Lambert et al. (1999; Experiment 1) however, participants are not told which letters are valid and which are invalid, they are merely told to try and use the letters to prepare for a target on the left or right, and to respond to the target asterisk as quickly as possible. This experimental paradigm has not previously been used to study how ageing effects implicit learning. In this experiment, as in Experiment 1 the valid letter is associated with the asterisk on 80% of trials, and the effects of masking and ageing are examined.

Experiment 4

It is widely known that the difference in performance between valid and invalid trials in the covert orienting paradigm (validity effect) increases as the proportion of valid trials increases. This 'proportion valid' effect was examined in a series of experiments by Bartolomeo et al. (2007) using a categorical measure of post-experiment self-reported awareness. Bartolomeo and colleagues looked at the contributions of implicit and explicit processes to orienting in a series of experiments differing in the proportion of valid versus invalid trials, and whether cues were central or peripheral. A post-experiment questionnaire similar to that of Lambert et al. (1999; Experiment 1) was administered to probe explicit awareness of the cue-target relationship. Results suggested that with peripheral cues, implicit learning provided a good explanation for proportion valid effects and that learning occurred independently of explicit awareness.

The effect of masking stimuli has been studied very little in relation to ageing and no previous research has looked at this in relation to implicit visual orienting. He, Cavanagh and Intriligator (1996) performed a visual masking study looking for evidence of implicit processing in younger adults. They presented a single item in the visual periphery and found that participants were aware of the orientation of the item, yet when the item was surrounded by similar items (crowding) they were unable to report its orientation. When subjects were however tested on this, both the flanked target and the single target were equally effective in eliciting orientation-specific adaptation. This indicated that some form of learning had occurred without explicit awareness when the peripheral item was crowded.

Lambert et al. (1999; Experiment 1) examined how covert visual attention was affected by peripheral cue stimuli, using a bilateral version of the cueing paradigm. Right and left peripheral cue letters predicted target location, and participants were not informed of this association. Letter cues were found to influence visual orienting of attention in the absence of explicit awareness of the relationship between the cue and the target.

In the present experiment a task similar to that of Lambert and colleagues was used, to examine the effects of ageing and additionally of masking on the visual orienting of attention and the contribution of implicit and explicit processes to this orienting. In Experiment 1 whilst orienting effects were still present on masked trials, masks were found to reduce these effects for both older and younger adults. Experiment 4 examined whether the reduced cueing effect that occurred on masked trials could be explained by implicit or unconscious processes of orienting that might be operating. Four identical blocks of 80 trials were used with 80% of the trials in each block being valid and 20% invalid. As each participant was only required to perform one task, the likelihood of fatigue was reduced. Thus, in order to increase the number of invalid trials, two additional blocks were added to this experiment. The task was followed up by a categorical post-experiment questionnaire similar to that used by both Lambert et al. (1999) and Bartolomeo et al. (2007).

Method

Participants

The younger adults consisted of 15 participants (12 females) aged 20-31 years (mean age = 22.4 years, SD = 2.90 years). The older adults consisted of 14 participants (9 females) aged 59-81 years (mean age = 67.4 years, SD = 6.89 years). Two older adults were in full-time employment, 5 were in part-time employment and the remaining 7 worked part-time in voluntary positions. 14 younger adults and 13 older adults were right-handed. Further details are available in Experiment 1.

Apparatus

As described in Chapter 2.

Display and Stimuli

As in Experiment 1 the cue stimulus was either an 'X' or a 'T' and four 'S' masks surrounded the 'X' and 'T' on half of the trials. See Chapter 2 for additional details.

Procedure

Half of the participants received a version where the 'X' was the valid letter and 'T' was the invalid letter, whilst the other half received the reverse. As in Lambert et al. (1999; Experiment 1) participants were told to try and use the letters to prepare for a target appearing on the left or the right, and to keep their eyes fixated on the central cross, but they were not informed of the actual cue-target relationship. Participants were also informed that on random trials mask 'S' stimuli would appear around the cue letters and

that they should respond in the same manner as when these were not present. After the experiment was completed, participants answered a questionnaire that probed their awareness of the relationship between the cues and the target. See Appendix A for the post-experiment questionnaire used in this experiment.

Results

Analysis

Anticipations were .35% for the younger adults and .63% for the older adults. Delayed responses were .25% for the younger adults and 1.5% for the older adults. Response errors were .87% for the younger adults and 1.72% for the older adults.

Mean response times were calculated for each participant in each condition (see Figure 13a and 13b). The data were entered into a repeated measures four-factor ANOVA. The independent groups factor was Age Group (Older vs. Younger), and the repeated measures factors were Masking (Masked vs. Unmasked), SOA (150 ms vs. 500 ms) and Cue Validity (Valid vs. Invalid). A three-way interaction was found between Masking, SOA and Age Group, $F(1, 27) = 12.37$, $p = .002$. This showed that in masked conditions, younger adults had a significantly smaller decrease in mean response times from the short to the long SOA (26 ms), compared to the older adults (43 ms). However, on unmasked trials, both groups showed a similar decrease in mean response time at the longer SOA (older = 43 ms, younger = 45 ms). The main effect of Cue Validity was found to be non-significant, $F(1, 27) = 3.265$, p = n.s. and there were no significant interactions which involved the factor Cue Validity.

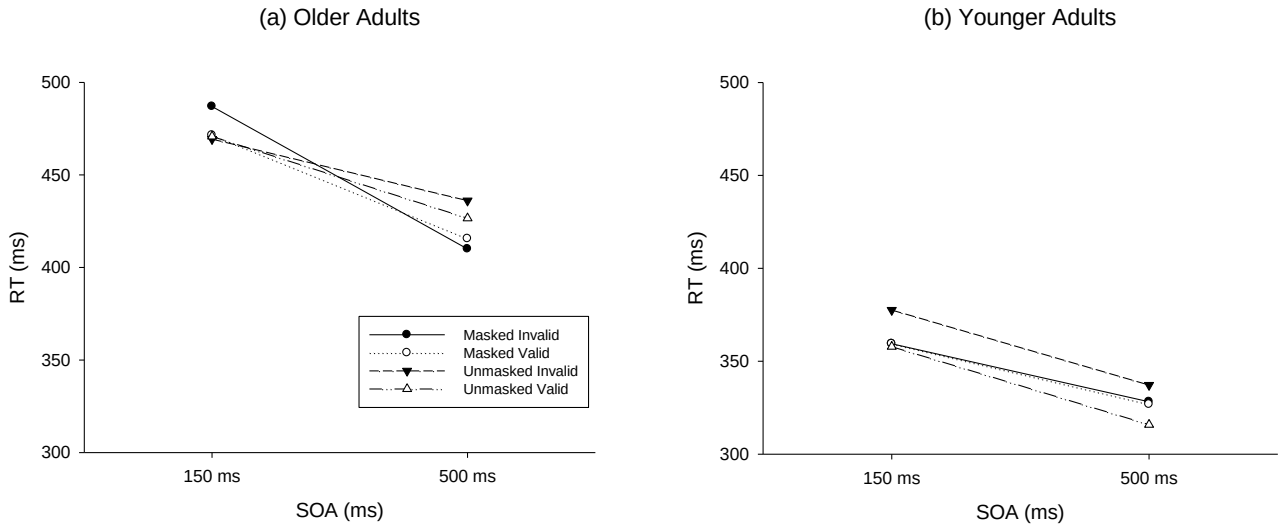


Figure 13: Results for Experiment 4: Mean response times (RT) in ms as a function of stimulus onset asynchrony (SOA) for (a) older and (b) younger adults.

Postexperiment questionnaire analysis

When participants were asked to choose the correct statement, between one that described the cue-target relationship and one that described the reverse of this relationship (Item 3), only 3/14 older adults made the correct choice (21%) whilst 9/15 younger adults (60%) made the correct choice with more confidence than a pure guess. A chi-square test for categories of data showed a significant difference between the older and younger adults based on the number of participants classified into these groups (chi-square = 4.43, DF = 1, $p < .05$). Thus we can reject the hypothesis that the samples came from the population defined by the null and can accept that there is a relationship between 'Age Group' and 'Awareness'. Compared with older adults, younger adults were more likely to make the correct choice.

The responses of all participants on the post-experiment questionnaire were used to categorise them into three groups. The 'aware' group consisted of those participants who

were aware of the cue-target relationship in Item 1 and successfully described it (Item 2). There were 5 younger adults in the aware group (33%) but only 1 older adult (7%). The 'unaware' group were those who had failed to describe the cue-target relationship in Items 1 and 2, and also chose the incorrect statement on the forced choice two-alternative Item 3. There were 6 younger adults and 8 older adults in this group. The 'ambiguous' group were those participants who had failed to describe the cue-target relationship correctly in Items 1 and 2, but had chosen the correct statement in Item 3. There were 4 younger adults and 5 older adults in this category. Within the older adults in this group, 2 reported that their choices were possibly correct (C), and 3 felt their choices were a pure guess (A). Within the younger adults in the ambiguous group, 2 felt that their choices were mainly guesswork (B), 1 felt that it was possibly correct (C), and 1 felt that it was probably correct (D). A chi-squared analysis was performed on Age Group (Older vs. Younger) and Awareness Group (Aware vs. Unaware vs. Ambiguous). No significant differences in Awareness were found for older and younger adults (chi-square = 3.2094, DF = 2, p = n.s.).

The data were entered into a repeated measures' ANOVA with Masking, SOA and Cue Validity as repeated measures factors. Age Group and Awareness (Unaware vs. Ambiguous vs. Aware) were grouping factors (see Corballis (2009) for a discussion on ANOVA using small groups, including groups where n=1 as in the current analysis for the older adult 'aware' group). The interaction between Masking, SOA and Age Group was significant, $F(1, 23) = 5.016$, $p = .035$ and showed that at the long SOA, older adults had significantly longer mean response times on unmasked trials (403 ms) compared to

masked trials (391 ms), whereas at the short SOA, mean response times were similar on masked (449 ms) and unmasked trials (447 ms). For younger adults however, mean response times were significantly longer for unmasked trials (368 ms) compared to masked trials (356 ms) at the shorter SOA, but were the same for masked and unmasked trials at the longer SOA (325 ms). The interaction between Masking, SOA and Awareness was also significant, $F(1, 23) = 5.744$, $p = .009$. This showed that in the masked condition mean response times for the aware group were faster on both the shorter SOA (367 ms) and the longer SOA (326 ms) than those of the ambiguous group (shorter SOA = 410 ms, longer SOA = 376 ms), or the unaware group (shorter SOA = 431 ms, longer SOA = 374 ms). In the unmasked condition, the response times of the ambiguous group at the short SOA (426 ms) and the longer SOA (382 ms) were very similar to those of the unaware group (421 ms and 385 ms respectively). This was also the case at the longer SOA on masked conditions (ambiguous group mean = 376 ms, unaware group mean = 385 ms), though at the shorter SOA on masked trials, the mean response time for the unaware group (431 ms) was longer than for the ambiguous group (410 ms). There was no interaction between Cue Validity and Awareness, $F(1, 23) = .432$, p = n.s., which showed that mean response times did not differ significantly from valid to invalid trials across the three awareness groups.

What is the influence of explicit 'awareness'?

The data for the unaware group i.e. those participants who chose incorrectly on the forced-choice Item 3; was analysed separately using a repeated measures ANOVA, to examine whether a relationship existed between the attentional effect of the cue and the lack of conscious awareness of the cue-target relationship (see Figure 14a and 14b). The

grouping factor was Age Group, and the repeated-measures factors were Masking, SOA and Cue Validity. The interaction between Masking and SOA was significant, $F(1, 13) = 12.626$, $p = .004$. This showed a significantly greater difference between mean response times on masked trials, when comparing the shorter SOA (431 ms) and the longer SOA (374 ms), to unmasked trials (420 ms at the shorter SOA versus 385 ms at the longer SOA). The three-way interaction between Masking, SOA and Age Group was significant, $F(1, 12) = 19.86$, $p = .001$, as was the three-way interaction between Masking, SOA and Cue Validity, $F(1, 12) = 5.298$, $p = .039$ (see Figure 14).

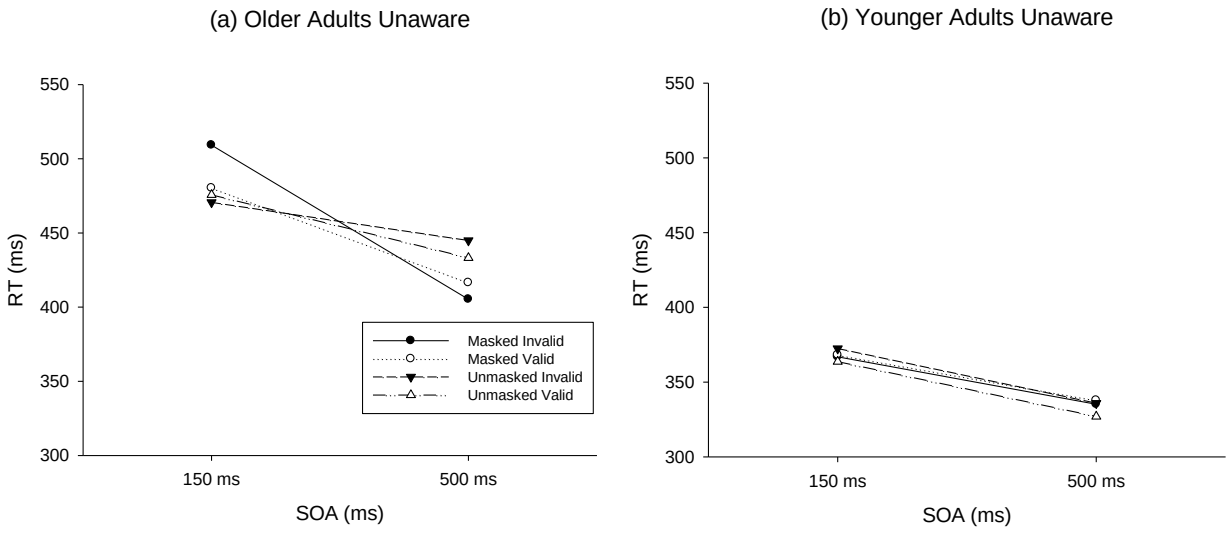


Figure 14: Results for Experiment 4: Mean response times (RT) in ms as a function of stimulus onset asynchrony (SOA) for (a) older (N=8) and (b) younger (N=6) adults in the unaware category.

The data for the ambiguous and aware groups (see Figure 15a and 15b) were combined and examined under unmasked conditions for the older and younger adults separately. For the younger adults, a significant effect of Cue Validity was found, $F(1, 8) = 6.846$, p

= .035. This showed that on valid trials the mean response time for younger adults was significantly faster (329 ms), when compared to invalid trials (360 ms). For the older adults however, there was no effect of Cue Validity in the ambiguous/aware group (however, fewer participants were included in this older group (N=6) thus statistical power was reduced).

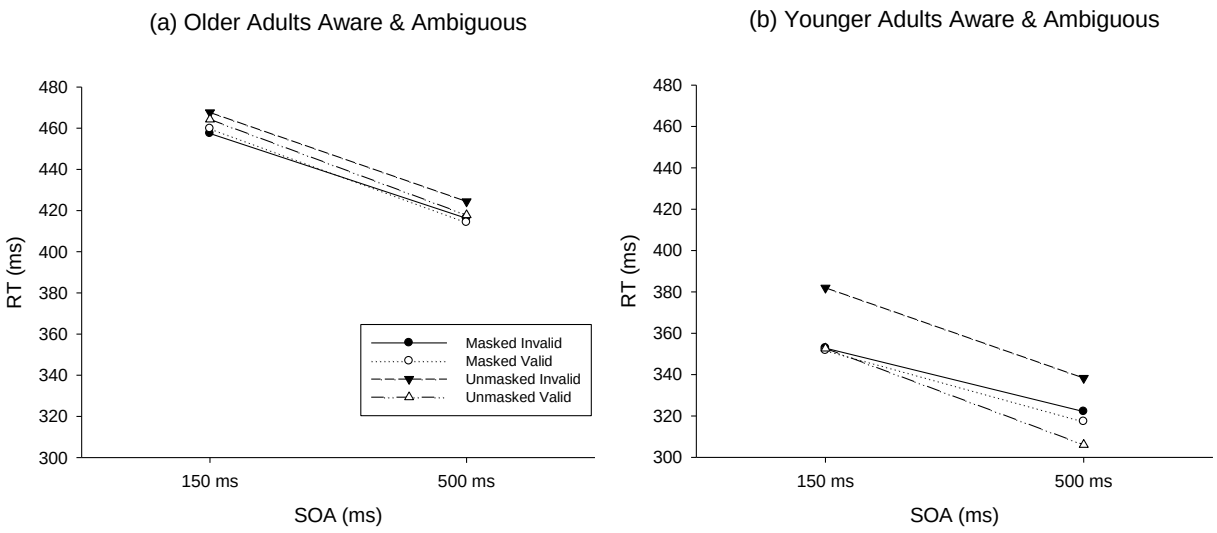


Figure 15: Results for Experiment 4: Mean response times (RT) in ms as a function of stimulus onset asynchrony (SOA) for (a) older (N=6) and (b) younger (N=9) adults in the aware and ambiguous categories combined.

Discussion

The primary question of interest in this experiment was whether any evidence for orienting to cue stimuli would be found in the absence of self-reported awareness, and if so, would this effect differ for the older and younger adult groups. More specifically, I was interested in seeing whether the unaware participants would show effects of cue validity. Of relevance to this question was whether ageing would influence the awareness groups' that participants were classified into based on their responses to the post-experiment questionnaire.

A chi-square test for categories of data showed a significant difference between the older and younger adults based on the number of participants classified into the groups 'Aware', 'Ambiguous' and 'Unaware'. Thus we can accept the hypothesis that there is a relationship between the factors 'Age Group' and 'Awareness'. Compared with older adults, younger adults were more likely to make the correct choice, showing that younger adults were more likely to gain explicit awareness of the cue-target relationship.

Results from Experiment 4 showed that under implicit unmasked conditions younger adults showed an effect of cue validity, whilst older adults did not. Whilst only one older adult showed that they were explicitly aware of the cue-target relationship on the post-experiment questionnaire, five younger adults showed that they had developed explicit awareness of the relationship. The chi-square value testing for differences between the groups exceeded the required significance value and therefore indicated a difference in

categorisation based on awareness for the two age-groups, where younger adults were more likely to make the correct choice when compared with older adults.

The absence of an interaction between Cue Validity and Awareness showed that mean response times did not differ significantly from valid to invalid trials across the three awareness groups. When the data from the Ambiguous and Aware groups was combined, whilst younger adults in this category showed a strong effect of cue validity, the older adults did not. However, for the unaware participants neither younger nor older adults showed an effect of cue validity. Thus it would appear that any effect of cue validity found in the younger adult group was a learned explicit effect rather than an implicit one. The reduced by nevertheless significant effect of orienting on masked trials that was found in Experiment 1 for both age-groups may have been a result of implicit processes operating during masked trials. However, evidence from this experiment, indicates that no attentional orienting has occurred without explict awareness of the cue-target contingencies, thus that explanation appears unlikely. The greater number of younger than older adults who reported explicit awareness of the cue-target contingencies is consistent with Fischman (2005) who found that on an artificial grammar task, younger adults often reported accurate explicit knowledge of the rules used in the artificial grammar, whilst older adults reported either no, or little explicit knowledge.

The results of Experiment 4 are inconsistent with Lambert et al. (1999; Experiment 1), Bartolomeo et al. (2007) and Risko and Stolz (2010) who all found evidence for implicit effects (orienting in the absence of any self-reported awareness of the cue-target

relationship) in younger adults. Whilst Experiment 4 was similar in procedure to Lambert et al. (1999; Experiment 1) there were some important variations. The main differences were that in the present experiment the target was an asterisk rather than a dot, and half of the trials were masked, whilst Lambert and colleagues had only unmasked trials. Also Experiment 4 consisted of four blocks of 80 trials whilst Lambert and colleagues had four blocks of 44 trials. In addition, the response mode differed between the two experiments. The earlier study used a simple one-key detection response whilst the present experiment used a choice-key (left/right) response.

The most plausible explanation for the absence of any implicit orienting found in Experiment 4 centres on response mode. In Experiment 4 participants were required to make a choice response based on target location, whereas in Lambert et al. (1999) a simple time detection response was required. This idea could be tested by replicating this experiment and using a simple, time-detection required response.[8] One explanation for this discrepancy of results, is that in Lambert et al. (1999), as the cues merely indicated the likely location of the target, there was less incentive to actively use the cues. However, in Experiment 4 when a choice response was required, the cues gave two sorts of information; the probable target location and the required target response, thus it was more advantageous for participants to work out the contingencies between the cue and the target. It was therefore possible that they were working more actively to do this, resulting in a disappearance of implicit effects as explicit processes took over. Consciously trying

[8] This experiment was performed and the implicit orienting effect found in Lambert et al. (1999) was replicated. The validity effect sizes in this omitted experiment were similar to those in Experiment 4 (choice responding) thus reducing the likelihood of any influence of spatial effects. The experiment was not included as there was no young/old comparison thus the results were not of central concern.

to discover and learn a pattern has been shown to impede successful learning (e.g. Howard & Howard Jr, 2001). This was first demonstrated by Reber (1976) who asked students to memorise letter strings. Those who were told of the existence of a pattern and asked to try and discover it performed more poorly on a discrimination task, than those who were uninformed. Other studies have found similar results to these (e.g. Berry & Broadbent, 1988) although none have used cueing paradigms.

Other findings from Experiment 4 were that under masked conditions the results were similar for both age-groups, where neither group showed an effect of cue validity. When the relationship between the cue and target was not specified in the instructions, the presence of visual masks appeared to produce conditions too difficult for the cue-target relationship to be learned. Thus visual orienting could not be performed regardless of age-group. Also, consistent with a large body of prior research, older adults responded more slowly to the target stimulus than younger adults (e.g. Salthouse, 1988a; Hartley, 1992; Pesce, et al., 2005).

The attentional effect of the cues in Experiment 4 failed to resemble the previously observed reflexive orienting pattern (e.g. Posner & Cohen, 1984). That is, a fast facilitatory effect of the cue at the short SOA would have been expected, and an inhibitory effect of longer response times at the likely location for the longer SOA (IOR). Instead, the results resembled the pattern observed in voluntary orienting. 'Explicit' validity effects (effects which were self-reported by participants) were found at both the long and the short SOA, showing an overall advantage for targets appearing at the

expected location for those participants who were 'aware'. These results differed from those of Lambert et al. (1999; Experiment 1) who found slower latencies for targets appearing at the probable location on long SOA trials and facilitatory effects of the cues at the shorter SOA. In this earlier paper, as in previous research (e.g. Lambert, Spencer & Hockey, 1991) IOR has indicated implicit learning of the cue-target relationship. As well as finding no effect of orienting on trials where participants remained unaware of the cue-target relationship, there was no evidence of an interaction between SOA and Cue Validity thus confirming an absence of IOR at the long SOA.

One reason for this more 'endogenous pattern' could be that the Attention Task used in the present study cannot be neatly pigeon-holed in terms of the dichotomy between endogenous and exogenous orienting. On the one hand, it could be argued that the task involves endogenous orienting, because participants orient their attention under voluntary control, towards the valid letter (X or T). On the other hand, the task shares two important features with previous studies of exogenous orienting. Firstly, the cue stimuli are presented at a relatively peripheral visual location and secondly, in common with earlier studies of peripheral cueing (e.g. see Müller & Rabbitt, 1989; Klein, 2004) the cues elicit very rapid covert orienting. For example, Lambert and Duddy (2002) describe five experiments using this paradigm in which clear attentional effects were observed even when the delay between presentation of the cue and target stimuli was extremely brief (100 ms or less; see also, Lambert et al., 2006). In addition, as mentioned earlier, this dichotomy between exogenous and endogenous orienting has become less clearly distinguished than it once was, as researchers such as Hommel et al. (2001), Tipples

(2002) and others, have found evidence for fast, reflexive orienting (typically seen with peripheral cues) occurring in response to centrally based cues.

In conclusion, the results of Experiment 4 have shown that any effects of attentional orienting using this paradigm and requiring a choice response are occurring largely through explicit processes of attention for both older and younger adults. The required choice response appeared to provide the most feasible explanation for the apparent absence of any implicit effects of orienting.

Chapter 5: Neural Activation during Orienting and Perception

Introduction

Electroencephalography (EEG) uses electrodes positioned on the scalp to measure the electrical activity of the brain. It is commonly used in cognitive neuroscience to look at neural correlates of mental activity in both low-level (e.g. perceptual and motor) as well as higher cognitive processes such as attention. Cognitive research frequently uses event-related potentials (ERPs) where EEG signals from each trial are averaged within a condition, as they provide high-resolution measures of the time course of neuronal activity patterns. Most of the research performed using ERPs to study visual attention has focused on younger adult groups. The first study of visuospatial attention in humans using electrophysiological methods was performed by Eason, White, and Oden in 1967. The study involved the flashing of lateralized stimuli and comparison of ERPs on trials when they were attended to, with trials when they were explicitly ignored. ERPs that occurred within 100-200 ms after the stimulus onset were found to be altered by the direction of attention in the visual fields.

Extensive EEG research in the area of visual attention has been conducted by Hillyard and colleagues. Spatial focusing of attention has been studied across a variety of tasks and typically stimuli at attended locations elicit enhanced P1 amplitudes compared to those at unattended locations (as indicated earlier in Chapter 1, P1 is the first positive

going component with a peak typically around 100 ms). This is the case when stimuli are presented in a continuous and randomized way as in Clark and Hillyard (1996) where patterned stimuli were presented rapidly in a random order to the left and right of the central fixation point. It is also the case for trial-by-trial cued attention tasks (as seen in Experiment 5). Behaviourally, precued target locations are associated with faster response times and improved target detection (Mangun, 1995; Mangun & Hillyard, 1991; Luck, Hillyard, Mangun & Gazzaniga, 1994; Anllo-Vento, 1995). This, combined with the fact that the localisation of the P1 effect is occipital which is consistent with enhancement of early sensory/perceptual processing, suggests ERP changes in amplitude reflect changes in sensory information used for perceptual judgement (Hillyard & Anllo-Vento, 1998; Anllo-Vento, Schoenfeld & Hillyard, 2004).

Whilst scarce, there have been some studies that have used EEG to examine the effects of ageing on attentional processes. One such study performed by West and Bell (1997) found evidence supporting an age-related decline of the anterior attentional system (Davis, Bruce & Gunnar, 2002; Posner & Petersen, 1990) using the Stroop task. Colour and word were either congruent or incongruent, and spatially integrated or separate. EEG was recorded from frontal, parietal and occipital regions. Greater cortical activation and a larger Stroop interference effect were found for older adults when stimuli were integrated (colour and word presented at the same location on the monitor). This effect was significant over medial, lateral frontal and parietal regions. However, with separated stimuli there was no effect of ageing on interference and EEG activation.

A visual detection task was used by Kutas, Iragui and Hillyard (1994) to examine the effects of ageing on ERPs. Participants were required to respond to the location of a flashing light which occurred on either the right or left side or in both visual fields simultaneously. Older adults showed reduced amplitudes in the posterior P1 component. They also showed increased amplitude of anterior positivity at 75-150 ms, and a P3 component with both increased amplitudes over frontal scalp areas and a linearly increasing latency. Short-latency ERPs provided an indication of changes in visual attention with ageing.

Whilst the behavioural literature using cueing paradigms to assess the covert orienting of visuospatial attention is vast, few ERP studies have investigated this and even fewer have used peripheral cueing or short SOAs. However, previous ERP research (mainly on central cueing) in this area, has typically found enhanced P1 amplitudes in occipital regions on valid trials. This has been attributed to the enhancement of perceptual processing of the attended stimuli due to sensory gain mechanisms (Mangun, Hansen & Hillyard, 1987). Luck et al. (1994b; Experiment 3) recorded ERPs using a central cueing paradigm and found that attention produced changes in sensory-evoked brain activity which began during the first 100 ms of sensory processing. Sensory responses to attended stimuli were enhanced whilst those to unattended stimuli were suppressed. Stimuli presented inside the focus of attention led to increases in sensory-level neural responses whilst for stimuli outside, decreases in these responses were seen. Effects were greatest over visual cortical areas of the occipital lobe.

Only two reported EEG studies have used Posner's cueing paradigm (Posner, 1980) to study the effects of ageing on attention. Curran et al. (2001) used ERPs to look for effects of ageing using a central version of Posner's cueing paradigm (with a central arrow indicating the likely target location) and a constant long SOA of 795 ms. For earlier components following the target such as P1, cueing influenced the amplitude similarly for both age-groups, although the P1 component was slower for older adults.

Lorenzo-Lopez, Amenedo, Pascual-Marqui and Cadaveira (2002) also used this paradigm to explore the effects of ageing on covert visuospatial orienting. As well as a central condition, Lorenzo-Lopez and colleagues measured P1 amplitudes and response times in a peripheral condition. Participants performed simple cueing tasks, either with an arrow or a blinking set of dots signalling the likely location of the vertical bar target. In central cue conditions at all SOAs (100, 300, 500 and 700 ms) the P1 amplitude was larger on valid trials, as has been found in previous research (e.g. Hillyard, Luck & Mangun, 1994; Mangun & Hillyard, 1991; Anllo-Vento, 1995). However, in the peripheral cue condition whilst subtle age-related changes occurred in the P1 amplitude, overall P1 enhancements following valid trials were not present for either age-group. In addition, older adults had lower P1 amplitudes in both peripheral and central conditions, as well as longer response times overall.

Whilst few ERP studies have used trial-by-trial cueing to look at spatial orienting, for those that have, methods have employed mainly central cues with long SOAs, and have found enhanced P1 amplitudes on valid trials in occipital areas. Even fewer studies

(Lorenzo-Lopez et al., 2002) have looked at peripheral cueing and whether the P1 effect observed with central cues also occurs with peripheral cues. The bilateral letter version of Posner's cueing paradigm has not previously been used in an EEG experiment. ERP studies can be useful in localizing the mechanisms involved in information selection, which can change with ageing, thus they can help to detect age-related deficits in attention.

One phenomenon which has been observed in earlier studies is referred to as age-related 'overactivation' and describes greater cortical activation in older than younger adults despite age-equivalent performance. As explained by Reuter-Lorenz and Cappell (2008) overactivation is relative and merely describes sites that are activated more by older than younger adults. It has been found across a wide variety of tasks and regions of the brain and due to its frequent occurrence in situations of age-equivalent performance, it has been viewed as a compensatory mechanism, whereby overactive sites in the brains of older adults are a result of their having to 'work harder' than younger adults (Reuter-Lorenz & Cappell, 2008).

De Sanctis et al. (2008) used high-density visual-evoked potentials to provide evidence for age-related overactivation of basic sensory processing in early components. Participants viewed alphanumeric stimuli but were not required to perform a task, in order to rule out the possibility that previous effects found due to compensatory mechanisms in older adults, may have been evoked by increased response complexity. Both the amplitude and latency of N1 were significantly increased for older adults, which

indicated age-related differences in early sensory processing. This was found to be in the form of reduced hemispheric asymmetry for early sensory processing with ageing, indicating that compensatory processing can be activated even in simple stimulus settings as well as in the previously demonstrated higher-order functions (Cabeza, Anderson, Houle, Mangels & Nyberg, 2000). Older adults also showed additional frontal activation when compared to younger adults, and it was suggested that perhaps older adults engaged automatically in a task, without instruction to do so. Overall, this provided evidence for compensatory hyper-activation in frontal networks, and enhanced sensory-perceptual processing in early regions of the ventral visual stream with ageing.

In an fMRI study, Langenecker, Nielson and Rao (2004) found greater activation for older adults in frontal areas of the brain such as the left inferior frontal gyrus during Stroop task performance. Similarly, Mattay et al. (2002) found overactivation in older adults using fMRI when they performed a speeded button-press task. Greater activation was found in the sensorimotor cortex, premotor cortex, supplementary motor area and regions of the cerebellum when compared to younger adults. It was likely that this reflected reorganisation and redistribution of functional networks occurring in older adults to compensate for structural changes in the brain with ageing.

Experiment 5

In the present study the Attention and Perception tasks from Experiment 1 were modified slightly to suit electrophysiological methods. Both tasks were performed by a group of

younger and older adults and cued attentional orienting (Attention Task) and target detection responding (Perception Task) were examined.

Of possible relevance to the present experiment is the early component of the 'Cognitive Negative Variation' (CNV). The CNV is a slow negative movement, sensory-related potential and has two main components the 'early' and the 'late' CNV (Lim, Polych, Hollander, Kirk, Byblow & Hamm, 2006). The early component involves the prefrontal and cingulate motor areas and is linked to arousal and attention associated with the 'warning stimulus' (Brunia, 1999). Thus, this is of interest in the Experiment 5, as both of the tasks involve a warning stimulus component. In the Attention Task the cues serve as a warning stimulus as to where the target is likely to appear (p = .75). In the Perception Task, the first screen presented which is a perceptual preview to the target response screen, serves as warning stimulus as to where the target will appear (p = 1) – see method section for more detail.

In the Perception Task instead of presenting the cue letters and requiring an accuracy response to the 'valid' letter (as in Experiments 1-3), the letters were presented as a perceptual preview to the 'target' screen which followed (an identical display which required a response to the 'valid' letter). This change was made in order to separate in time the stimulus, from the physical activity of responding. This allowed artifacts and preparation for motor activity to be separated out, in order to look clearly at cortical activation in response to the cue letters, thus reducing the possibility of the results being influenced by CNV. This did not completely prevent motor preparation, as participants

would still have prepared to respond to the side where they knew the target would appear. However, the design of the Perception Task allowed the left and right-hand responses (of which there were half of each) to be collapsed over which cancelled out this effect. Due to presentation of the cues in the Attention Task, it was likely that participants would have started to prepare for a motor response on the side of the valid letter (the response would occur on this side on 75% of trials). Therefore, this change in the Perception Task in Experiment 5 allowed for a closer comparison between the two tasks. Although there was a higher probability (p = 1) for the side that a motor response would be occurring in the Perception Task, compared to the Attention Task (p = .75), the similarity between the tasks was nevertheless increased.

In the Attention Task, SOAs of 0 ms and 700 ms were used. Lengthening of the 500 ms SOA to 700 ms was required in order to avoid 'smearing' of the ERPs to the cue and target. Physical overlay between the cues and target on the zero SOA was avoided, as the cues were presented above the target (consistent with previous experiments). The SOA of zero was interesting due to the fact that in previous similar studies (e.g. Lambert & Duddy, 2002; Experiment 3A) orienting in response to peripheral cues has been so fast, that it has been observed even in the absence of a delay between the cue and target. Thus even though it is time-consuming to discriminate between two letters it was predicted that orienting would be observed in Experiment 5 at the SOA of zero due to these earlier findings. Results of Experiment 3A and 3B of Lambert and Duddy (2002) indicated that it was the spatial correspondence between the cue and the target that elicited this rapid orienting and I was interested in examining the zero delay condition further.

ERP correlates on both tasks were assessed, as were ERPs to both the cues and the target. Measuring ERPs to the target allowed for comparison of activation on valid trials with invalid trials, whilst measuring ERPs to the cues allowed for a comparison of the activation elicited by the letters when they were presented in the context of the Attention Task, with activation when they were presented in the context of the Perception Task.

The absolute latency of P1 was examined and due to the mixed results found by previous cueing studies (and the limited amount of EEG research in this area) it was unclear whether greater P1 amplitudes would be found on valid trials in the Attention Task (see Curran et al., 2001 for a central cueing condition and Lorenzo-Lopez et al., 2002 for both peripheral and central cue conditions). Response times on valid and invalid trials were also recorded and analysed with the hypothesis that responding would be faster on valid trials (Posner, 1980). In addition, the present experiment used statistical non-parametric mapping (SnPM – Manly, 2007) as well as standardised Low Resolution Electromagnetic Tomography (sLORETA), to compare areas of neural activation within and between tasks, and also between age-groups. The use of sLORETA in conjunction with the ERP analysis technique helped to link together the cognitive and brain functioning elicited during the performance of these two tasks.

As proposed by Goodale and Milner (1992) in their model of cortical visual processing, vision for action and vision for perception can be distinguished as being dependent on the dorsal and ventral streams respectively, whereby each stream processes and transmits information about object structures and locations in very different ways. As the dorsal pathway has been linked with rapid attention shifts (Lambert & Shin, 2010), it was

predicted that letter processing in the context of the Attention Task would elicit rapid dorsal activation. As conscious perceptual discrimination has been linked with the ventral visual pathway (Goodale, 2007), it was predicted that letter processing in the context of the Perception Task would elicit strong ventral activation (e.g. Merigan & Maunsell, 1993).

Method

Participants

The younger adults consisted of 13 participants (7 females) between the ages of 19 and 28 years (mean = 21.54, SD = 2.82) with a mean of 16.5 years of formal education (SD = 0.89). The older adults consisted of 14 participants (6 females) between the ages of 59 and 75 years (mean = 63.07, SD = 4.35) with a mean of 16.1 years of formal education (SD = 1.30). 8 older adults were in full-time employment, 4 were in part-time employment and the remaining 2 worked part-time in voluntary positions. 12 younger adults and 13 older adults were right-handed.

Stimuli and Apparatus

Refer to Chapter 2 for details of the visual stimuli for the Attention and Perception tasks. EEG signals were recorded continuously with a sampling rate of 1000Hz using a high-density 128-channel Ag/AgCI electrode net (Electrical Geodesics Inc., Eugene, OR, USA). Electrode impedances ranged from 30 to 50 kΩ. Data were acquired using a common reference electrode (Cz), positioned anatomically, and were later re-referenced

to the average. Signals were band-pass filtered (0.1 – 40Hz) using a digital 3-pole Butterworth bi-directional filter.

Analysis

The EEG data were segmented into three time epochs, the early epoch (80-110 ms), the epoch around the older adult P1 peak (113-143 ms) and the epoch around the younger adult P1 peak (130-160 ms). Data contaminated by eye movements (blink threshold set at 70µV) were discarded. Out of the correct trials, the percentage accepted without eye movements or any other artifacts were 79.1% of all trials for the younger adults, and 77.8% of all trials for the older adults.

The P1 component of the average evoked potential was defined as the greatest amplitude peak of the first positive wave occurring at least 50 ms after stimulus presentation. P1 amplitudes and latencies were calculated for each participant by taking the average voltage of electrode 70 and 83 (O1 and O2) (standard 10-20 system).

Procedure

The paradigms used in Experiment 5 were similar to the two Attention and Perception experimental tasks used throughout this thesis (see Figure 1 & 2, Chapter 2), which were designed to assess visual processing by the dorsal and ventral streams respectively (Lambert & Shin, 2010). Participants were tested in a quiet, electrically shielded Faraday chamber and were seated 57 cm from a 15-inch SVGA computer monitor (640 x 480 pixel resolution) on which stimuli were presented. In both tasks a pair of letters (X & T)

was presented on either side of a visual display, whilst neural activity was monitored via high-density EEG recording.

In the Attention Task the letters acted as spatial cues and participants were informed that a target object, a small asterisk, was likely to appear on the same side as one of the letters (e.g. X). Throughout the experiment, the SOA randomly alternated between 0 ms and 700 ms. The 700 ms delay condition enabled direct comparison between neural activity elicited when the letters triggered visual orienting (Attention Task), and neural activity when explicit conscious discrimination of the letters was required (Perception Task – see below). For half of the participants the target would usually (p = .75[9]) appear on the same side as the letter 'X', whilst for the other participants the target would usually appear on the same side as the letter 'T'. Participants were clearly informed of the group that they were in. The task consisted of 32 practice trials followed by six blocks of 80 experimental trials.

The primary purpose for including the Perception Task in Experiment 5 was to look for a distinction in cortical activation between performance on the Attention Task (where processing was predicted to occur in the dorsal stream) and performance on the Perception Task (where ventral stream processing was predicted) (see Goodale & Milner 1992; Milner & Goodale, 2006 & 2008). The temporal structure of the Perception Task was identical to the 700 ms delay condition of the Attention Task. On each trial the 'X' and 'T' would appear on the left and right side of the screen, followed by a 700 ms SOA

[9] In order to increase the number of invalid trials for EEG analysis, the predictive value of the valid cue was decreased from 80% to 75% and all trials were unmasked (as orienting effects in previous experiments had been strongest in unmasked trials, and were inconsistent on masked trials).

before they appeared again in the same position. Participants were instructed to press the correct side for the target letter as quickly as possible after they detected it for the second time. Thus the initially presented letter pair acted as a perceptual preview. Participants who had 'X' as the valid letter in the Attention Task were required to indicate whether 'X' was on the left or right of the display, by pressing the 'z' or '/' keys respectively. Participants who had 'T' as the valid letter in the Attention Task were required to indicate whether 'T' was on the left or right. Participants performed 20 practice trials followed by two blocks of 80 experimental trials. The order of performing the Attention and Perception tasks was counterbalanced across participants.

Results

Behavioural data comparing age-groups: Attention Task

ANOVA was conducted on the mean response times for each participant in each condition for the Attention Task. The independent groups factor was Age Group (Older vs. Younger), and the repeated measures factors were SOA (0 ms vs. 700 ms) and Cue Validity (Valid vs. Invalid). There was a significant main effect of Age Group, $F(1, 25) = 18.726$, $p < .001$, where mean response times were slower for older adults (584 ms) than for younger adults (493 ms). The main effect of SOA was significant, $F(1, 25) = 60.136$, $p < .001$, showing that mean response times were faster at the longer SOA (505 ms) than at the shorter (571 ms). The main effect of Cue Validity was also significant, $F(1, 25) = 32.865$, $p < .001$, which indicated that mean response times were faster on valid trials (516 ms) than on invalid trials (561 ms). The interaction between SOA and Cue Validity was significant, $F(1, 25) = 26.241$, $p < .001$, which showed a greater mean

decrease in response times from invalid to valid trials at the long SOA when compared to the short SOA (see Figure 16). There was a significant interaction between SOA and Age Group, $F(1, 25) = 12.994$, $p = .001$, where the older adults showed a much greater increase in mean response times from the long to the short SOA when compared to the younger adults (see Figure 16). The interaction between Cue Validity and Age Group was significant, $F(1, 25) = 7.383$, $p = .012$, where the decrease in mean response times from invalid to valid trials was much greater for the older adults than for the younger adults (see Figure 16). Finally, the three-way interaction between SOA, Cue Validity and Age Group was significant, $F(1, 25) = 18.726$, $p < .001$ (see Figure 16) whereby older adults showed a greater effect of cue validity than younger adults, which was more pronounced at the long SOA.

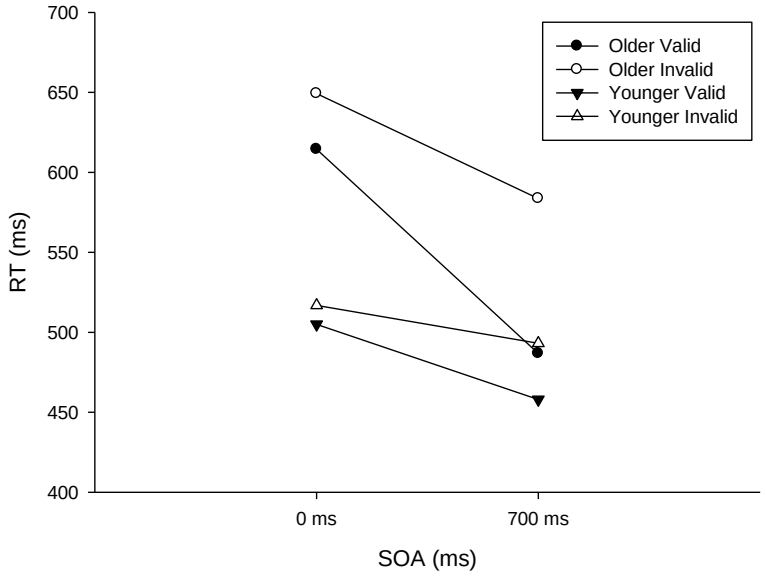


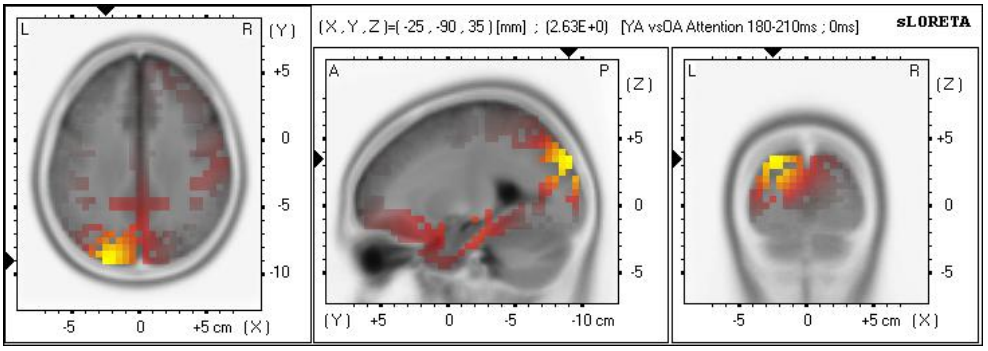
Figure 16: Behavioural data for the Attention Task for Experiment 5: Mean response times (RT) in ms on valid and invalid trials as a function of stimulus onset asynchrony (SOA) for older and younger adults.

As in Experiment 2 proportional cueing scores were calculated for each participant, using the procedure employed by Curran et al. (2001). When ANOVA was performed on the proportional cueing scores for older and younger adults, the Cue Validity x Age Group interaction remained despite scaling the data. The significant main effect of Age Group remained, $F(1, 25) = 5.408$, $p = .038$, where the scaled proportions were significantly greater overall for older adults (.119) than for younger adults (.049). The SOA x Age Group interaction was also significant, $F(1, 25) = 5.405$, $p = .038$, showing significantly greater variation between age-groups in the scaled scores at the longer SOA when compared to the variation at the shorter SOA.

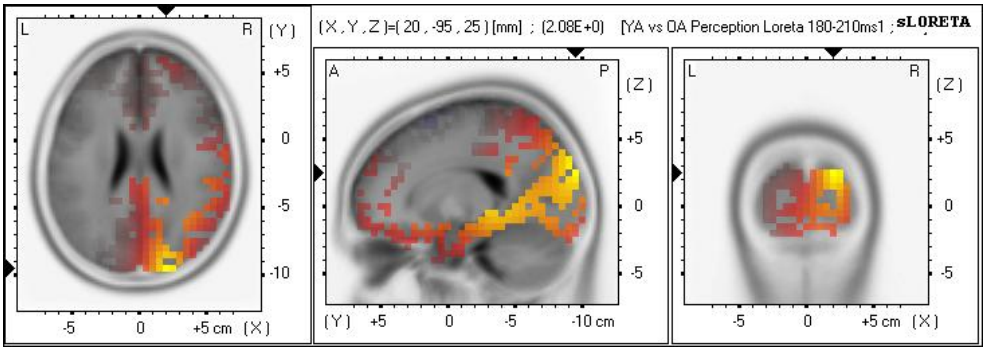
EEG data comparing age-groups

Statistical, non-parametric mapping was used to compare brain activation between the older and younger adult groups. Three time epochs were used, the early epoch (80-110 ms), the epoch around the older adult P1 peak (113-143 ms) and the epoch around the younger adult P1 peak (130-160 ms). In the early epoch (Figure 17a, b) for both the Attention Task and the Perception Task the older adults showed significantly greater activation overall in response to the cue stimuli than younger adults, which was maximal in the cuneus of the occipital lobe (Attention: $t(25) = 2.63$, $p < .05$; Perception: $t(25) = 2.08$, $p < .05$). Similarly, the older group showed greater activation in the time epoch around their own P1 peak (113-143 ms) than the younger group for both tasks (Figure 17c, d) with maximal activation at the cingulate gyrus for the Attention Task ($t(25) = 2.53$, $p < .05$) and the posterior cingulate for the Perception Task in the limbic lobe ($t(25) = 2.44$, $p < .05$). There were no significant differences in activation levels between the

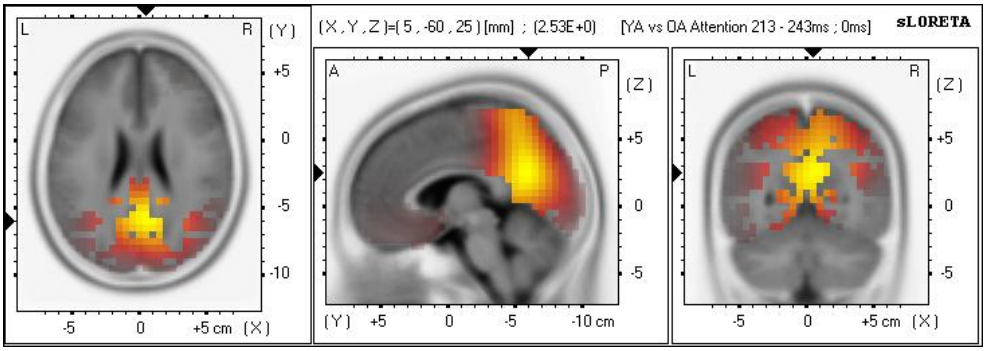
age-groups found on either task, for the time epoch around the P1 peak of the younger group (130-160 ms).



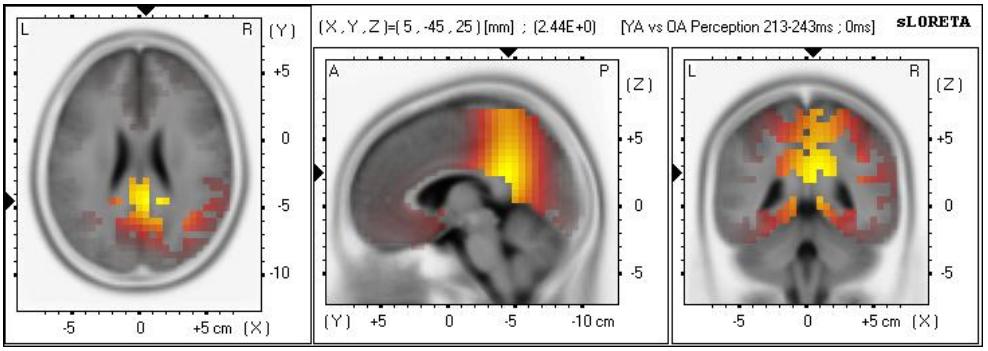
(a) Early Attn.



(b) Early Perc.



(c) Late Attn.



(d) Late Perc.

Figure 17: Comparison of activation in response to the cue stimuli at the 700 ms SOA for Older and Younger Adults on the Attention and Perception tasks. The Older Adults showed stronger activation than the Younger Adults at both the early time epoch of 80-110 ms (panels a, b) and the later time epoch of 113-143 ms (panels c, d).

Younger Adults behavioural data

ANOVA was conducted on the behavioural data for the younger adults for each condition on the Attention Task using repeated measures factors of SOA (0 ms vs. 700 ms) and Cue Validity (Valid vs. Invalid). Results revealed a significant main effect of Cue Validity with faster mean response times on valid (481 ms) than invalid trials (505 ms); $F(1, 12) = 15.453$, $p = .002$. The main effect of SOA was also significant; $F(1, 12) = 32.58$, $p < .001$, where mean response times were faster at the longer delay (476 ms) than at the zero delay (511 ms). There was a significant interaction between SOA and Cue Validity; $F(1, 12) = 9.358$, $p = .010$, where younger adults showed a greater increase in mean response times from valid to invalid trials at the long SOA compared to the zero delay. The validity effect was significant at both SOAs (see Figure 16).

As the Perception Task was performed to examine whether ventral stream cortical activation would be seen, the only behavioural statistics of interest were the accuracy and mean response times for each age-group. For the younger adults, response accuracy was 99.9% correct and the mean response time across all trials was 379 ms.

Older Adults behavioural data

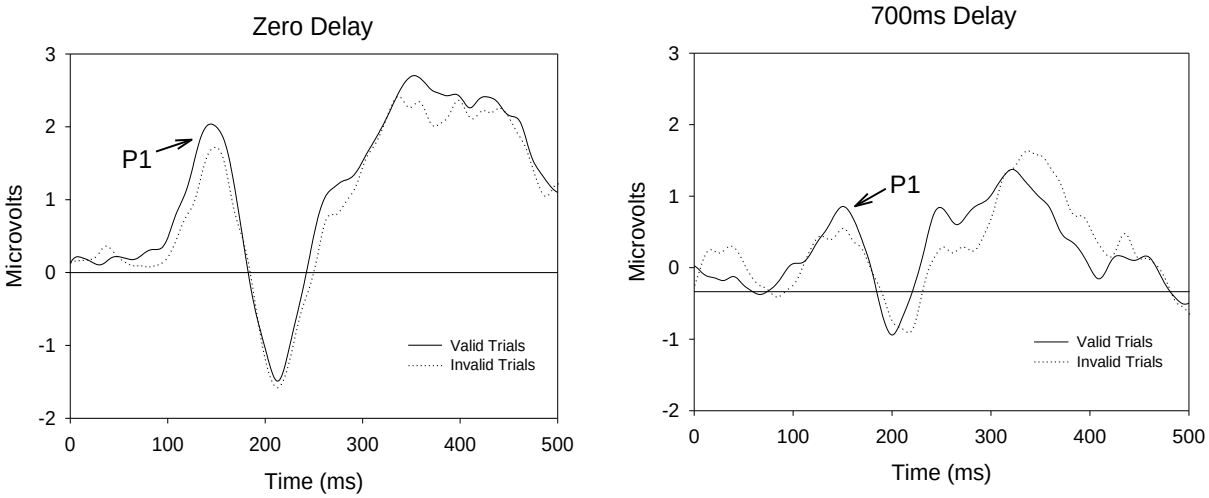
ANOVA was conducted on the behavioural data for the older adults using the same factors. Results revealed a significant main effect of Cue Validity with faster mean response times on valid (551 ms) than invalid trials (616 ms); $F(1, 13) = 22.318$, $p < .001$. A significant main effect of SOA was found; $F(1, 13) = 39.697$, $p < .001$, showing faster mean responses at the longer SOA (535 ms) than at the zero delay (632 ms). Results also

revealed a significant interaction between SOA and Cue Validity; $F(1, 13) = 18.584$, $p = .001$. This showed a greater increase in mean response times from valid to invalid trials at the long SOA compared to at the zero delay for older adults (see Figure 16).

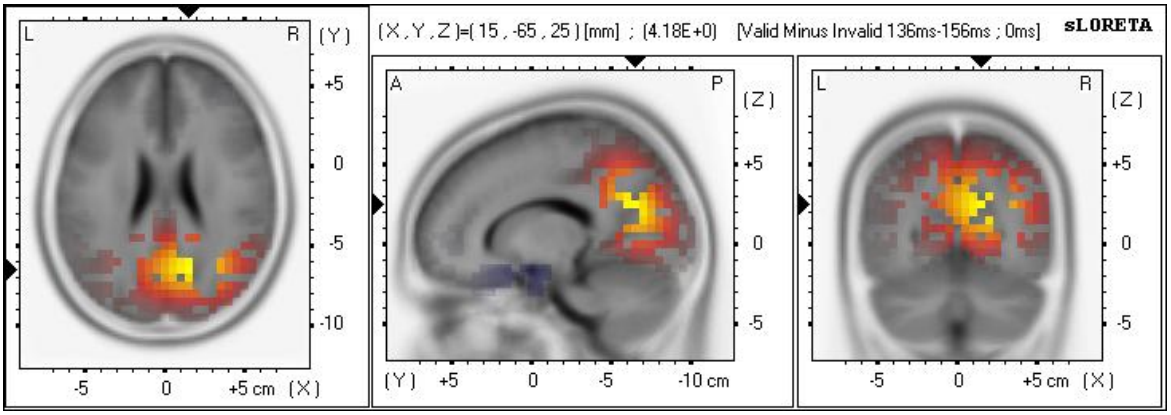
As with the younger adults, response accuracy was near-perfect at 99.6% correct and the mean response time across all trials was 429 ms.

Younger Adults EEG data

ANOVA was used to compare the amplitude of the P1 evoked potential in the valid and invalid conditions of the Attention Task. Statistical non-parametric mapping was used to compare neural activation elicited by peripheral letters in the context of the Attention and Perception tasks. For the Attention Task the factors Cue Validity, SOA and Hemisphere (LVF or RVF: O1 or O2) were used. Activation on valid and invalid trials was compared within a 30 ms time window (130-160 ms) located around the P1 peak for the younger adults. The P1 evoked-potential was enhanced on valid trials (where the target appeared at the likely cued location) over occipital electrodes, when compared to invalid trials (where the target appeared at the less likely location); $F(1, 12) = 8.081$, $p = .015$, (see Figure 18a, b). In addition, sLORETA (Pascual-Marqui, 2002; Fuchs et al., 2002; Jurcak et al., 2007) was used together with SnPM to compare neural activation in response to the target stimuli, on valid trials with invalid trials in the zero delay condition. The results, illustrated in Figure 18c, confirmed that the P1 enhancement effect shown in Figure 18a was accompanied by stronger activity in visual areas of the occipital lobe; $t(12) = 4.18$, $p < .01$.



(a) (b)



(c)

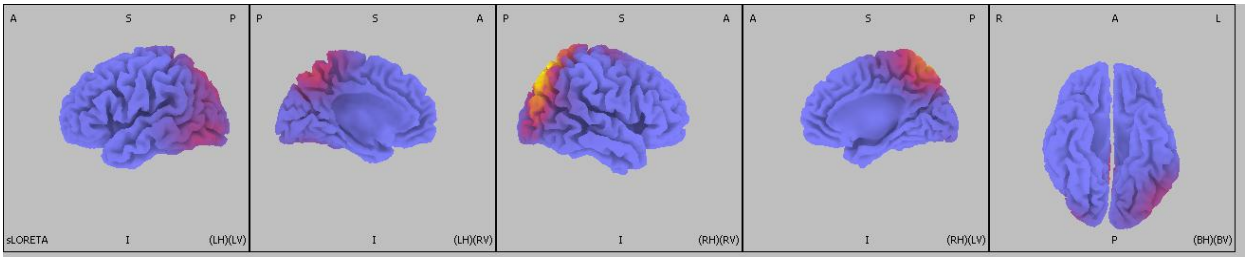
Figure 18: Effects of letter cues on target processing for Younger Adults. The upper panels (a, b) show that perceptual processing of the target was enhanced by spatial cueing. The lower panel (c) shows the outcome of statistical non-parametric mapping analysis of the zero delay condition.

The data shown in Figures 18a and 18c show that reliable top-down enhancement of target processing in occipital cortex occurred within 136-156 ms from onset of the letter

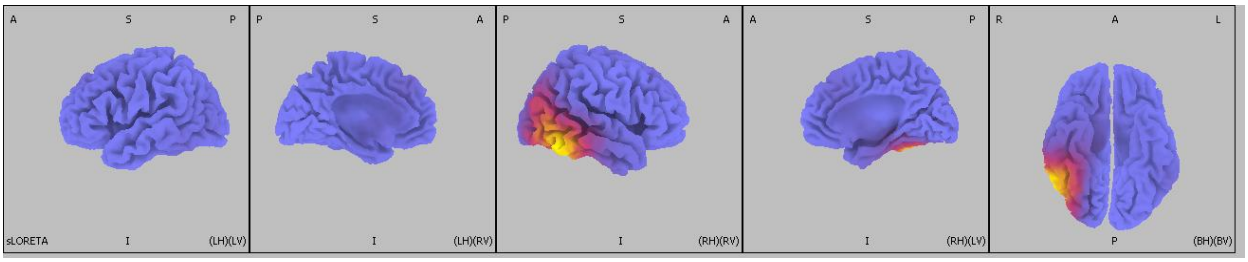
cues. Therefore the cue-encoding processes responsible for generating this attentional effect must have occurred before this.

Figure 19 shows the outcome of sLORETA analyses (in response to the cue stimuli), applied to an early time window (80-110 ms from letter onset) and a later time window (130-160 ms from letter onset). These windows correspond to the onset of the P1 wave-form evoked by the letters, and the peak of that wave respectively. When the letters served as spatial cues in the Attention Task, early activation was apparent in the dorsal pathway, particularly in the right hemisphere (see Figure 19a).

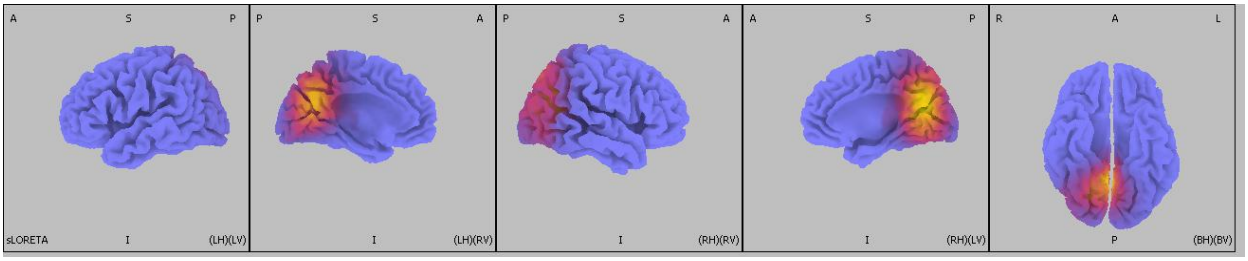
The sLORETA solution suggested maximal activation in the superior parietal lobule (SPL) (Gitelman, 1999) of the right hemisphere. In contrast, when the letters served as perceptual previews, in the Perception Task, sLORETA indicated early activation at a high level of the ventral pathway, in the inferior temporal gyrus (see Figure 19b). In the later epoch, corresponding with the P1 peak, sLORETA analysis indicated very similar patterns of activation in the Attention Task and Perception Task. In both cases this was characterised by widespread occipital activation (see Figures 19c, 19d). Thus, closely similar patterns of occipital activation observed at the peak of the P1 waveform in each task, had dramatically different precursors, involving high level dorsal and ventral activation in the Attention and Perception tasks respectively.



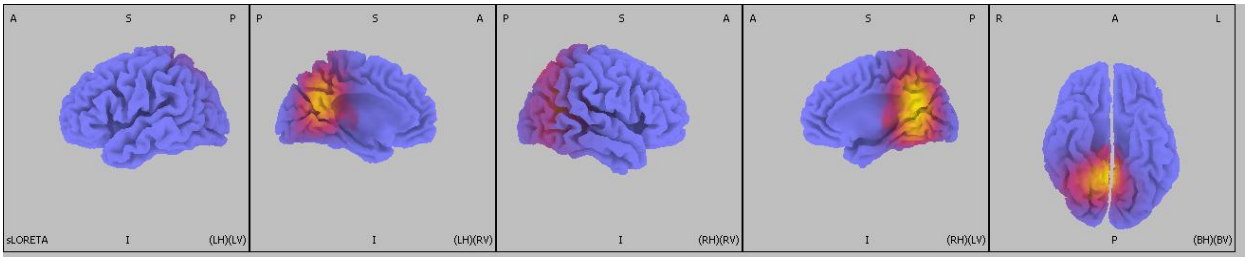
(a) Early activation: Attention Task.



(b) Early activation: Perception Task.



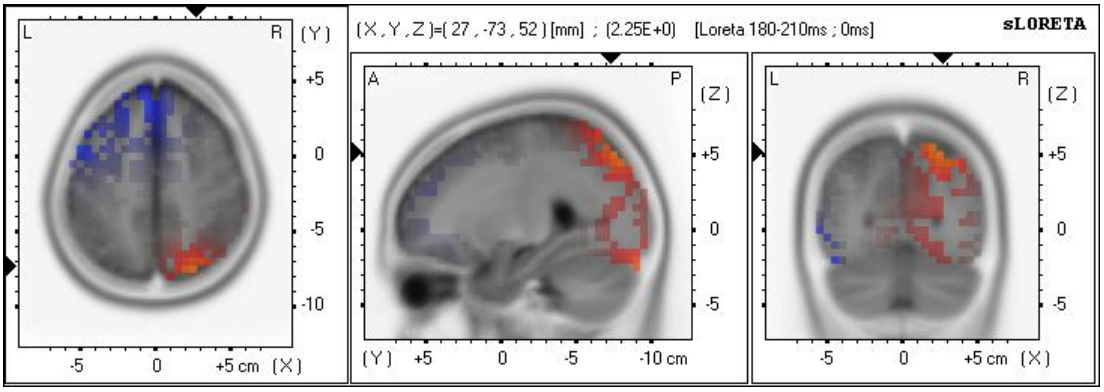
(c) Late activation: Attention Task.



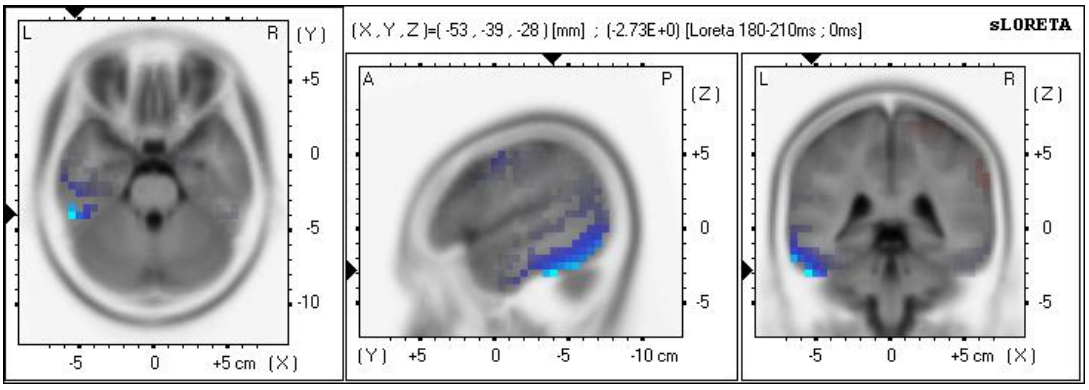
(d) Late activation: Perception Task.

Figure 19: Neural activation in response to the cue stimuli in the Attention and Perception tasks at the 700 ms SOA for the Younger Adults. Early activation (a, b) occurs 80-110 ms after letter onset, whilst late activation (c, d) occurs 130-160 ms after letter onset.

SnPM was used to compare early activation elicited by letters in the context of the Attention Task with activation elicited by the same stimuli in the context of the Perception Task. This confirmed that early activation patterns elicited by peripheral letters in the two task contexts differed reliably. As Figure 20 shows, this difference had two principal sources: letters elicited stronger early activation in the superior parietal lobule of the right hemisphere when they acted as spatial cues in the Attention Task, $t(12) = 2.25$, $p < .05$; and letters elicited stronger early activation in the inferior temporal lobe of the left hemisphere when they served as perceptual previews in the Perception Task, $t(12) = 2.73$, $p < .05$.



(a)

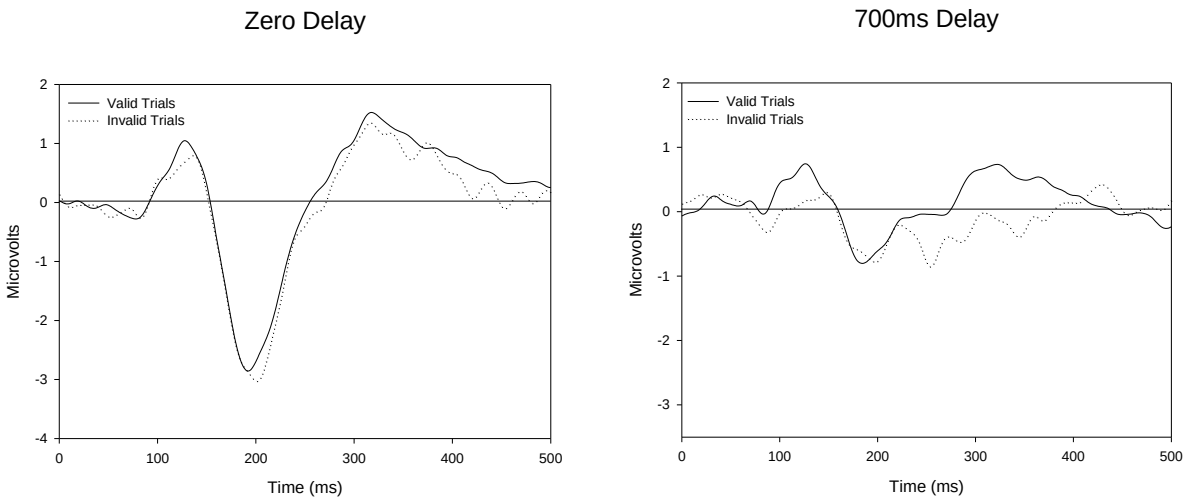


(b)

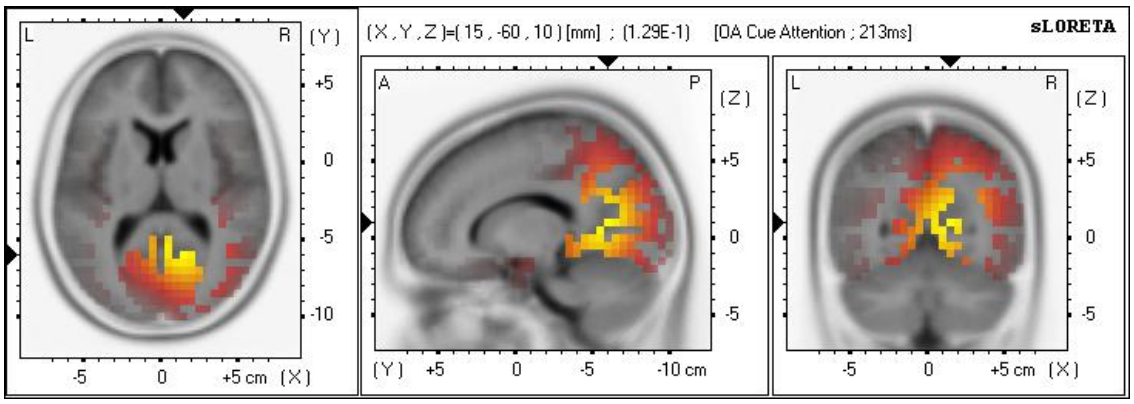
Figure 20: Comparison of early activation in response to the cue stimuli in the Attention and Perception tasks at the 700 ms SOA for Younger Adults. Panel (a) shows that stronger activation was observed in the Attention Task at parietal and superior parietal sites. Panel (b) shows that stronger activation was observed in the Perception Task in the inferior temporal lobe.

Older Adults EEG data

ANOVA was used to compare the amplitude of the P1 evoked potential in the valid and invalid conditions of the Attention Task. SnPM was used to compare neural activation elicited by onset of the peripheral letters in the context of the Attention and Perception tasks. The P1 evoked potential was again enhanced over occipital electrodes; $F(1, 13) = 6.192$, $p = .027$ (see Figure 21a), indicating a significant P1 effect where the amplitude was greater on valid trials compared to invalid trials. No other significant factors or interactions were present. However, unlike the younger adults data, Figure 21c (resulting from sLORETA and SnPM, showing activity in response to the target on zero delay trials) showed a non-significant effect and thus failed to confirm that the P1 enhancement effect in 21a was accompanied by stronger activity in the visual areas of the occipital lobe; $t(13) = 1.29$, $p < .01$.



(a) (b)

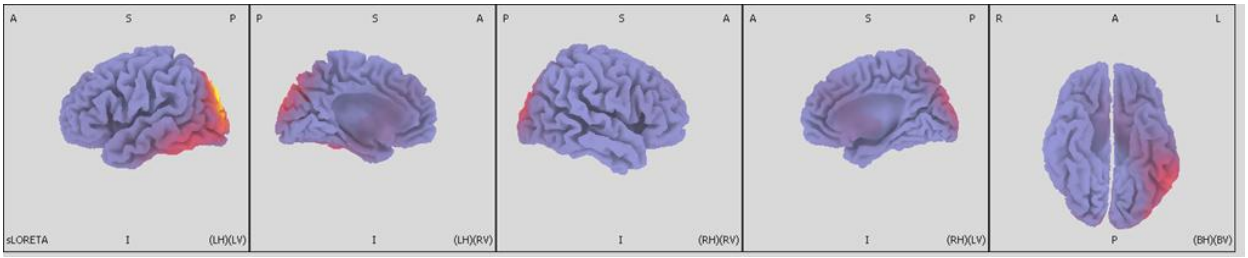


(c)

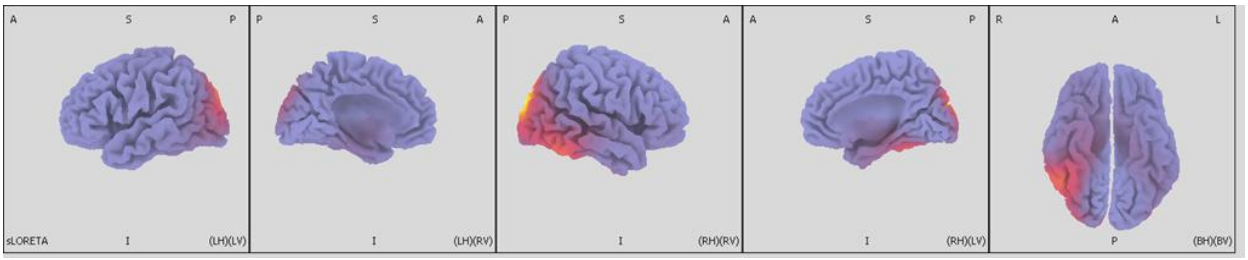
Figure 21: Effects of letter cues on target processing for Older Adults. The upper panels (a, b) show the perceptual processing of the target was enhanced by spatial cueing. The lower panel (c) shows the outcome of statistical non-parametric mapping analysis of the zero delay condition.

The data in Figure 21 show that top-down enhancement of target processing occurred within 113-143 ms from letter cue onset; earlier than the time window of 133-156 ms which was found for the younger group. In Figure 22 the outcome of the sLORETA analyses in response to the cue stimuli, applied to an early (80-110 ms) and late (113-143

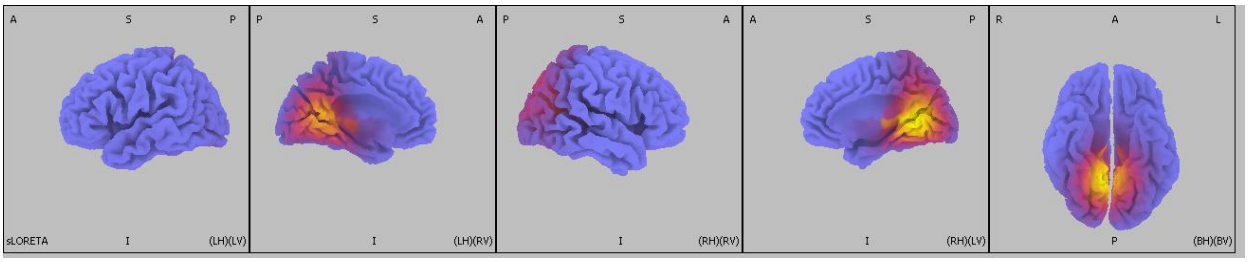
ms) time window from the letter onset is displayed. These windows were chosen to correspond with the onset of the P1 wave form, and the peak of that wave form for the older adult group. In the Attention Task when the letters functioned as spatial cues, early activation was seen in the cuneus in the occipital lobe. Early activation in the Perception Task was also strongest in the cuneus when the letters served as perceptual previews of the target. This was unlike the younger adult group where the areas of maximal early activation were found to be very different for each task. In the later time window, activation was again similar for the Attention and Perception tasks for the older adults. For both tasks, the sLORETA solution suggested maximal later activation in the posterior cingulate limbic lobe.



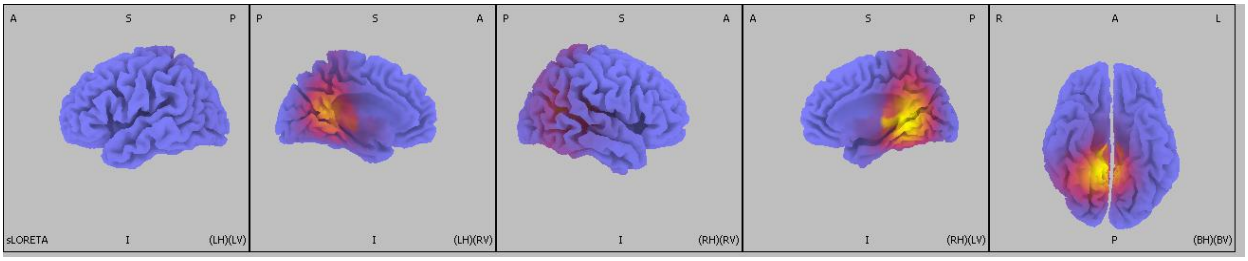
(a) Early activation: Attention Task.



(b) Early activation: Perception Task.



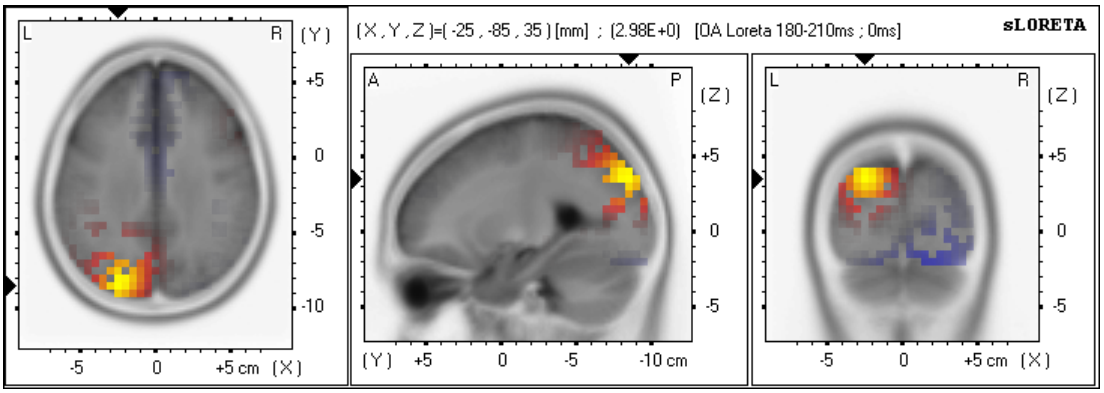
(c) Late activation: Attention Task.



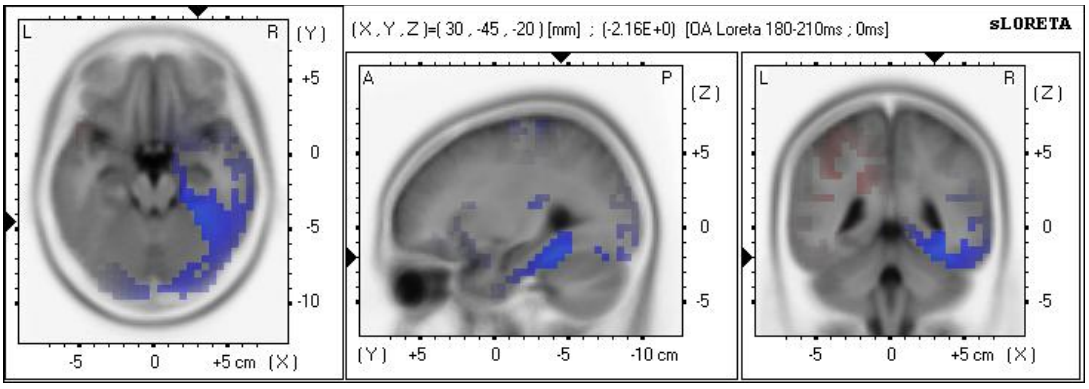
(d) Late activation: Perception Task.

Figure 22: Neural activation in response to the cue stimuli on the Attention and Perception tasks at the 700 ms SOA for the Older Adults. Early activation (a, b) occurs 80-110 ms after letter onset, whilst late activation (c, d) occurs 113-143 ms after letter onset.

Early activation elicited by the cue letters in the Attention Task was compared with early activation elicited by letters in the Perception Task, using non-parametric mapping. Reliable differences were found between early activation patterns in response to the cue stimuli elicited in the two tasks (see Figure 23). When the letters served as spatial cues in the Attention Task, stronger early activation occurred in the superior parietal lobule of the left hemisphere; and when letters served as perceptual previews in the Perception Task, they elicited stronger early activation in the fusiform gyrus of the right hemisphere. When compared to the younger adults' data, a reversal of laterality is present in the older group on both tasks.



(a)



(b)

Figure 23: Comparison of early activation in response to the cue stimuli on the Attention and Perception tasks at the 700 ms SOA for Older Adults. Panel (a) shows that stronger activation was observed in the Attention Task at parietal and superior parietal sites. Panel (b) shows that stronger activation was observed in the Perception Task in the fusiform gyrus.

Thus, a comparison between Figures 22 and 23 revealed an apparent paradox in the results for the older adults. Whilst in Figure 22a and 22b, similar early activation was seen for both tasks, the SnPM analysis in Figure 23 revealed reliable differences between the tasks. In creating Figure 22, the software has searched for the strongest area of activation within a task/condition and this is highlighted. However, the SnPM analysis has searched for differences in activation between conditions. Thus it would appear that reliable differences exist between the tasks in areas that are not showing the strongest absolute activation e.g. SPL left hemisphere (Attention Task), and fusiform gyrus right hemisphere (Perception Task), and these have been highlighted by the SnPM analysis.

Discussion

The processes of consciously detecting an object and shifting our attention in response to an object are so intricately woven together that often we are unable to see a distinction between them in daily life. This chapter continues to use the model that has been used throughout this thesis as a way to explore the dissociation between the processes of perception and attentional orienting and examines this further by using ERP analysis in combination with sLORETA to measure brain activation and provide localisation information. Results have shown a dichotomy between fast dorsal activation when attention was shifted in response to peripheral visual objects, and fast activation of the ventral visual stream when a perceptual detection response was required. Rapid high level early activation was seen in the superior parietal lobe in the dorsal stream during the Attention Task and in the fusiform gyrus and inferior temporal lobe in the ventral stream during the Perception Task. In earlier work the SPL has been linked with movements of

covert attention (Gitelman, 1999), whilst the fusiform gyrus of the left hemisphere has been associated with perceptual identification of verbal stimuli (DeHaene, Le Clec'H, Poline, Le Bihan & Cohen, 2002).

It is interesting to note that for both age-groups in the dorsal and ventral visual pathways, lower level processing is being influenced by higher level processing which appears to be 'feeding back'. The completion of higher level processing must thus be extremely rapid in order for it to have any influence over this earlier stage. Whilst the ventral visual stream consists of fibres from both the parvocellular (P) and magnocellular (M) layers of the lateral geniculate nucleus (LGN), the dorsal stream consists mainly of fibres from the M layer only and it is these M-fibres, which conduct visual signals the fastest (Merigan & Maunsell, 1993). Visual stimuli are responded to more rapidly by cells in the parietal lobe of the dorsal pathway due to the high concentration of M-fibres, in comparison to the longer response latencies from many cells in V1. One hypothesis which is relevant to the results of Experiment 5 and has been proposed by Bullier (2001), is that visual stimuli elicit an initial burst of feed-forward processing which is carried by M-fibres along the dorsal pathway. Re-entrant feedback from computations in the parietal lobe is then fed back to occipital areas, which influences visual processing of the target in the ventral system.

In Lambert and Shin (2010) the luminance contrast of the peripheral letters was varied, in a task very similar to my Attention Task, in order to examine whether encoding during the task was mediated by M pathways in the dorsal stream, as M and P fibres are known

to differ in luminance contrast sensitivity. Whilst orienting in the Attention Task remained at the same magnitude for high and low levels of luminance, performance on the Perception Task was impaired at lower levels. As explained by Merigan and Maunsell (1993) lower contrast levels have little effect on M-cells and a much greater effect on P-cells. This helps to understand the link between dorsal stream encoding of peripheral cues and fast attentional shifts (see Figure 19a, which shows more early activation than Figure 19b).

As can be seen clearly in Figure 17 stronger early ventral activation was present for both age-groups on the Perception Task compared to the Attention Task (where the strongest levels of activation occurred in the SPL). I predicted that the time course of processing in the Perception Task would be slower than in the Attention Task. However on both tasks rapid activation occurred during the time window of 80-110 ms. One explanation for this could be that in the Perception Task, the 'perceptual preview' was acting in one sense as a cue. Thus, there is earlier activation than there would be in a straight discrimination task, as the similarity between the Attention and Perception tasks is increased. This increased similarity was necessary however, in order for the two tasks to share the same temporal structure to allow direct comparison between them.

In terms of the ageing effects, the behavioural data for the Attention Task revealed an interaction between Cue Validity and Age Group (consistent with Curran et al., 2001; Greenwood et al., 1993 & Hartley et al., 1990) where the validity effect was greater for older adults than for younger adults. It was possible that the difference found between

the Age Groups may have been related to overall differences in response times between the groups. As the response times of the older adults were much longer than those of the younger adults, comparing the size of the effect may have posed some problems in terms of scaling. Thus, as in Curran et al. (2001) the data was scaled by calculating proportional cueing scores. Inconsistent with Curran and colleagues who found that this effect disappeared after scaling, the proportion valid scores of older adults remained significantly greater than those of younger adults, particularly at the longer SOA.

Whilst this interaction was not present in Experiment 1, it has been found in previous research on ageing and can indicate reduced ability to disengage from a target with ageing (e.g. Madden, Connelly & Pierce, 1994). Perhaps there was a greater element of anxiety experienced by the older adults in this experiment compared to those in Experiment 1. In Experiment 1 participants were required only to perform two simple behavioural tasks on a computer (which most of them were familiar with). Experiment 5 however, required participation in a more uncomfortable and unfamiliar situation. Although speculative, it is possible that this could have increased their anxiety levels. Laguna and Babcock (1997) found that older adults had significantly greater levels of anxiety when performing computer-based tasks, where computer-based testing was novel due to the fact that most of the older adults had little experience with computers. Whilst this heightened level of anxiety due to the novel situation did not degrade the performance of older adults, it did increase their response times.

Previous research has shown that disengaging of attention (which consequently can result in increased response times) can be difficult for older adults (e.g. Madden et al., 1994). The influence of anxiety on the inability to disengage attention from neutral or threatening information has been covered in a variety of studies which have mainly focused on trait anxiety (Derryberry & Reid, 2002; Fox, Russo & Dutton, 2002; Koster, Crombez, Verschuere & De Houwer, 2004; Waters, Nitz, Craske & Johnson, 2007; Yiend & Mathews; 2001). Koster, Crombez, Verschuere and De Houwer (2006) looked at the components involved in orienting to threat using a pictorial version of the dot probe task. An attentional bias to threat was found in more highly anxious participants. Results suggested that this was mainly due to problems experienced in attempting to disengage attention from threat. This is a common finding in studies using exogenous cueing paradigms due to the more automatic nature of orienting. However, as in Experiment 1 the main effect of Cue Validity was significant for both groups where mean response times were faster on valid trials than invalid trials. In addition, on the Perception Task, accuracy levels were near perfect for both groups.

Analysis of the P1 amplitudes for the Attention Task revealed that for both the younger and older adults, P1 amplitudes were enhanced for valid trials when compared to invalid trials. In earlier studies, this has been linked with focusing covert attention on a target location (see Klein, 2004; Anllo-Vento et al., 2004). No previous research has examined whether the attentional effects of bilateral spatial correspondence cues result in the same pattern of electrophysiological effects as the more traditional central and peripheral cues.

Thus this study is the first to show that the electrophysiological correlates of bilateral letter cues are similar to those elicited by central and peripheral spatial cues.

In both the Perception and Attention tasks older adults showed significantly greater early activation overall than younger adults. The over-activation that is present in this older group in the cuneus and the posterior cingulate, adds to the already well-documented literature that provides support for age-related region-specific over-activation in areas such as executive function, motor control and memory. In addition to the research mentioned in the introduction, Cabeza et al. (2004) found increased pre-frontal and parietal activity in older adults performing a visual attention task, reflecting functional compensation. Madden et al. (2007) found increased activation in frontal and parietal areas in older adults in a visual search task and proposed that if a task involved top-down control it was associated with increased frontoparietal activation in older adults. This is consistent with the increased activation in the superior parietal lobule for older adults when compared to younger adults on the Attention Task. Early activation for the older adults was found to be maximal in the cuneus for both tasks. This area of the occipital lobe is known to be involved in basic visual processing (e.g. Ferber, Mraz, Baker & Graham, 2007; Plomp, van Leeuwen & Loannides, 2010). No differences in activation were found between the groups for the time epoch around the younger adults P1 peak, however for the epoch around the older adults P1 peak the older adults again showed significantly greater levels of activation which were maximal in the limbic lobe.

The P1 was found to be later for younger adults than for older adults, which was unexpected based on previous research (e.g. Curran et al., 2001; Clapp & Gazzaley, 2011). However increased use of attentional processes can result in an earlier P1 as seen in Couperus (2010). In this study, the effects of perceptual load on visual attention were manipulated during performance of a discrimination task. When high levels of attention were required during the high perceptual load conditions, P1 occurred earlier. In the present study the increased activation in the cuneus found in the older adults, provides evidence for increased attentional processes operating in this group and thus may help explain the earlier latency of the P1.

As with the younger adults, data from the older group also replicates the distinction between dorsal and ventral streams of processing (see Figure 23). Dorsal activation is strongest during performance of the Attention Task whilst ventral activation is strongest during the Perception Task (see Figures 22 & 23). In addition, it can be concluded that the results could not be influenced by motor preparation or CNV. This is because firstly, the tasks were matched in the sense that an allowance for motor preparation was built into both tasks. Also, the magnitude of the activation elicited by CNV would have been larger than what was found in Experiment 5 (typically > 3 mv), and it would have occurred temporally later in time at approximately 1000 ms after the onset of the cue stimuli/perceptual preview (Lim et al., 2006).

Figure 20 shows that for younger adults, early activation during the Attention Task occurred in the dorsal stream primarily in the superior parietal lobule, whilst early

activation during the Perception Task occurred primarily in the inferior temporal gyrus in the ventral stream. For older adults early activation in the Attention Task also occurred in the SPL whilst during the Perception Task it occurred mainly in the ventral stream in the fusiform gyrus. The dorsal/ventral distinction in activation was clear for both age-groups although older adults did have more additional early activity in the cuneus for both tasks than younger adults. The dorsal/ventral differentiation for the younger adults was apparent from visual inspection of early activations in the Attention and Perception tasks (see Figure 19a and 19b) and from the difference map between the two conditions. For the older adults however, whilst dorsal/ventral differentiation was present in the difference map it was not really apparent upon examination of the activation maps for the two tasks separately (see Figure 22a and 22b). It appeared that for the older adults' early activation in both the Attention and Perception tasks was dominated by overactivation in the cuneus, so that the dorsal/ventral distinction was only apparent once the difference map had been calculated.

One difference between the data from the two age-groups is the apparent shift in laterality. In Figure 17 it is evident that the younger adults showed the greatest activation in the right hemisphere of the dorsal stream during the Attention Task (Figure 20a) and stronger activation in the left hemisphere of the ventral stream during the Perception Task (Figure 20b). In contrast, the older adults appeared to have greater dorsal activation in the left hemisphere and more ventral activation in the right hemisphere. This apparent shift of laterality is very interesting and would provide a fascinating area of future research to explore. I have investigated the literature and can find no precedent for this

apparent laterality shift, and in addition, I am not focusing on hemispheric differences in this thesis but rather on ageing effects and the dorsal/ventral distinction. Thus I have decided not to pursue this finding in too much detail aside from touching briefly on a few vision-based studies where hemispheric differences have been found with ageing.

In the previously mentioned EEG study by De Sanctis et al. (2008) where older adults showed increased frontal early activation, reduced hemispheric asymmetry was also found in older adults and this was thought to indicate a decline in hemispheric specialization with ageing. Gerhardstein, Peterson and Rapcsak (1998) looked at age-related hemispheric asymmetry in object discrimination where older and younger adults' judged whether two images were the same or different when they were presented to the left or right visual field. Older adults were less sensitive overall to differences between images and in particular were less sensitive to stimuli in the LVF – right hemisphere, compared to the RVF – left hemisphere. Thus faster declines in visual cognitive functioning with ageing were found in the right hemisphere. Similar results to these were found in a study by Cherry, Adamson, Duclos and Hellige (2005) using a letter-matching task where matches were either within or between hemispheres. As in Gerhardstein et al. (1998) a LVF – right hemisphere advantage was found for the younger adults suggesting greater age-related decline in right than left-hemisphere function.

In summary, findings from this experiment support the dual-pathway model of vision (Milner & Goodale, 2006). When a peripheral object shifts attention automatically, rapid activation is seen in the dorsal stream specifically in the superior parietal lobule for both

age-groups. In contrast when a conscious detection response is made to a peripheral object, early ventral activation occurs in the temporal lobe, again for both age-groups.

Chapter 6: General Discussion

Introduction

The effects of normal ageing on visual attention and perception have been examined in this thesis through a series of five experiments looking at attentional orienting and perceptual cue discrimination. Both younger and older adults were able to orient their attention using the cue letters and also performed accurate cue discrimination, with a simple pair of valid and invalid letter-cues. However, when there was an increase in the number of cues to four valid and four invalid letters, whilst both age-groups were able to perform the Perception Task accurately, the older adults were unable to use these cues to orient their attention. As supported by experimental results, the ability to categorise stimuli into a familiar category (vowels) appeared to enable the older adults to overcome the deficit that was apparent in Experiment 2, so that they could orient appropriately with a perceptually diverse set of cue stimuli. Electrophysiological methods provided localisation information supporting the dichotomy between Attention and Perception Task performance found in the older adults.

Complexity and the bilateral letter paradigm

It is well-known that ageing is associated with a decline in performance across a broad range of sensory and cognitive functions. In Craik and Anderson (1999) a review of the evidence on age-related decline in some of these functions such as visual and auditory

processing, divided attention and working memory is presented. Evidence related to ageing effects on visual attention however still remains under-researched and variable.

Lambert and Holmes (2004) used two tasks very similar to the ones used throughout this thesis and found dissociation between older adults' ability to successfully discriminate between and respond to four valid letter cues and their inability to orient attention to a target based on those same cues. Whilst perceptual cue discrimination remained intact in older adults, attentional orienting was found to be impaired. In Chapter 2, two studies were presented (Experiment 1 and 2) that further explored this dissociation between attentional orienting and perceptual cue discrimination and the effects of ageing and visual task complexity on performance.

The aim of Experiment 1 was to explore reasons behind this previously-discovered dichotomy and to establish which of my two proposed hypotheses could be used to explain it. The first hypothesis was that older adults in Lambert and Holmes (2004) exhibited a *general impairment* in their ability to orient attention in response to letter cues. The second hypothesis was that older adults in this same study were unable to orient appropriately due to the *high encoding demands* of the task, when there were four valid and four invalid letters. Experiment 1 tested 18 younger adults and 17 older adults on a simplified version of the Perception and Attention tasks which used only one valid and one invalid letter. Older adults were able to successfully orient their attention in response to the cues as well as perform accurate perceptual cue-discrimination. The unimpaired performance of attentional orienting with ageing in response to peripheral

cues was consistent with a number of previous studies (e.g. Folk & Hoyer, 1992 Experiment 1; Hartley et al., 1990 Experiment 3; Lincourt et al., 1997). Findings provided evidence that refuted the first hypothesis, whereby results showed that older adults did not have a general impairment in orienting *per se*, but that they may instead experience problems with cue-encoding using a larger cue set (as in Lambert & Holmes, 2004). Findings also provided support for the second hypothesis whereby older adults were able to orient their attention successfully when the cue-encoding demands were reduced.

In Experiment 2 ten younger and ten older adults were tested and each performed both the Attention and Perception tasks. These tasks were identical to Experiment 1 however instead of one valid and one invalid letter cue, there were four valid and four invalid letters. This further increased the similarity to the Lambert and Holmes (2004) experiment. Consistent with the results of Lambert and Holmes, whilst the older adults were unable to successfully use a group of valid letter cues to orient their attention in the Attention Task, they were still able to use these letters to perform successful cue discrimination during the Perception Task with a high level of accuracy. This provided evidence in favour of an impairment in cue-encoding for attention with ageing. It appeared that unlike younger adults, older adults were unable to use multiple cues to speed their attentional orienting towards the likely location of the target in a complex and random eight-cue situation.

In both Experiment 1 and 2, visual masks surrounded the stimuli on half of the trials. The purpose of this was to investigate the influence of distractors (which served to increase perceptual load), on the ability to discriminate accurately between cues and orient attention and to see how this would be affected by ageing. Research into the influence of masks on normal ageing is scarce and there is a need for more experimental research in this area. The degraded visual systems of older adults (Fozard, 1990) can mean that their coping mechanisms in dealing with visual clutter are reduced which can result in problems in applied areas such as driving (McPhee, Scialfa, Dennis, Ho & Caird, 2004).

Overall age-group appeared to have little influence on the effect of masks on responding in Experiments 1 and 2, serving to reduce both attentional orienting and the accuracy of perceptual cue-discrimination for older and younger adults alike. The absence of orienting seen on masked trials in Experiment 2 for both age-groups helped to tease out the order of operations that contributed to the orienting process. This absence indicated that in order to orient attention using this paradigm, it must be necessary for the identity of the letter stimuli to be clearly distinguished. With multiple cues on masked trials (as in Experiment 2 & 3) this was too difficult for participants, thus accounting for the absence of orienting seen on masked trials in these experiments. The absence of orienting on masked trials also helps to clarify the lack of involvement of implicit processes in orienting, as participants did not show any effects of orienting in situations where they could not explicitly see and respond to the cues (as confirmed in Experiment 4).

In Experiment 1 participants' accuracy levels on the Perception Task decreased significantly on masked trials and the magnitude of the mean validity effect on the Attention Task was also reduced. This was particularly interesting as it highlighted a contrast between the effects of two very different forms of visual impairment. Whilst visual masking was found to degrade performance on both the Perception and Attention tasks, reducing luminance contrast (Lambert & Shin, 2010), was found to massively degrade performance on the Perception Task, but have little or no effect on the Attention Task. Whilst visual masking and decreased luminance contrast are both methods of impairing vision, performance on the Attention Task in Lambert and Shin remained robust at low luminance levels due to the fact that as mentioned in Chapter 5, the dorsal stream consists of M-fibres only, which are not affected by changes in luminance (Merigan & Maunsell, 1993).

In Experiment 2 whilst accuracy levels on the Perception Task remained equivalent for both age-groups, accuracy was severely degraded to near-chance on masked trials. On the Attention Task the effect of visual masks was again similar for both age-groups where no effect of cue validity was found on masked trials. It appeared that the increased visual complexity in Experiment 2 (in the form of eight, rather than the original two visual cues), had obliterated any orienting or cue-discrimination on masked trials. This was the case even for the younger adults who were able to successfully orient on unmasked trials in this experiment, but found the increased level of visual noise too difficult.

In Experiment 3 in Chapter 3, the hypothesis that the deficit in attentional orienting was related to an inability to categorise the valid letter cues due to their random nature (consonants, of which there are 20) was explored. This experiment was similar to Experiment 2 but instead of random consonants being used as the valid letters, four vowels (A E I O) were used. As these were such a highly familiar and over-learned cue-set it was hypothesised that older adults would be able to categorise them into the group 'valid letters' more easily and thus orient their attention using the cues, as categorisation is known to influence attentional set size (e.g. Jonides & Gleitman, 1972). The participants consisted of 14 younger adults and 13 older adults who all performed both tasks. The older adults used the cues to orient their attention and also showed accurate perceptual cue discrimination, where performance on both tasks was similar to that of the younger adults. This suggested that the ability of older adults to successfully use a complex cue-set to orient their attention could be based on whether or not categorisation of the cue stimuli was possible.

It is likely that when the stimuli were able to be categorised, the category of valid letter vowels became increasingly similar to one valid letter cue (rather than representing four completely distinct and unrelated stimuli as in Experiment 2). This change would have increased the similarity between Experiments 1 and 3 and made the task of orienting using a greater number of cues possible (see Jonides & Gleitman, 1972). In addition, performance on the Attention Task appeared to be explicit in nature regardless of age-group. That is, an effect of cue orienting was found to be present only in participants who also reported conscious/explicit awareness of the cue-target relationship.

When compared to the results of Experiment 2, however, mean response times of older adults were found to be significantly slower on the Attention Task. It is unclear why older adults chose to adopt a different response strategy in this experiment, compromising speed in order to orient attention appropriately. It would appear that as utilisation of the cues in Experiment 3 was perhaps perceived as more achievable to older adults, they were provided with an incentive to respond more slowly in order to 'successfully perform the task'. As mentioned above in Experiment 3, the stimulus-cue mappings had become increasingly similar to the one-to-one mapping that was required in Experiment 1. In contrast, Experiment 2 appeared so difficult to older adults due to the four-to-one mapping required, that pressing the key as quickly as possible in order to finish the experiment seemed to be the optimal approach. The term 'satisficing' used in survey completion research can be used to help understand these findings. As explained by Krosnick (2006) when the perceived cognitive effort required to optimally answer a survey question is too great, respondents will provide any response that seems acceptable and plausible. In the Experiment 2 Attention Task, this could be viewed in parallel to a 'passive' key-press response whereby older adults responded passively to the asterisk in order to move onto the next trial, rather than in response to the direction provided by the cue letters. Adopting this maladaptive strategy would help to explain the faster response times in Experiment 2 whereby older adults appeared to be ignoring the cues when presented with these more complex stimulus-cue mappings. Two main factors that increase the likelihood of satisficing occurring are task difficulty and respondent ability. The difficulty level of the task in Experiment 2 was high and the ability of the older

adults to perform it relative to the younger adults' was reduced due to the natural effects of ageing mentioned earlier. Thus, although drawn from a very different task situation, this explanation whilst speculative does appear plausible.

In terms of the effects of masks in Experiment 3, for the Attention Task faster responding was seen on masked trials than unmasked trials for the older adults. The increase in response times on masked trials was consistent with Experiment 2 and provided further evidence of a maladaptive strategy to ignore the cues on those masked trials with more complex stimulus-cue mappings (Experiment 2 & 3) particularly as this pattern was not present in Experiment 1. Both age-groups showed cue validity effects on unmasked but not masked trials. On the Perception Task accuracy levels were similarly decreased by masks for both age-groups and remained comfortably above chance (around 60%) on masked trials. Masks seemed to be functioning in a similar way for Experiment 2 and 3 (which both required complex stimulus-cue mappings), whereby they dramatically reduced accuracy in the Perception Task, and completely removed any effects of cue validity in the Attention Task for both age-groups.

Results of Experiment 3 indicated that older adults did not have a pure deficit in visual cue-encoding for attention. Once they were able to categorise the valid letters, their attentional set size increased so that they were able to perform the complex attentional task successfully with a group of eight letters. There has been very little research into the ability to categorise cue stimuli in a typical cueing paradigm and the effects of this on performance, however previous research has looked at categorisation in visual search

tasks (e.g. Taylor & Hamm, 1997; Daoutis, Pilling & Davies, 2006). In the latter experiment when the target and distractors fell within the same colour category visual search was slower and more difficult than when they fell within different categories, highlighting the facilitation of visual search through use of categorisation. In Goldstone (2000) task performance was shown to improve with significantly with practice (becoming faster and more accurate) when categorisation was made possible through factors such as contiguity (when stimuli were connected) and proximity (when stimuli were adjacent vs. separated by other stimuli). Results suggested that the speed and sensitivity with which we process perceptual properties of an object can be strongly influenced by learned categories and in the present research, orienting for the older adults was made possible in Experiment 3 (Attention Task) through the use of the learned vowel category.

Working memory interpretation

One possible interpretation for the results of Experiments 1-3 is that the varying patterns of orienting behaviour observed were driven by variations in the working memory demand associated with performing the Attention and Perception tasks in each experiment. Thus, in the Attention Task of Experiments 1 and 3 where older adults oriented attention appropriately, participants only needed to hold in memory that the target was likely to appear (p = .8) on the same side as the valid cue letter (either X or T – Experiment 1), or on the same side as one category of cue letter (vowels – Experiment 3). In contrast, in the Attention Task of Experiment 2 working memory demands appeared to be higher, because participants needed to hold in memory that the target was likely to

appear on the same side as any of the four distinct letters in the valid cue set. One problem with this explanation is that it also predicts that older adults should show worse performance than younger adults on the Perception Task of Experiment 2. In both the Attention and Perception tasks, the distinction between item(s) in the valid and invalid cue sets is central to performance. In the latter case, encoding of the distinction between valid and invalid cues is assessed by the accuracy and latency of the direct response made to the target letter. In the former case, this encoding is assessed by participants' covert orienting response, which is measured by the size of the cue validity effect. If older participants failed to orient in Experiment 2 because they found it difficult to maintain the valid and invalid letters in working memory this would be expected to influence their ability to perform the Perception Task (as this task also involves maintaining representations of the cue letters in working memory). However, results of the Perception Task on Experiments 1-3 all showed that older adults discriminated between valid and invalid peripheral cues with levels of accuracy that were closely comparable to those obtained by younger adults.

Stimulus-cue mapping interpretation

A second interpretation of the results of Experiments 1-3 is that older adults were unable to orient in Experiment 2 due to increased complexity of the stimulus-cue mappings that were required. In Experiment 1 orienting was intact for the older adults when there was a one-to-one mapping between the valid letter and the target asterisk. In Experiment 2 however, there were four valid letters, of which the older adults had no prior associations with these letters. They also could not relate the letters in any way to one another. Thus

four distinct cue mappings were required to the target stimulus (one for each valid letter). This required participants to hold the four valid letters in memory throughout the whole experiment as they were unable to determine which letters would be presented on any one trial. Thus, although memory had been shown to be intact with ageing through accurate performance of the Perception Task, the mapping that was required in conjunction with the memory component became too difficult as the number of stimuli increased. This explanation is further supported by examining the results of Experiment 3. In this experiment, mapping was simplified due to the introduction of a vowel category for the valid letters. This change meant that the mapping process became more similar to that of Experiment 1 as the many-to-one mapping aspect of Experiment 2, became more closely aligned with the one-to-one mapping required in Experiment 1 (where vowels were chunked as one stimulus). However, four letters were still required to be identified (as evidenced through poor performance on masked trials where identification was too difficult). Whilst older adults appeared to be using the cues in Experiment 3, this was accompanied by increased response times, which may account for the more difficult stimulus-cue mapping that was required.

Exploration of implicit contributions to attentional orienting

In Chapter 4 the nature of participants' awareness during performance of the Attention Task and the relative contribution of explicit and implicit processes to performance was examined in older and younger adults. Implicit orienting has previously been demonstrated with younger adults during the performance of a similar task (Lambert et al., 1999; Experiment 1) and exploring this finding more deeply whilst examining the

effects of ageing was of interest in this chapter. Experiment 4 differs from Experiments 1-3 in terms of the implicit learning instructions that were given to participants. Unlike the earlier experiments, participants in Experiment 4 were not informed of the cue-target relationships and following completion of the final block, they were probed with a survey to establish their level of awareness.

In Experiment 4 there were 15 younger adults and 14 older adults who participated in a task similar to the simple Attention Task from Experiment 1. After completion of the final fourth block of 80 trials and execution of a categorical survey, there was little evidence for any implicit orienting of attention found in either age-group. Whilst some participants did show a development of explicit awareness of the contingencies by the end of the task (i.e. they showed a validity effect and were also able to report the cue-target relationship), any participants who were unable to explicitly report the cue-target relationship, also failed to show an effect of cue validity. Thus neither age-group demonstrated any implicit learning (learning without awareness) of the contingencies.

As mentioned in Chapter 4, the primary reason for this absence of implicit effects is suspected to be the choice response mode that was required in this experiment. Previous experiments (e.g. Lambert et al., 1999; Shin, Marrett & Lambert, 2011) that have used a simple detection response have found orienting in the absence of reported awareness. This is likely to be due to the additional information that the cues carry in the choice situation (both location and identity-based information) making the explicit learning of the cue-target contingencies more worthwhile (see Chapter 4 for a more detailed

discussion on this). The absence of any implicit orienting in this experiment also confirmed the necessity to actually see, and actively process the cues, in order to use them to orient in this situation and helps to explain the absence of orienting on masked trials in Experiment 2 and 3. In these experiments the masks would have impaired vision and when this impairment was added to the complex four-to-one mappings required in Experiments 2 and 3, it is unlikely that any explicit (conscious) orienting would have been possible.

Neural activation during orienting and perception

Experiment 5 is presented in Chapter 5. This experiment was designed in order to explore the dorsal/ventral distinction (Milner & Goodale, 2006) and age-related effects on this, by comparing performance on the Attention and Perception tasks using electrophysiological methods. Behavioural response time and accuracy data and the absolute magnitude and latency of P1 were examined and sLORETA was used to compare specific localized areas of neural activation between the tasks and age-groups. A sample of 13 younger adults and 14 older adults performed both the Attention and Perception tasks whilst 128-channel EEG was recorded.

Both younger and older adults showed strong effects of cue validity and high accuracy levels, with slower response times overall for older adults as has been consistently demonstrated throughout this thesis and in the literature (e.g. Hartley, 1992; Lambert & Holmes, 2004). Greater P1 amplitudes were present on validly cued trials when compared with invalid trials for both age-groups on the Attention Task (consistent with

Curran et al., 2001 & Lorenzo-Lopez et al., 2002). However this P1 effect occurred later for younger adults (130-160 ms after letter onset) when compared to older adults (113-143 ms after letter onset). Of primary interest was the early activation elicited in response to the cues. Results showed that within an early time window of 80-100 ms for both older and younger adults, a strong dorsal/ventral distinction was present. For the Attention Task sLORETA indicated that maximal cortical activation occurred in the superior parietal lobule, whilst for the Perception Task activation was maximal in the temporal lobe.

These results provided support for the dual-pathway model of vision – see below (Milner & Goodale, 2006). In addition to this, older adults showed strong early activation in the cuneus in the occipital lobe for both tasks, an area which is involved in basic visual processing. This 'overactivation' in the cuneus adds to the existing literature on ageing where overactive sites in the brains of older adults are thought to provide a compensatory mechanism, as neural areas have to 'work harder' in order to achieve success on a task (e.g. Madden et al., 2007).

Summary of electrophysiological and behavioural evidence

The results of Experiment 5 were consistent with those of Experiments 1-3. As predicted, in Experiment 2 dissociation was found between intact performance on the Perception Task and impaired performance on the Attention Task. Localization information on the areas of activation during each task was provided in Experiment 5. For early activation this can be summarised as the superior parietal lobe (dorsal stream)

for the Attention Task and the temporal lobe (ventral stream) for the Perception Task. The overactivation of the cuneus in older adults, provides evidence for the compensation that is required by this age-group in order to successfully perform the Attention Task, as the cuneus is an area that is involved in basic visual processing.

Dorsal and ventral visual processing

An overall explanation to summarise and tie together the findings from the experiments in this thesis draws upon evidence outlined in the introduction and confirmed in Experiment 5. That is, letter encoding in the context of the Attention Task and letter encoding in the context of the Perception Task rely on processing in two distinct neurocognitive pathways. According to this interpretation, cue encoding in the Attention Task relies primarily on processing in the dorsal visual stream, whilst cue encoding in the context of the Perception Task relies primarily on processing in the ventral visual stream. Several converging lines of evidence throughout this thesis and in the literature are consistent with the proposal that dorsal visual processing plays a vital role in the Attention Task:

(1) Attentional orienting occurs when luminance contrast is low, consistent with the physiological properties of the M-cells which dominate the dorsal visual stream (Lambert & Shin, 2010).

(2) Accurate performance on the Perception Task is not possible for patient DF who has visual form agnosia resulting from bilateral damage to the ventral stream. However, DF is able to effectively use these same letter cues to orient her attention (Lambert et al., 2011).

(3) In Experiment 5 letters presented in the context of the Attention Task evoked early activation in the dorsal stream, whereas letters presented in the context of the Perception Task evoked early activation in the ventral stream.

(4) Peripheral letter cues affect target processing, even at SOAs of zero, or when the delay between cue and target onset is extremely brief (Experiment 5; see also Lambert & Duddy, 2002). This is consistent with temporal properties of dorsal visual processing (Bullier, 2001; Milner & Goodale, 2006).

(5) Consistent with evidence that dorsal visual processing is largely unconscious (Milner & Goodale, 2006), it has been found using simple detection responding, that bilateral peripheral cues influence visual attention, even when participants are unaware of the predictive relationship between the cues and target location (Shin et al., 2011; see also Risko & Stolz, 2010, Peterson & Gibson, 2011).

(6) Consistent with neuroanatomical evidence that parafoveal and peripheral visual regions are well represented in the dorsal stream (Merigan & Maunsell, 1993), attentional effects of bilateral cues are similar, regardless of whether the cues are presented in central

vision, or more peripherally, at 5° - 9° eccentricity (Lambert & Duddy, 2002; Lambert & Shin, 2010).

Taken together, these six lines of evidence provide clear support for the view that the dorsal visual stream plays a critical role in visual encoding of cues, when these stimuli are presented in the context of the Attention Task. That is, evidence suggests that shifts of attention observed in the Attention Task are driven by dorsal encoding of the peripheral cue stimuli. The evidence described here shows that for older adults, this process operated successfully in Experiments 1, 3 and 5, but not in Experiment 2, whilst younger adults oriented appropriately in response to the cues in all four experiments. Thus, it appears that older adults, when confronted with the visually and informationally complex environment of Experiment 2, found it difficult to link their explicit knowledge of the cue set, indexed by accurate performance of the Perception Task, with the frontoparietal systems involved in the control of attention and the formation of top-down attentional expectancies (Corbetta & Shulman, 2002; Vuilleumier & Driver, 2007). Thus older adults found it more difficult than younger adults to use their explicit knowledge of the cue to guide covert attention rapidly and effectively to appropriate locations, in a novel and relatively complex environment, which required them to map four random valid cue letters to the target stimulus.

In reference to the working memory interpretation mentioned earlier, it is unlikely that a simple explanation, which attributes older adults' inability to orient attention appropriately in Experiment 2 to increased working memory demand, provides a viable

explanation for these findings. However, this finding should not be interpreted as implying that working memory plays no role in performance of the Attention Task. Recent fMRI work suggests substantial overlap between the neural systems that subserve working memory and those responsible for spatial attention (Ikkai & Curtis, 2011). Thus, older adults' failure of cue utilisation in Experiment 2 could be interpreted in terms of a failure to establish linkages between working memory representations of items in the cue set and dorsal stream mechanisms that implement the top-down attentional expectancies that reflect the spatially predictive information carried by the cues. Hence, although a simple explanation of the results from of this group of experiments in terms of working memory demand does not seem appropriate, the role of working memory representations in performance of the Attention Task cannot be completely ruled out.

On the other hand, evidence recently reported by Shin et al. (2011) indicates that in the bilateral cueing paradigm, conscious awareness of the predictive relations between cues and targets plays little or no role in the covert orienting effects that are observed. Thus, to the extent that one identifies working memory with information that is represented explicitly in conscious awareness, this evidence can be viewed as indicating that explicit, working memory representations of the cue stimuli may play a minimal role in the Attention Task. Similarly, the presence of reliable covert orienting in the brief, SOA 150 ms condition is consistent with the notion that cue encoding in the Attention Task relies on a rapid, non-conscious processing route that does not depend on the generation of an explicit conscious representation of the cue in working memory. Whilst no evidence was found in support of this non-conscious processing route in Experiment 4, this was

attributed to the choice response that was required, as evidence for implicit processing was found in another study which was identical in all respects except for the simple detection response required (see Shin, et al., 2011).

Future research

Older adults showed overactivation in the cuneus during performance of the simple Attention Task in Experiment 5, which they were able to successfully perform based on the behavioural results. It would be interesting to see whether the cortical activation of older adults during the more complex attentional orienting task from Experiment 2 (where older adults failed to show evidence of using the cues), would show a different picture of activation when compared to the younger adults. Further research to investigate the effects of ageing on the complex attentional task using EEG would provide a valuable contribution to this area. It would also be interesting to look at electrophysiological correlates of cue encoding in a task similar to Experiment 3, where the cue distinction is categorical.

Also of interest would be an extension of this research by using fMRI and Diffusion Tensor Imaging (DTI) to examine the connectivity between the brain cells of older adults during performance of the Attention Task (where impairment has been seen). By looking along the appropriate white matter tract whilst participants perform this task it could be examined whether any white-matter variations existed between age-groups which might suggest impairment in the dorsal stream with ageing.

Conclusions

This thesis provides a thorough investigation into the nature of attentional orienting using the bilateral letter cueing paradigm and how orienting and perceptual letter discrimination are influenced by ageing. It also examines the dorsal/ventral distinction in terms of areas of cortical activation and the influence of ageing on these areas. It would appear that the nature of participants learning whilst performing these experiments was primarily explicit in nature, as Experiment 4 failed to provide any evidence of implicit learning.

The results in this thesis provide evidence in support of Milner and Goodale's (2006) proposal of the existence of separate visual processing streams for attention and perception, namely the dorsal and ventral streams. This has been supported through behavioural experiments, designed to test covert visual attentional orienting in response to letter cues and perceptual letter discrimination. These experiments have shown dissociation in older adults between intact perceptual cue-discrimination and impaired attentional orienting during complex multiple letter-cue tasks. It has been proposed that this dissociation reflects a difficulty that the older adults had in using their explicit knowledge of the cue set to shift attention rapidly and appropriately in a complex multiple-cue situation. Orienting using a multiple cue-set of perceptually distinct letter-stimuli was only possible for older adults through use of methods such as categorisation, which allowed the stimulus-cue mappings of the four distinct letter-cues to function more as one group.

The dorsal/ventral distinction has also been supported with electrophysiological evidence that is consistent between age-groups. Results clearly indicate the area of strongest early cortical neural activation during the Attention Task to be dorsal in nature occurring in the parietal lobe and during the Perception Task to be ventral in nature occurring in the temporal lobe. This is consistent with previous research using this paradigm which has found evidence for a dorsal/ventral distinction whereby perceptual cue discrimination remains intact whilst attentional orienting shows impairment with ageing (Lambert & Holmes, 2004). Results add to existing evidence supporting separate systems of attention and perception (e.g. Lambert et al., 2011; Lambert & Shin, 2010). Subtle differences between older and younger adults were discovered using EEG which could be further explored in more detail using fMRI. The present research builds upon other literature demonstrating differences between older and younger adults both behaviourally and in neural function and provides behavioural and electrophysiological evidence for separate processing streams for visual attention and perceptual cue discrimination.

Appendix A:

Post-experiment Questionnaire for Experiment 4

There were four items in the post-experiment questionnaire and participants were instructed to complete the first two before turning the page and completing the second two.

1. While you were carrying out the experiment were you aware of any relationship between the nature of the briefly presented letters to the side of the central cross and the location of the target asterisk?

   Please circle: Yes / No

2. If yes, please describe this relationship.

Participants were then asked to fill out Item 3:

3. Two pairs of statements concerning the experiment you have just performed are provided below. Your task here is to decide which of them is true. Please indicate which pair of statements you think is true by circling the appropriate letter.

   A The asterisk usually appeared on the same side of the central cross as the "T," and on the opposite side of the central cross to the "X".

B The asterisk usually appeared on the same side of the central cross as the "X," and on the opposite side of the central cross to the "T".

There were four versions of Item 3. For 7 older adults and 7 younger adults Statement A was correct and Statement B was incorrect. For 7 older adults and 8 younger adults, Statement B was correct and Statement A was incorrect. This counterbalancing was necessary in order to reduce response bias arising particularly from those participants who chose 'A pure guess' in Item 4 (below). For 7 older and 7 younger adults, the same-side contingency was mentioned first and for 7 older and 8 younger adults, the opposite-side contingency was mentioned first.

Finally, participants filled out Item 4:

4. Please indicate your confidence in the judgment you have just made by circling the appropriate letter. I feel that my choice in Item 3 was

A A pure guess.

B Mainly guesswork.

C Possibly the correct choice.

D Probably the correct choice.

E Very likely the correct choice.

F Almost certainly the correct choice.

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