UNIVERSITY OF SOUTHAMPTON

FACULTY OF MEDICINE, HEALTH AND LIFE SCIENCES

School of Psychology

Categorical and coordinate visuospatial processing in younger and older adults

by

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Thesis for the degree of Doctor of Philosophy

June 2009

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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CATEGORICAL AND COORDINATE VISUOSPATIAL PROCESSING IN YOUNGER AND OLDER ADULTS

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In this thesis, four experiments were conducted in which participants made a categorical or coordinate spatial relation judgement concerning the location of a dot in relation to a bar. The main aim was to investigate how, if at all, categorical and coordinate VS processes changed with older age. In addition, the importance of task demand and the underlying cognitive processes involved in categorical and coordinate VS judgements were also examined.

In every experiment participants were faster and more accurate to make categorical visuospatial judgements than coordinate visuospatial judgements. This was taken to suggest that categorical visuospatial judgements are less demanding than coordinate visuospatial judgements. Younger adults were also found to process visuospatial information more quickly than older adults; however, accuracy rates and discrimination ability were similar. Furthermore, in contrast to expectation, coordinate visuospatial processes were not disproportionately affected by age-related decline.

Processing of categorical and coordinate visuospatial judgements was found to be affected by the distance of the dot from the bar and by the visual field in which stimuli were presented. However, the inconsistent effects of visual field across experiments made interpretation of these findings difficult.

Experiment 4 examined patterns of eye movements associated with categorical and coordinate visuospatial processes to gain insight into the underlying cognitive processes. The results indicated that visuospatial cognitive processing that occurs for above/below and near/far judgements is often qualitatively different from that which occurs when the task required precise distance estimation.

In conclusion, the experiments presented in this thesis provide significant insight into the cognitive processes associated with categorical and coordinate visuospatial judgements.

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Declaration of Authorship

I, Katie Louise Meadmore, declare that the thesis entitled ‘Categorical and coordinate visuospatial processing in younger and older adults’ and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- some of this work has been submitted for publication.

Signed: …………………………………………………………………………..

Date:……………………………………………………………………………….

Publications and Dissemination

Data from Experiment 2 has been published in a peer reviewed journal 'Laterality: Asymmetries of Body, Brain and Cognition' (Meadmore, Dror, & Bucks, 2009). Data from Experiment 4 has recently been submitted for publication (Meadmore, Dror, Bucks, & Liversedge, under review), and a manuscript with data from Experiment 3 is in preparation. The results of Experiment 4 were presented at the annual meeting of the Psychonomic Society in Chicago, November 2008 and at the annual conference for the Cognitive Section of the British Psychological Society in Southampton, September 2008. The results from Experiment 2 were presented in conjunction with the results from Experiment 3, at the Annual Conference for the Cognitive Section of the British Psychological Society in Aberdeen, August 2007, and the Faculty of Medicine, and Life Sciences in June 2007. Finally, Experiment 1 (younger adult data only) was presented at the Annual Conference for the Cognitive Section of the British Psychological Society in Lancaster, September 2006.

Acknowledgements

First of all, I would like to thank my supervisors, Dr Romola Bucks, Dr Itiel Dror and Professor Simon Liversedge for all their support, advice and guidance. In particular, I will be forever grateful for Simon's excellent supervision over the last year, and would like to thank him for the many hours and constructive comments that he has given me.

I would also like to thank all my friends and family for their encouragement and support. Special thanks go to all the members of office 3109 for making the last four years so enjoyable; and to my partner, Dan, who has been very patient and put up with a great deal.

I would like to thank all of my participants; especially my older adult volunteers who have taken the time to participate in my research and without whom this research would not have been possible. Finally, I would like to thank the Economic and Social Research Council who funded my research.

I would like to dedicate this thesis to the memory of my Grandpa, who did not have the chance to finish his own.

Chapter 1
Categorical and Coordinate Visuospatial Processing

1.0. Thesis Introduction

Information regarding the relationships between objects in the environment is necessary for a variety of successful actions. It aids navigation and identification of objects and visual scenes in the environment (Kosslyn, 1987; Chabris & Kosslyn, 1998). Visuospatial (VS) processing is not unitary but comprises numerous skills and abilities (Kessels, De Haan, Kappelle, & Postma, 2002). Kosslyn (1987) suggested that categorical and coordinate VS processes are two independent VS processing systems that encode different types of spatial relation information. The dissociation between these two VS processes has received considerable attention in younger adult populations, however, very little is known about how older adults carry out categorical and coordinate VS processing. Accordingly, this thesis examines categorical and coordinate VS processing across adult age. Specifically, categorical and coordinate VS processing will be examined through four studies in order to investigate how, if at all, VS processing of categorical and coordinate spatial relations changes with age.

With this in mind, the introductory chapters are divided into two sections: Chapter 1 provides an overview of the literature regarding categorical and coordinate VS processing. Specifically, this will provide insight into how younger adults process categorical and coordinate spatial relations, and will provide a benchmark pattern of results from which older adults can be compared. Chapter 2 provides an overview of the cognitive ageing literature, and concludes with the implications of age for categorical and coordinate VS processing.

Chapter 1 is structured as follows: Section 1.1 will describe the dichotomy between categorical and coordinate VS processes. Section 1.2 will introduce the theory of categorical and coordinate hemispheric specialisation before describing two possible theories as to why specialisations may be observed. Section 1.3 will describe and evaluate the empirical research from four converging methodological approaches that have investigated categorical and coordinate VS processes. Section 1.4 will describe the importance of task demand in hemispheric specialisation and the possibility that the cognitive processes underlying categorical and coordinate VS processes are not qualitatively distinct will be introduced. Finally, Section 1.5 will summarise what is known about categorical and coordinate VS processes in younger adults, and conclusions will be drawn.

1.1. Categorical and Coordinate Spatial Relations: An Introduction

Kosslyn (1987) suggested that spatial relations can be described by two independent VS processing systems: categorical and coordinate VS processes. Categorical spatial relations describe broad directional relationships between objects, without specifying precise location details. For example, describing that the computer mouse is to the right of the keyboard gives an accurate categorical description concerning the whereabouts of the mouse; it is to the right. This information gives a broad representation of our environment, but is insufficient for an individual to grasp the mouse accurately (Jager & Postma, 2003). Indeed, the keyboard may have a large area to its right and the mouse could be located anywhere in this space. For successful interaction with the mouse we need to know its precise location. For example, that it is 5 cm north east of the top right corner of the keyboard. This is a coordinate spatial relation, which is much more specific and indicates the precise position of an object, with particular emphasis on the metric distance between objects (Kosslyn, 1987; Kosslyn, Chabris, Marsolek, & Koenig, 1992).

It is argued that categorical spatial relations are, essentially, verbal labels that provide simple, relative information (see Laeng, Chabris, & Kosslyn, 2003; Landau & Jackendoff, 1993; Noordzij, Neggers, Ramsey, & Postma, 2008). As such, categorical spatial relations are suggested to be discrete, often binary judgements (Laeng et al., 2003). That is, categorical descriptions are usually derived from one of two options; an object is either above or it is below another object, it is either to the right or it is to the left, and so forth. For example, imagine describing the location of the computer mouse in relation to the keyboard. To make this categorical judgement, one must discriminate between two possibilities based on the recognition of a predetermined pattern (Martin, Houssemond, Schiltz, Burnod, & Alexandre, 2008); the mouse is to the left of the keyboard *or* it is to the right. This left/right location can be confirmed through visual examination (Laeng & Peters, 1995). In this way, it is proposed that categorical VS processes are involved in prototypical shape, pattern and object identification (Chabris & Kosslyn, 1998; Cooper & Brooks, 2004; Kosslyn, 1987; Martin et al., 2008). For example, if you break down a cup into the items that comprise it; there is a bowl and a handle. Regardless of the exact shape and size of these separate items, knowing that the handle is located on the side of the bowl, instantly makes these items recognisable as a cup. Thus, through understanding and recognising the relations between object parts or, on a wider scale, between objects in a visual scene, we are able to recognise and identify specific objects and surroundings (see Biederman, 1987; Chabris & Kosslyn, 1998; Cooper & Brooks, 2004; Niebauer, 2001).

In contrast, coordinate spatial relations are on a more continuous scale, as they provide a measure of distance quantity (Laeng et al., 2003). For example, coordinate spatial descriptions could provide the exact distance between two objects which could range from 1 mm to 1 metre. From this, information such as whether an object is near or far from another object can be derived. Consequently, coordinate VS processes are suggested to be critical for navigation and guiding actions (Cooper & Brooks, 2004; Kosslyn, 1987; Kosslyn et al., 1992; Rybash & Hoyer, 1992). For example, as detailed earlier, in order for successful interaction with our environment, we need to know the exact whereabouts of the objects that comprise it. In this way, we can avoid colliding with obstacles in our path, or can pick up a coffee cup without knocking the contents over ourselves. Given the precise nature of coordinate spatial relations, it is argued that these VS processes are more demanding to compute than categorical VS processes. However, although it is generally assumed that coordinate VS judgements require some sort of distance computation, the extent to which precise distance computations are required is not clear. Indeed, the exact cognitive processes underlying categorical and coordinate VS processes have not received a great deal of research, and insight and understanding of these processes is limited. This is central to the thesis and will be further discussed in Chapter 1, Section 1.5.

1.2. A Theory of Categorical and Coordinate Hemispheric Asymmetry

To reiterate, categorical and coordinate VS processes are suggested to utilise different processing systems (Kosslyn, 1987; Kosslyn et al., 1992). Kosslyn and colleagues (Kosslyn, 1987; Kosslyn et al., 1989; Kosslyn et al, 1992) further suggested that the two VS processes predominantly activate neural processing in different hemispheres. Specifically, the LH is suggested to be more efficient at processing categorical spatial relations, whereas the RH is suggested to be more efficient for processing coordinate spatial relations (Kosslyn, 1987). Thus, typically, hemispheric asymmetries between categorical and coordinate VS processes are interpreted to reflect functional differences.

It is important to note that it is not suggested that only one hemisphere is involved in each of the VS processes, but instead that one hemisphere is more dominant, processing the information relatively more efficiently (e.g., faster and with fewer errors) than the other (see Koslyn et al., 1992; Sergent, 1991). Accordingly, the hemispheric specialisations of categorical and coordinate VS processes described throughout this thesis refer to *relative processing advantages*, rather than absolute advantages (Sergent, 1991).

Before empirical evidence investigating these specialisations is reviewed it is first important to consider how these specialisations may come about. The remainder of this section will describe the snowball mechanism and receptive field size in obtaining categorical and coordinate hemispheric specialisations. Task demand has also been postulated to contribute to hemispheric specialisations obtained; however, the importance of task demand will be discussed in greater detail in Section 1.4.

1.2.1. Snowball mechanism.

The snowball mechanism was the first explanation put forward to motivate the distinction between categorical and coordinate VS processes. The snowball mechanism assumes that each hemisphere is predisposed to certain types of cognitive processing, and that due to a positive feedback training system, the processing system gradually accrues in neural strength, reinforcing specific functioning in that hemisphere (Kosslyn, 1987). For example, language processing is suggested to be innately biased towards LH processing systems (e.g., see Harrington, 1995). Spatial categories typically employ a single verbal label to describe a location. It is suggested that this label, in itself, automatically has language-based attributes (Carlson & Van Deman, 2004; Hartley, Speer, Jonides, Reuter-Lorenz, & Smith, 2001; Landau & Jackendoff, 1993; Noordzij et al., 2008). Kosslyn (1987) suggested that categorical spatial relations are represented in much the same way as language representations. Thus, it seems reasonable to assume that the processing systems already set-up in this hemisphere (i.e. the LH) will be more effective at processing categorical information. Specifically, when assessing categorical spatial relations between objects in the environment, an individual can compare the recently encoded categorical representation to the representations already stored in the LH. When a representation is matched, positive feedback is transmitted back down the processing stream, so that a response/action can be made. This feedback serves to strengthen the neural pathways utilised for this process, reinforcing specialisation of the LH for this type of information (Kosslyn, 1987).

Conversely, Kosslyn (1987) argued that the RH is more predisposed towards visual search, a necessary component of navigation; if an individual does not know exactly where obstacles in their path are, they cannot navigate around them. In order to navigate successfully and interact with objects in the environment, first the precise locations of these objects must be encoded, as must the distance between objects. Thus, much like categorical and language information, it seems reasonable to assume that processing systems already available in the RH would be more effective at processing precise location information. That is, precise location information will be better stored in the RH in order that it can be used for later navigation or action guiding. Again, positive feedback is transmitted back down the processing system, and serves to enhance the neural connections utilised and reinforces that this hemisphere is more efficient at processing precise locational information.

To be clear, the snowball mechanism is based on the assumption that the LH and RH are innately predisposed to certain types of processing; language and visual search. These functions have similarities with categorical and coordinate representations, respectively, so that when spatial information is processed it is immediately more efficiently processed by one hemisphere. Positive feedback systems then reinforce this, and, gradually, every time certain types of information are processed, the system strengthens resulting in hemispheric specialisation. In this way, it is suggested that different cognitive processes underlie categorical and coordinate spatial relations.

1.2.2. Receptive fields and attentional bias.

Since Kosslyn's theorising in 1987, his initial theories have undergone some change and different explanations have been postulated regarding the hemispheric dissociation between categorical and coordinate VS processes. For example, it has been suggested that hemispheric asymmetries found for categorical and coordinate VS processes may be caused by the type of output that is attended from low-level neurons (Kosslyn, Anderson, Hillger, & Hamilton, 1994; Kosslyn, Chabris & Baker, 1995; Kosslyn et al., 1992; Jacobs & Kosslyn, 1994; Sergent, 1991; see also Jager & Postma, 2003; Laeng et al., 2003). Specifically, it is argued that the two hemispheres are more biased towards encoding information from neurons with different sized receptive fields (Chabris & Kosslyn, 1998). The receptive field of a neuron is 'the region of space from which that neuron receives stimulation' (Chabris & Kosslyn, 1998; p.10), and the size of a neurons receptive field differs, as does the overlap between the receptive fields. Importantly, different sized receptive fields are suggested to lend themselves more readily to categorical or coordinate VS judgements.

Broadly speaking, large receptive fields often overlap. Sampling output from many neurons whose receptive fields overlap is suggested to allow for more precise localisation of objects (Chabris & Kosslyn, 1998; Jager & Postma, 2003; Kosslyn et al., 1992). In this way, Kosslyn et al. (1992) suggested that output from large receptive fields facilitates coordinate VS processing. By contrast, small receptive fields are suggested to have very little, if any, overlap (Kosslyn et al., 1992). Accordingly, it is argued that visual space can be divided into specific regions, and this is suggested to facilitate categorical VS processing (Chabris & Kosslyn, 1998; Jager & Postma, 2003; Kosslyn et al., 1992). That is, the location is within one spatial region or another. Kosslyn et al. (1992) further argue that when stimuli do not easily fit into one region (i.e. appear in several regions, or close to a region's boundary), they become more difficult to judge. It is suggested that the LH is biased to encode information from neurons with small receptive fields, whereas the RH is biased to encode information from neurons with large receptive fields; hence, causing the observed hemispheric advantages.

Kosslyn et al. (1992; Experiment 3) assessed whether differences in receptive field contributed to categorical and coordinate hemispheric asymmetries through computational modelling. They programmed a computational neural network model in which input was either filtered through large receptive fields or small receptive fields. The model computed near/far judgements in the coordinate task, and above/below judgements in the categorical task. Kosslyn et al. (1992) found that when input was filtered through small receptive fields, the model more accurately computed categorical judgements. However, the model was more accurate in the coordinate task when the input was filtered through large receptive fields. Similarly, when receptive fields were not fixed but, instead, were allowed to adapt during learning, large receptive fields developed for the coordinate computations, and small receptive fields developed for the categorical computations (Kosslyn et al., 1992). These results have been replicated and extended in similar computational models (e.g., see Baker, Chabris, & Kosslyn, 1999; Jacobs & Kosslyn, 1994).

Differences in receptive fields are further supported by Cowin and Hellige's (1994) study involving the blurring of stimuli. They argued that blurring of stimuli would affect neurons with small receptive fields, and thus, categorical VS processing. This is because the boundaries that defined the category regions would become degraded, and without definite distinctions it would become more difficult to categorise certain positions. Cowin and Hellige presented participants with a blurred image of a dot and a bar from which participants had to make a spatial judgement regarding the dot. In the categorical task, participants had to judge whether the dot was above or below the bar and in the coordinate task participants had to make a near/far judgement. As predicted, presenting participants with a blurred image of a dot and bar stimuli impaired categorical but not coordinate VS judgements.

There is a relatively strong theoretical argument that receptive fields/attentional biases are important in determining categorical and coordinate hemispheric specialisations; however, there also exists a body of research that disagrees with the empirical evidence found (Cook, Früh, & Landis, 1995; Oleksiak, Postma, Van der Ham, & Van Wezel, 2009). Recently, Oleksiak et al. (2009) highlighted several discrepancies that exist between the small/large receptive field hypothesis and the findings from categorical and coordinate tasks. For example, they suggest that information received from neurons with large receptive fields should lead to faster processing than information received from neurons with small receptive fields. However, research has consistently found that participants make categorical judgements more quickly than coordinate judgements (see Jager & Postma, 2003). That is, arguably, information is processed more quickly from small receptive fields. Oleksiak et al. specifically investigated receptive field size and the time course of processing, and found no differences in processing speed between categorical and coordinate tasks. Thus, providing no evidence to support the assumption that categorical VS processes use small receptive fields and coordinate VS processes use large receptive fields.

In conclusion, theories for the hemispheric dissociation between categorical and coordinate VS processes are by no means complete and are still evolving from new research. Nevertheless, it would seem that there are theoretical rationales that motivate hemispheric asymmetry between categorical and coordinate VS processes. The research investigating this claim will be reviewed in the following section.

1.3. A Review of Categorical and Coordinate Hemispheric Specialisation Research

A number of techniques have been used to study hemispheric specialisations associated with categorical and coordinate VS processes; ranging from computational neural network models to brain imaging. In addition, studies have investigated categorical and coordinate VS processes in simple visuoperceptual tasks (e.g., Banich & Federmeier, 1999; Cowin & Hellige, 1994; Hellige & Michimata, 1989; Hoyer & Rybash, 1992; Kosslyn et al., 1989; Niebauer & Christman, 1998; Rybash & Hoyer, 1992; Sergent, 1991; Wilkinson & Donnelly, 1999; for recent reviews see Jager & Postma, 2003; Laeng et al., 2003), spatial imagery tasks (Kosslyn, Maljkovic, Hamilton, Horwitz, & Thompson, 1995; Michimata, 1997; Palermo, Bureca, Matano, & Guariglia, 2008; Rinck & Denis, 2004; Trojano et al., 2002; Trojano, Conson, Maffei & Grossi, 2006) and spatial memory tasks (Kessels, Kappelle, De Haan, & Postma, 2002; Postma, Izendoorn, & De Haan, 1998; Slotnick & Moo, 2006; Van Asselen, Kessels, Kappelle, & Postma, 2008; Van der Lubbe, Schölvinck, Kenemans, & Postma, 2006).

Typically, previous research examining categorical and coordinate VS processing has used a simple bar-dot visuoperceptual paradigm, in which participants are presented with a horizontal bar and a dot located at varying distances above or below the bar (Hellige & Michimata, 1989; Kossyln et al., 1989). This bar-dot stimulus is presented to the LH or RH (e.g., by lateralising stimuli: further details follow), and participants make a judgement regarding the location of the dot. Categorical tasks require an above/below decision based on the position of the dot in relation to the bar, irrespective of distance. In contrast, for coordinate tasks, participants are required to make a judgement regarding the distance of the dot from the bar, such as a near/far decision.

It is argued that a double dissociation between task (categorical, coordinate) and hemisphere (left, right) indicates that the two tasks utilise separate VS processes (see Jager & Postma, 2003). Specifically, it is predicted that VS processing in the LH will be faster and more accurate for categorical VS judgements whereas processing in the RH will be faster and more accurate for coordinate VS judgements.

Before the research is reviewed, it is important to note that the studies described focus on right-handed individuals. Organisation in the brain is suggested to be more lateralised in right-handed individuals (Hellige, 1993; Josse & Tzourio-Mazoyer, 2004). Accordingly, hemispheric specialisation for categorical and coordinate VS processes should be more pronounced in right-handed than in left-handed individuals (Kosslyn, 1987). Kosslyn et al. (1989; Experiment 4) examined this by analysing results with respect to handedness (as defined by Oldfield, 1971). Participants were grouped as very strongly right-handed or weakly right-handed. Kosslyn et al. (1989) found that overall hemispheric advantages for the categorical and coordinate tasks were largely driven by the results of the strongly right-handed participants. Additionally, Laeng and Peters (1995) did not find any prominent hemispheric advantages for categorical and coordinate VS tasks with left-handed participants. As such, this review focuses on categorical and coordinate VS processing in right-handed individuals only.

The following section will review the existing research investigating hemispheric specialisations in VS processing. The findings from four main methodological approaches will be discussed: visual half-field studies; computational studies; clinical studies; and brain imaging studies.

1.3.1. Visual half-field studies.

The most commonly used method to examine categorical and coordinate asymmetries is the visual half-field paradigm. Typically, in visual half-field studies, participants fixate on a central point and a stimulus is presented in one VF for about 150 ms (Jager & Postma, 2003). Briefly presenting the stimuli on one side, projects the information to the contralateral hemisphere, allowing this hemisphere initial access to the spatial information (Jager & Postma, 2003). More specifically, it is suggested that in each eye the retina is split (see Hellige, 1993; see also Jordan, Paterson, & Stachurski, 2008; Lavidor & Walsh, 2004; Shillcock, Ellison, & Monaghan, 2000; Shillcock & Monaghan, 2001 for reviews of split fovea theory), so that information appearing in the space furthest from the nose is projected to the ipsilateral (i.e. same) hemisphere, whereas the visual information appearing in the space nearest to the nose is projected to the contralateral (i.e. opposite) hemisphere (e.g., see Hellige, 1993). In this way, when participants are fixating a central point, anything presented to the right of the fixation point (i.e. RVF) is initially projected to the LH (via the corpus callosum), whereas anything presented to the left of the central fixation (i.e. LVF) is initially presented to the RH (Hellige, 1993). From this, relative advantages can be obtained according to which hemisphere the information is initially presented and activated. To be clear, in visual half-field studies, a Task by VF interaction is sought in which there is a RVF-LH advantage for categorical VS processing and a LVF-RH advantage for coordinate VS processes.

Hellige and Michimata (1989) were among the first to examine hemispheric specialisations for categorical and coordinate VS processes. In their tasks, they presented participants with a bar and a dot located above or below the bar at 1 of 6 distances away from the bar. For the categorical task, participants were required to make an above/below judgement, whereas in the coordinate task, participants had to judge whether the dot was within (near) or further than (far) 2 cm from the bar. Importantly, Hellige and Michimata found an interaction between Task and VF. This showed that participants were faster and more accurate to respond in the coordinate task when the stimuli were presented in the LVF-RH. In contrast, for the categorical task, participants were faster and more accurate to respond when the stimuli were presented in the RVF-LH.

An interaction between Task and VF has been found in a great deal of visual half-field experimental studies (e.g., Banich & Federmeier, 1999; Hellige & Cumberland, 2001; Hellige & Michimata, 1989; Hoyer & Rybash, 1992; Kosslyn et al., 1989; Niebauer & Christman, 1998; Rybash & Hoyer, 1992; Sergent, 1991; Wilkinson & Donnelly, 1999; for recent reviews see Jager & Postma, 2003; Laeng et al., 2003). However, a Task by VF interaction is not always found, and many studies have shown that categorical and coordinate hemispheric advantages are highly susceptible to influences from modulating factors such as task demands, both in relation to the cognitive resources involved in the task and the experimental conditions (e.g., Banich & Federmeier, 1999; Bruyer, Scailquin & Coibion, 1997; Okubo & Michimata, 2002; Okubo & Michimata, 2004; Parrot, Doyon, Démonet, & Cardebat, 1999; Van der Lubbe et al., 2006; Wilkinson & Donnelly, 1999). For example, Wilkinson and Donnelly (1999; Experiment 3) demonstrated that exposure time is a critical factor in gaining evidence for VS specialisation. Specifically, the authors found a Task by VF interaction when participants viewed the stimuli for 100 ms but not when the stimuli were viewed for 200 ms. Banich and Federmeier (1999) manipulated the position of the bar; in one condition the position of the bar was held constant (i.e. always appeared on the vertical midline), whereas in the other condition the bar could appear at 1 of 3 positions (at the vertical midline or 2^{o} above or below the midline). Banich and Federmeier demonstrated that when the bar to which a judgement was being made varied in position, an interaction between Task and VF was observed. However, when the bar was held constant there was no interaction.

Importantly, even when a Task by VF interaction is obtained, a double dissociation is not always found. That is, the interaction is sometimes driven by one advantage only. More specifically, the RVF-LH advantage for categorical judgements is not always significant (e.g., Hellige & Michimata, 1989; Hoyer & Rybash, 1992; Kosslyn et al., 1989; Michimata, 1997; Sergent, 1991).

One explanation for non-significant RVF-LH advantages for categorical tasks is that although categorical spatial relations are associated with the LH, they are still a VS process and so may have numerous neural connections within the RH (given that this hemisphere is traditionally associated with VS processing). Indeed, the hemispheric specialisations found are only relative, and it is argued that both hemispheres are involved to a certain degree in both categorical and coordinate VS processes (Sergent, 1991). As such, it may be that during categorical judgements the RH is more involved in categorical processes than the LH is in making coordinate judgements.

This explanation is consistent with Niebauer (2001), who speculated that categorical VS processing is involved in the early stages of coordinate VS processing and, as such, the RH may already have a network for computing this type of judgement. That is, before precise distance coordinates are computed the location may be first mapped in terms of broad relational details. Hence, for the categorical task, when stimuli are initially presented to the RH, the network system associated with this hemisphere may be activated and reduce the overall advantage of the LH.

Alternatively, the lack of a clear RVF-LH advantage may be due to power issues. Indeed, although not always significant, a trend for specialisation of categorical processes is often found in the predicted direction (i.e. a RVF-LH advantage). That is, numerically participants are faster to respond in a categorical task when the stimuli are presented in the RVF (e.g., Hellige & Michimiata, 1989; Kosslyn et al., 1989). In a meta-analysis, Laeng et al. (2003) found that the average advantage in terms of RT was nearly twice as long in the coordinate task (a LVF-RH advantage of 14 ms) compared to the categorical task (a RVF-LH advantage of 8 ms). Importantly, this shows that the hemispheric advantages for categorical and coordinate VS processes are relatively small, and further suggests that the advantage for categorical tasks is much smaller than in coordinate tasks; however, Laeng et al. did not provide effect sizes for each task individually. Importantly, when a significant Task by VF interaction is teamed with a trend for a RVF-LH advantage, many authors argue that this provides support for independent VS processing systems (e.g., Hellige & Michimata, 1989; Kosslyn et al., 1989).

The LVF-RH advantage for coordinate tasks is more consistently found, however, this advantage has been shown to attenuate with practice (e.g., Baciu et al., 1999; Hoyer & Rybash, 1992; Kosslyn et al., 1989; Rybash & Hoyer, 1992), and some authors have found a RVF-LH advantage for coordinate processes (Parrot et al., 1999; Parrot, Doyon, & Cardebat, 2000; Slotnick et al., 2001). For example, Hoyer and Rybash (1992) found a LVF-RH advantage only in block 1 of 3. With the rapid disappearance of LVF-RH advantages, some authors suggest that with time and practice, coordinate judgements are taken over by processing systems in the LH. Specifically, Kosslyn et al. (1989) suggested that with practice new categories were developed specifically to evaluate whether a coordinate distance condition has been met, without having to measure the actual distance.

This explanation is in line with Huttenlocher, Hedges and Duncan's (1991) category-adjustment model for VS memory. Huttenlocher et al. (1991) agree there are two VS processes, and suggest that spatial locations are retrieved through an interaction between the two processes. However, coordinate information is suggested to decay at a much faster rate than categorical information (Huttenlocher et al., 1991; Van der Ham, Van Wezel, Oleksiak, & Postma, 2007). Huttenlocher et al. (1991) further suggested that when coordinate information decays and becomes inexact, categorical information is given greater emphasis. That is, when precise location information is uncertain, categorical processes are the default processes for encoding spatial relations, and compensate for the lack of location precision (Postma, Huntjens, Meuwissen, & Laeng, 2006; Van der Ham et al., 2007). For example, Postma et al. (2006) asked participants to relocate a previously viewed dot back to its original location in a circle. The interval between viewing the dot and relocating it was manipulated. They found that participants were biased towards relocating the dot near to the centre of a quadrant and near to the circumference of the circle, and that these biases increased as a function of retention interval. Thus, it seems that with practice or when precise coordinate information is not available, processes underlying categorical VS judgements can be used to make different types of spatial relation judgements.

Together, these findings suggest that coordinate VS judgements may utilise similar cognitive processes, or at least similar neural networks, as those underlying categorical VS judgements. Furthermore, it questions whether coordinate tasks that have shown RVF-LH advantages, such as the near/far coordinate task, are sensitive assessments of coordinate VS processes. The limitations of this task have been raised before, and adaptations of the task have been developed with varying degrees of success (Banich & Federmeier, 1999; Bruyer et al., 1997; Rybash & Hoyer, 1992; Sergent, 1991). This issue is discussed in Section 1.5, and is addressed throughout the thesis.

Visual half-field studies have, therefore, provided some evidence to support a RVF-LH advantage for categorical VS processes and a LVF-RH advantage for coordinate VS processes. However, these studies do not always report consistent findings and it is clear that hemispheric advantages are highly dependent on experimental conditions. In addition, these studies alone do not offer a great deal of insight about the processes that underlie categorical and coordinate VS processing. Thus, it is difficult to conclude definitively whether categorical and coordinate VS processes are independent processing systems as suggested by Kosslyn and colleagues (Kosslyn, 1987; Kosslyn et al., 1992; Kosslyn et al., 1989).

1.3.2. Computational models.

Computational models are designed to compare systems and make predictions, and can be used to test whether two systems are computationally similar or different (Kosslyn et al., 1992). This is achieved by mapping input to output responses that correspond to those found in the brain (Kosslyn et al., 1992). Accordingly, computational models have been used as a methodological approach to provide support for the dissociation between categorical and coordinate VS processes.

Kosslyn et al. (1992) were the first to publish a series of computational studies that examined whether there were differences between categorical and coordinate VS processes. Their model computed the bar-dot categorical and coordinate tasks used by Hellige and Michimata (1989) and Kosslyn et al. (1989). This was run on two types of neural network; a split and an unsplit neural network. In the unsplit network, the model performed the tasks as if only one process was underlying VS encoding. In contrast, the split network performed the tasks as if VS encoding comprised two separate processing systems; one for categorical and the other for coordinate spatial relations. The aim of this study was to see which network performed the task most efficiently, in order to establish whether or not categorical and coordinate VS processes used similar computations. The results showed that the split network model was more efficient at performing the two tasks than the unsplit model. That is, when the network was split into separate computations, performance was significantly better than when one undifferentiated network performed both tasks. Arguably, in the split network, each separate system specialised in a different computation (i.e. categorical and coordinate), whereas in the unsplit network it was more difficult for resources to divide and, thus, there was interference from the competing tasks. Again, this is consistent with the idea that two distinct neural processes underpin categorical and coordinate VS judgements, and this could correspond to the predicted hemispheric specialisations. These findings with computational models have since been replicated (Baker et al., 1999; Jacobs & Kosslyn, 1994). However, as with the visual half-field studies, computational modelling does not provide any detail about the actual processes or, the areas of the brain that are involved in categorical and coordinate VS processing.

1.3.3. Clinical studies.

Studies have also been conducted with patients with damaged functioning in one hemisphere (e.g., Kessels, De Haan et al., 2002; Laeng, 1994; Laeng, 2006; Sergent, 1991). That is, patients with a unilateral lesion causing deficits to the functioning undertaken by that hemisphere. Specifically, it is argued that lesions disrupt the processes that occur within the damaged hemisphere, thereby allowing assessment of the involvement of processes within that hemisphere. In addition, these studies allow speculation regarding the areas of the brain that are involved in these processes.

Laeng (1994) examined categorical and coordinate VS processing in patients with unilateral brain lesions. Specifically, the lesions occurred in the parietal lobes only, the parietal and temporal lobes or the parietal and frontal lobes. Laeng showed patients pictures of one or two animals or objects. After a short delay, patients were shown this picture again, along with a second picture that differed from the first in either a categorical or coordinate fashion. Categorical changes included the direction in which the animal was facing, whereas a coordinate change included the distance between two animals. Patients were asked to judge which picture was the same as that previously viewed. Laeng found that while patients with LH damage made more errors for the categorical changes (i.e. correctly identified fewer pictures with categorical changes), those with RH damage made more errors for coordinate spatial changes (i.e. correctly identified fewer pictures with coordinate changes).

There is some reservation about conclusions drawn from patients with brain damage, since the results might not reflect the same processes as those that take place in an undamaged brain due to plasticity and reorganisation of some functioning (Sergent, 1991). Indeed, often when a brain has suffered damage, to compensate, the remaining neural pathways reorganise and create new networks utilising different areas of the brain (e.g., Jansen, Flöel, Menke, Kanowski, & Knecht, 2005). Accordingly, just because one area of the brain is damaged, does not necessarily mean that the processes subserving this area are completely disabled.

An innovative study, by Slotnick, Moo, Tesoro, and Hart (2001), which simulated patients with unilateral brain damage, explored hemispheric lateralisation of VS encoding using the intracarotid amobarbital procedure to deactivate one hemisphere temporarily. This technique anaesthetises one hemisphere, so the functioning of the other hemisphere can be assessed. Slotnick et al. (2001) administered five tasks: two categorical and three coordinate, which differed in task demand. When task demand was high, participants made more errors on a coordinate task when the RH was deactivated. By contrast, when task demand was low, LH advantages were found in both the categorical and coordinate tasks.

Evidence from patients with unilateral damage, therefore, provides some support for hemispheric specialisation of categorical and coordinate VS processes and provides further insight into the neural networks utilised for these processes. Specifically, they indicate that the parietal lobes are involved in the processing of categorical and coordinate VS processes, and demonstrate that there is a double-dissociation between categorical and coordinate VS processing in relation to specialisations in the LH and RH, respectively. However, in line with the visual-half field studies, Slotnick et al.'s (2001) study highlights that these specialisations are highly dependent on experimental conditions such as task demand, and this will be further discussed in Section 1.4. In contrast to the visual-half field research, studies with clinical populations provided further insight into categorical and coordinate VS processes utilised, at least in respect to the areas of the brain involved.

1.3.4. Brain imaging.

Investigation of the areas of the brain involved in categorical and coordinate VS processes can be better examined through the use of imaging studies (e.g., functional magnetic resonance imaging – fMRI; Baciu et al., 1999; Buron et al., 2003; Martin et al., 2008; Trojano et al., 2002) or recordings of electrical activity (e.g., Event Related Potentials – ERPs; Parrot et al., 2000; Van der Lubbe et al., 2006). These types of study are often used in conjunction with visual half-field studies, and provide converging evidence in support of categorical and coordinate hemispheric specialisations.

In line with the clinical studies, imaging studies have shown that categorical and coordinate VS processes activate areas in the parietal lobes, and in particular, the angular gyri. The angular gyri are located deep within the parietal lobes and are suggested to be involved in processing visual information (Leigh & Zee, 2006). Importantly, these studies have demonstrated that hemispheric activity is differential for categorical and coordinate VS tasks. For example, Baciu et al. (1999) used fMRI specifically to explore the involvement of the angular gyri in processing categorical and coordinate spatial relations in a simple bar-dot experiment. Baciu et al. (1999) found increased activation in the left angular gyrus during the categorical task, whereas on initial blocks of the coordinate task, greater activation was found for the right angular gyrus.

These results were replicated by Trojano et al. (2002) in a mental imagery task. Specifically, Trojano et al. (2002) asked participants to imagine clock faces depicting certain times that were given to them. In the categorical task, participants were then asked to judge whether both clock hands were in the same half of the clock face (top, bottom, left or right). In the coordinate task, participants were asked to imagine two clocks, and had to judge which time produced the greater angle between the clock hands. Trojano et al. (2002) found that the coordinate task elicited more activation in the right parietal lobe, whereas the categorical task elicited greater left parietal lobe activation, especially in the angular gyri.

Research has also shown that areas in the frontal lobes are activated during categorical and coordinate tasks. The frontal lobes are involved in higher-order cognitive processes, which often require greater cognitive resources (e.g., see Harrington, 1995; West, 1996). For example, Slotnick and Moo (2006) presented participants with blocks of six stimuli that consisted of an irregularly shaped blob and a dot. The dot was located either on the blob's contour or outside the blob's contour, at varying distances. Once all six stimuli had been shown, there was a short interval, before the blob stimuli (without the dot) were re-presented. Participants were asked to make judgements concerning the location of the dot. In the categorical task, participants had to judge whether the dot was on or off the contour of the blob, and in the coordinate task, participants had to judge whether the dot was near or far from the contour of the blob. Slotnick and Moo (2006) found more activation in the left prefrontal cortex (PFC:

an area located within the frontal lobes) during the categorical task and the right PFC during the coordinate task.

However, as with the previous methodological approaches, not all imaging studies have shown the predicted hemispheric specialisations. For example, Van der Lubbe et al. (2006) used ERP methodology to investigate categorical and coordinate VS processing. Interestingly, Van der Lubbe et al. found evidence to suggest that at about 168 ms after presentation, stimuli presented in the LVF activate areas in the RH and stimuli presented in the LVF activate areas in the RH. However, beyond this they found no evidence to support hemispheric dissociation. Specifically, the LH was not more activated during categorical tasks and the RH was not more activated during coordinate tasks. Instead, it was found that when encoding a spatial relation to memory, the areas of cortical activation were similar during both tasks, with the only difference being that there was greater activation in the coordinate task than in the categorical task. Van der Lubbe et al. interpreted this quantitative difference in activation to indicate that more attentional processes were required for successful performance in the coordinate task.

In summary, brain imagining studies have provided greater insight into the processing systems utilised by categorical and coordinate VS processes. Specifically, some studies have highlighted that there is greater activation in the LH during categorical tasks, whereas there is greater activation in the RH during coordinate tasks. Furthermore, it seems that the parietal and frontal lobes are particularly important. Thus, brain imaging studies can provide another strand of converging evidence in support of Kosslyn’s (1987) hemispheric asymmetry theory.

1.3.5. Summary.

In summary, it is suggested that categorical and coordinate spatial relations are two independent VS processes, and that this is demonstrated through differential hemispheric specialisation. To date, the majority of empirical research has focussed on investigating hemispheric specialisations for categorical and coordinate VS processes. However, despite converging methodological approaches, the hemispheric advantages were not always found and seem highly sensitive to experimental conditions, such as task demand. Not only does this question how robust these findings are but it also suggests that other factors may be moderating the specialisations. Indeed, recently, it has been suggested that task demand is a critical factor in obtaining the hemispheric advantages observed. This has important implications for the dissociation between categorical and coordinate VS processes and will be discussed in the following section.

1.4 The Importance of Task Demand in VS Processing

As mentioned earlier, task demand has been put forward as a possible factor in determining categorical and coordinate hemispheric specialisations. A number of studies have shown a LH advantage for categorical and low demand, 'easy' coordinate tasks, whereas the RH advantage for the coordinate task has been found under high task demand (e.g., Parrot et al., 1999; Slotnick et al., 2001; Trojano et al., 2002). This has led some authors to suggest that task demand drives hemispheric specialisation, with higher demand tasks requiring more input from the RH (Martin et al., 2008; Oleksiak et al., 2008; Parrot et al., 1999; Slotnick et al., 2001).

Martin et al. (2008) explored the importance of task demand directly. To do this, they administered three tasks in which participants had to judge whether a test figure correctly depicted five previously presented locations. In the first categorical task the display was divided into a 4x4 grid. A small cross was presented in five grid locations, sequentially, and participants were asked to imagine the whole grid square was filled in. In the second categorical task, the grid was distorted so that the categorical boundaries were less clear, and in the coordinate task no grid lines were visible. The test figure displayed a pattern in which five squares were coloured black, and participants had to judge whether this pattern matched the locations previously viewed. Martin et al. argued that by presenting five locations sequentially the amount of cognitive demand necessary to keep the locations active in memory could be assessed.

Consistent with previous research, Martin et al. (2008) found that neural networks in the parietal lobes and PFC were activated, as well as areas of the occipital lobes and premotor cortex. Activation patterns were not found to be differentially lateralised and the only task by hemisphere interaction was for activation in the parietal lobes. Interestingly, all three tasks showed greater activation in the right parietal lobe, however, overall activation was far greater in the coordinate task than in either of the two categorical tasks. These findings replicated the results reported by Van der Lubbe et al. (2006) who showed greater activation during the coordinate task compared to the categorical task when spatial relations were being encoded to memory. Martin et al. (2008) also found that there was a positive association between memory load and RH activation in that as memory load increased so did RH activation. That is, as more locations were viewed and encoded, activation in the RH increased.

From these findings, it has been suggested that categorical and coordinate VS processes are not qualitatively different but, instead, are quantitatively different (Martin et al., 2008; Oleksiak et al., 2009; Van der Lubbe et al., 2006). Specifically, Van der Lubbe et al. (2006) suggested that differential activation strength for categorical and coordinate VS processing may reflect the effects of a compensatory strategy involving the allocation of attention. It is suggested that judging precise distance is more demanding than judging relative positions, and so to maintain a high level of accuracy, more attention may be allocated to processing the stimuli when distance is to be judged in the coordinate task. This elicits greater cerebral activation.

Martin et al. (2008) further suggest that categorical and coordinate representations are located at opposite ends of a *continuous spatial code* and use similar cognitive processing networks. The perceived hemispheric advantages are suggested to reflect the different weightings of general cognitive resources (such as, VS attention and executive functioning), that each task requires. These general cognitive resources are thought to be subserved by RH neural networks (see Martin et al., 2008; Wager & Smith, 2003). Given that coordinate VS processes consistently have been found to be more difficult than categorical VS processes (see Jager & Postma, 2003), it can be argued that the observed LVF-RH advantage found for coordinate VS judgements are induced by task demand.

If hemispheric specialisations for categorical and coordinate VS processes are driven by task demand rather than different VS cognitive processes per se then this could explain the inconsistencies in the results. For example, recall that in coordinate tasks the RH advantage has been shown to attenuate with practice. In theory, with increased practice of coordinate VS judgements, the task becomes easier. If the RH is recruited for more demanding tasks, as task demand becomes sufficiently low the involvement of the RH will reduce. This is consistent with Baciu et al. (1999) who showed that, with practice, areas in the RH that initially had high activity, significantly decreased in involvement as the trials continued. This implies that the LH advantage develops when the RH becomes more deactivated (Rybash & Hoyer, 1992). These studies, therefore, put the interpretation of categorical and coordinate hemispheric dissociation into question. Specifically, if the RH was truly specialised in coordinate VS ability, with practice the RH should become more specialised in this ability, rather than de-specialised (Weissman & Compton, 2003).

In summary, recent work has suggested that hemispheric advantages found may not reflect the specialisations of the spatial processes per se, but instead reflect the hemispheres' involvement in resources required for different task demands. These findings, therefore, question Kosslyn's theory (Kosslyn, 1987; Kosslyn et al., 1989; Kosslyn et al., 1992) and suggest that the hemispheric dissociations associated with categorical and coordinate VS processes do not demonstrate qualitatively distinct cognitive processes. Instead, accordingly to Martin et al. (2008), the underlying processes for categorical and coordinate VS judgements are similar, and the extent to which hemisphere is more activated depends upon how much VS attention and executive functioning is required.

The importance of task demand has only recently been directly considered as an explanation for hemispheric dissociation of categorical and coordinate VS processes. Thus, it is clear that further work investigating the importance of task demand in obtaining the hemispheric specialisations in categorical and coordinate VS judgements is required. Accordingly, task demand, with respect to how difficult the tasks are and the amount of cognitive resources required, will be systematically investigated throughout the thesis.

1.5. Chapter Summary

In summary, in 1987 Kosslyn theorised that spatial relations could be processed in two distinct ways. Specifically, it was suggested that independent processing systems for categorical and coordinate VS judgements were shown through different hemispheric specialisations. That is, the LH advantage for categorical VS processes and the RH advantage for coordinate VS processes were suggested to be demonstrative of two independent cognitive processes. Over twenty years of research has led to a large body of studies from a variety of methodological approaches, and, in general, most studies have demonstrated a Task by Hemisphere (or VF) interaction. At face-value, therefore, previous work has been supportive of Kosslyn's (1987) theory for categorical and coordinate hemispheric asymmetry. However, the findings are not always clear cut; a LH advantage is not always found for the categorical task, nor is a RH advantage always found for the coordinate task. This has made it difficult to interpret the results, especially as the expected advantages seem dependent on specific experimental conditions.

It must be noted that obtaining hemispheric dissociations does not necessarily imply that categorical and coordinate VS processes are qualitatively distinct. That is, just because neural networks in different hemispheres are activated does not mean that the actual underlying cognitive processes are different. Indeed, recently, it has been proposed that the hemispheric specialisations obtained for categorical and coordinate VS processes reflect nothing more than a quantitative difference in the cognitive demand associated with the task (Martin et al., 2008; Van der Lubbe et al., 2006). Thus, it would seem that the theoretical background regarding categorical and coordinate VS processes is not complete and is still evolving.

The preceding literature review has also highlighted that very little research has investigated the actual cognitive processes involved in categorical and coordinate tasks. For example, it is argued that coordinate VS processes compute precise locations; however, it is uncertain as to whether precise distance is computed in near/far tasks. Furthermore, coordinate VS processes are suggested to be continuous, quantitative descriptions of space, and using tasks that require a binary near/far decision, may instead utilise cognitive processes underlying categorical spatial relation decision. Thus, it is also clear that future research needs to investigate the on-line cognitive processes underlying categorical and coordinate VS processes. Greater understanding of the actual cognitive processes involved in spatial relation tasks will also provide insight into whether categorical and coordinate VS processes are qualitatively distinct.

In conclusion, despite the attention that this topic has received, critical questions still remain unanswered, and it is these that research should now focus. Specifically, it seems that the effect of task demand requires further investigation, as do the cognitive processes involved. Furthermore, another area in which this research is limited is the populations recruited. To date, work mainly relates to processing in younger adults, and there are very few studies investigating categorical and coordinate VS processes in children or older adults.

Disproportionate age-related changes are found in both VS processing and hemispheric activation. Thus, it is likely that older adults will differ with respect to how they process categorical and coordinate spatial relations. Research that has investigated categorical and coordinate VS processes in older populations is limited. However, there is a substantial body of work that has investigated age-related changes in VS processing and hemispheric specialisation and this will be reviewed in the following chapter.

Chapter 2
Cognitive Ageing

2.0. Cognitive Ageing: An Introduction

With age, changes occur in physical, cognitive and neurological functioning (e.g., Daselaar & Cabeza, 2005). These changes can benefit or cause detriment to cognitive processing (Baltes, 1987; Reuter-Lorenz, 2002). For example, it is suggested that *crystallised intelligence,* such as vocabulary and general information is likely to increase or remain constant, whereas *fluid intelligence*, which relates to abstract reasoning and problem-solving, tends to decrease with progression into older adulthood (Horn & Cattell, 1967). In general, with age, cognitive performance declines (Balcombe & Sinclair, 2001), although the magnitude of cognitive gains and losses fluctuates (Baltes, 1987). For example, in memory tests, younger adults usually recall more items than older adults. This has been found in a range of tasks including object-location tasks, assessing spatial memory (e.g., Kessels, Hobbel, & Postma, 2007; Uttl & Graf, 1993), and in the verbal domain (e.g., Norris & West, 1993; Rönnlund, Nyberg, Bäckman, & Nilsson, 2003).

Normal cognitive ageing is suggested to be a gradual process, although there is individual variance both in and between different cognitive tasks. Those domains in which reliable age-related decline has been found include episodic memory (e.g., Uttl & Graf, 1993), a variety of WM tasks (Chen, Hale, & Myerson, 2003; Reuter-Lorenz & Sylvester, 2004; Salthouse, 1994), speeded tasks (Brigman & Cherry, 2002; Salthouse, 1996), and many tasks that involve executive functioning (Lewis & Miller, 2007; Souchay & Isingrini, 2004), such as inhibition and attention (Castel & Craik, 2003; Colcombe, Kramer, Erikson, & Scalf, 2005; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Reuter-Lorenz & Sylvester, 2004).

As detailed in the introduction of Chapter 1, the primary aim of this thesis is to examine how categorical and coordinate VS processing changes with age. To date, there have only been two published studies that have investigated categorical and coordinate VS processing in younger and older adults; Bruyer et al. (1997) and Hoyer and Rybash (1992). There is, however, a large body of literature that has examined VS processing and hemispheric specialisation in older adults. Accordingly, the following review will describe theories of ageing that are relevant to categorical and coordinate VS processing. Specifically, Section 2.1 will describe the theory of generalised slowing, and Section 2.2 will discuss networks in the frontal lobes and WM capacity in relation to age-related decline. Two theories of hemispheric specialisation will then be discussed: In Section 2.3 the Hemispheric Asymmetry Reduction in the Old model will be described and in Section 2.4 the right hemi-aging hypothesis will be described. These two hypotheses will then be evaluated in Section 2.5. Section 2.6 will summarise and conclude the literature review regarding cognitive ageing. Section 2.7 will then bring together evidence from the VS and the ageing review and demonstrate why the investigation of categorical and coordinate VS processing across age is theoretically and empirically intetesting. In particular, the implications for categorical and coordinate VS processing will then be explicitly considered in relation to cognitive ageing. Finally, in Section 2.8, the chapter will conclude with the aims and research questions of this thesis.

2.1. Generalised Slowing

As we age, the brain changes in dynamic ways. This includes both structural and neurological changes which can impact on cognitive functioning (Li, 2004). Indeed, a major observation in ageing research is that the speed at which responses are made is considerably slower for older adults compared to younger counterparts; older adults take longer to perform a cognitive task. Salthouse (1994; 1996) and others (e.g., Brigman & Cherry, 2002; Fisk & Warr, 1996; Park et al., 2002) have conducted extensive work that suggests many of the cognitive decrements found in older adults are mediated by speed of processing. This has led to a theory of *generalised slowing* in ageing, in which Salthouse (1996) suggests that reduced speed of processing, by which older adults encode and retrieve information, causes impairments in their cognitive performance. Head, Raz, Gunning-Dixon, Williamson, and Acker (2002) specified further, that decreases in speed at the early stages of encoding are most detrimental to older adults' performance. This has been supported by others (e.g., Stebbins et al., 2002).

Even though generalised slowing is found in most ageing research (e.g., Brigman & Cherry, 2002; Bryan, Luszcz, & Crawford, 1997; Der & Deary, 2006; Lawrence, Myerson, & Hale, 1998; McEvoy, Pellouchoud, Smith, & Gevins, 2001; Park et al., 2002; Verhaeghen, Cerella, & Basak, 2006), reduced speed of processing does not necessarily result in detrimental effects on cognitive performance. Indeed, even when older adults' RTs are longer than younger adults, accuracy rates often remain similar. For example, when told to be as quick but as accurate as possible, older adults often deliberately employ strategies which may use slower processing in order to maximise accuracy. This is sometimes referred to as a 'speed-accuracy trade-off' (Atkinson & Shiffrin, 1968; McEvoy et al., 2001; Salthouse, 1979; Salthouse, 1996; Touron, Hoyer, & Cerella, 2004). Although Salthouse (1979) agrees that older adults are more biased towards making accurate responses, this does not account for all of the age-related differences in speed. In addition, Ratcliff, Thapar, and McKoon (2006) also found that, with sufficient practice older adults were able to match the processing speeds of younger adults in a decision making task. Speed-accuracy trade-off, therefore, needs to be considered when comparing task performance with ageing populations compared to younger adult populations.

The exact cause of decreased processing speed is not entirely understood, and there are many possible explanations. For example, extensive declines in both grey and white matter volumes have been found throughout the older adult brain (Good et al., 2001; Nebes et al., 2006; Raz, 2004a; Raz, 2004b; Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003). Researchers have suggested that white matter changes, such as demyelination of axons, affect functioning by reducing neural transmission and interneural connectivity (Gunning-Dixon & Raz, 2000). Specifically, Salthouse (1994; 1996) suggests that generalised slowing may be due to inefficient neural connections and/or loss of cognitive resources, which leads to ineffective encoding or retrieval mechanisms.

More specifically, Salthouse (1996) suggests that the relationship between cognitive impairment and reduced speed of processing in ageing populations can be accounted for by two mechanisms. In the limited time mechanism, it is assumed that older adults' cognitive performance declines because processing happens too slowly resulting in too much time being spent on processing information early on in the cognitive operation. As a result, a limited amount of time is available for processing information later on in the cognitive operation. That is, there is insufficient time course for relevant information to be processed. Alternatively, the simultaneity mechanism assumes that relevant information may have decayed or been displaced before it is processed (Salthouse, 1996). In this way, the information processed early on in a cognitive operation is no longer available when needed for later processes. Ultimately, this causes cognitive impairments in older adults.

Older adults have also been found to be distracted by unimportant stimuli and when irrelevant information enters into the processing system, the distracting elements may cause a breakdown in selective attention (Grady, 1998; Reuter-Lorenz & Sylvester, 2004). Specifically, if older adults are unable to inhibit interference from irrelevant information, they may be prevented or slowed from processing the relevant information necessary for successful performance of the task at hand (e.g., Van Gerven, Paas, Van Merriënboer, & Schmidt, 2002). Combined with the loss of grey and white matter, and thus a decrease in cognitive resources, these changes contribute to generalised slowing of performance and may lead to cognitive decline (Gunning-Dixon & Raz, 2000; Nebes et al., 2006).

2.2. Frontal Lobes and Working Memory

The frontal lobes are particularly important areas of the brain as many cognitive processes require neural networks that involve them. Specifically, the frontal lobes are used in complex cognitive tasks that require numerous cognitive resources. For example, the frontal lobes are often activated in WM tasks (Klingberg, O'Sullivan, & Roland, 1997; Narayanan et al., 2005; Reuter-Lorenz et al., 2000; Wager & Smith, 2003).

Frontal lobe functioning has been found to be particularly vulnerable to age-related decline (Rajah & D'Esposito, 2005; Raz, 2004a). For example, older adults' frontal lobe volume consistently is found to be reduced compared to other lobes (Raz, 2004b; Resnick et al., 2003). Raz (2004a) found the PFC to have the largest age-related volume reduction. White matter tracts connect the hemispheres and join the frontal lobes to other lobes. Colcombe et al. (2005) suggest that deterioration of white matter reduces the effectiveness of communication between the lobes. Accordingly, consistent with the theory of generalised slowing, some age-related differences may be due to decreases in activation or loss of neurons in the frontal lobes (Aine et al., 2006; Colcombe et al., 2005; Oosterman et al., 2008; Raz, Briggs, Marks, & Acker, 1999; Reuter-Lorenz & Lustig, 2005; Rympa & D'Esposito, 2001). In support of this, neuroimaging studies have shown that, on tasks which rely on neural networks in the frontal lobes, older adults require additional areas of activation to those recruited by younger adults. This implies that older adults utilise different neural networks in the brain to those of younger adults when performing the same tasks (Aine et al., 2006;

Grady, 1998; Park et al., 2003; Reuter-Lorenz & Lustig, 2005; Reuter-Lorenz & Sylvester, 2004).

To be more specific, younger adults tend to display activation that is largely lateralised to one hemisphere; that is, each hemisphere is more specialised for specific tasks. Older adults, however, tend to show bilateral activation (Cabeza, Anderson, Locantore, & McIntosh, 2002; Reuter-Lorenz et al., 2000). Hence, older adults often recruit additional resources from similar areas from the contralateral hemisphere when performing a task. This is explained by the Hemispheric Asymmetry Reduction in the Old model (HAROLD; Cabeza, 2002; Cabeza et al., 1997), and will be further discussed in Section 2.3.

As mentioned earlier, the frontal lobes are known to be particularly important in WM tasks. WM plays an active role in many of the daily tasks that we undertake and contributes to many complex, cognitive operations. According to Baddeley and colleagues (e.g., see Baddeley, 1998; Baddeley, 2003; Baddeley & Hitch, 1994), WM is multifaceted and consists of a central executive component which is subserved by two independent 'slave' systems – the phonological loop and the visuospatial sketchpad (VSS). The central executive oversees all information processing, especially that requiring monitoring and coordination. The phonological loop is concerned with the processing of verbal information (i.e. verbal working memory), and the VSS with VS information (i.e. VSWM; Baddeley, 1998; Baddeley, 2003; Baddeley & Hitch, 1994). More is known about the phonological loop than the VSS, and these two subsystems are suggested to be highly related.

Visuospatial WM is suggested to be particularly dependent on areas in the dorsal lateral PFC, the posterior parietal cortex and the hippocampus (Finke, Bublak, & Zihl, 2006; Kessels, De Haan, Kappelle, & Postma, 2001; Kessels, Postma, Wijnalda, & De Haan, 2000; Klingberg, 2006; Park et al., 2003; Rajah & D'Esposito, 2005; Van Asselen et al., 2006; Wager & Smith, 2003). These are all areas which have previously been shown to be important in categorical and coordinate tasks (see Baciu et al., 1999; Slotnick & Moo, 2006; Trojano et al., 2002; Van Asselen et al., 2006). In addition, these areas are particularly vulnerable to age-related decline, in both brain matter volume and activation patterns (e.g., Raz, 2004b; Resnick et al., 2003). It is not surprising, therefore, that older adults also show deficits in performance on VSWM tasks compared to younger adults (e.g., Fisk & Warr, 1996; Jenkins, Myerson, Joerding, & Hale, 2000).

Charlton et al. (2006) suggest that decline in WM performance may, in part, be due to white matter hyperintensities (areas of demyelination and infarct). Specifically, Charlton et al. (2006) found a correlation between white matter hyperintensities and WM, and suggest that white matter is vital for WM performance. With age, white matter volumes decline, and so this may contribute to the decrease found in WM performance. Similarly, Oosterman et al. (2008) found that decreased WM performance correlated with increased white matter damage. Furthermore hyperintensities in the frontal deep matter were the most highly correlated with WM performance. Stebbins et al. (2002) suggested that memory deficits in older adults may be partially due to decreases in frontal lobe activation. However, others suggest that perceptual speed accounts for a large majority of variance in age-related decline in WM (Fisk & Warr, 1996; Salthouse 1994). All these explanations may be true to some extent and are, in fact, likely to be highly interlinked.

Other factors that influence older adults' cognitive functioning include changes in levels of neurotransmitters, such as dopamine; hormonal changes, such as Hormone Replacement Therapy; lifestyle and disease factors, such as stress, hypertension, and medication; and demographic factors, such as number of years of education (Braver & Barch, 2002; Nebes et al., 2006; Rajah & D'Esposito, 2005; Raz, 2004a; Raz, 2004b; Raz, Rodrigue, & Acker, 2003; Volkow et al., 1998; West, 1996). For example, positive correlations are often found between years of education and cognitive ability scores, and older individuals with higher education levels show better cognitive performance (see Powell, 1994). Nebes et al. (2006) found that less-well educated older adults showed a greater association between decreased processing speed and white matter hyperintensities than older adults who where more highly educated. This suggests that cognitive decline can be moderated by education levels.

2.3. Hemispheric Asymmetry Reduction in the Old

The finding that hemispheric activation patterns differ between younger and older adults led Cabeza and colleagues (Cabeza, 2002; Cabeza et al., 1997) to develop the HAROLD model. This model refers to the change in neural activity in older adults (Cabeza, 2002). Specifically, in this model, Cabeza (2002) postulates that lateralisation of functioning in the PFC is reduced with increasing age. That is, hemispheric specialisations found in younger adults across a multitude of domains (such as WM, episodic memory and perception) decrease with age, and instead, older adults show activation of both hemispheres (for reviews see Cabeza, 2002; Desalaar & Cabeza, 2005). The HAROLD model refers mainly to activation patterns in the PFC, although research is beginning to generalise these patterns to other areas of the brain (Desalaar & Cabeza, 2005; Dolcos, Rice, & Cabeza, 2002).

The HAROLD model has received considerable empirical support and evidence has shown hemispheric de-specialisations in older adults (see Cabeza, 2002). For example, Reuter-Lorenz et al. (2000) found that activation of only the right dorsalateral PFC for VS tasks, as found in younger adults, was no longer sufficient for successful performance in older adults, and similar areas in the LH were also found to be activated.

There are currently two mechanisms proposed to account for the change in neural circuitry with advancing age; *compensation* and *dedifferentiation*. In accordance with the compensation view, bilateral activation is suggested to be a strategy used to help counteract age-related cognitive decline. With age, cognitive tasks become more challenging and so more cognitive resources are required to achieve successful processing, hence, older adults recruit additional areas of the brain (Reuter-Lorenz, 2002; Reuter-Lorenz & Lustig, 2005). For example, Cabeza et al. (2002) asked older and younger adults to complete a battery of memory tasks. From the older adult sample, Cabeza et al. (2002) selected a group of older adults who performed similarly to the younger adults on the memory tasks and a group of older adults who performed significantly worse than the younger adults. Using fMRI, Cabeza et al. then scanned all the participants' during a recall memory task and source memory task. During the fMRI tasks, the younger adults showed activation in the right PFC. Interestingly, the older adults who performed worse than the younger adults also showed activation in the RH. By contrast, the older adults who performed as well as the younger adults on the battery of memory tests showed bilateral activation of the PFC. This was taken to indicate that bilateral recruitment of cognitive resources served to increase cognitive functioning.

The dedifferentiation account provides an alternative explanation for differences in activation patterns. According to this view, bilateral activation is the result of areas of the brain becoming less specialised and reverting back to the functional organisation used in childhood (see Cabeza, 2002; Chen, Myerson, & Hale, 2002; Desalaar & Cabeza, 2005; Rajah & D'Esposito, 2005; Reuter-Lorenz, 2002). Specifically, the brain undergoes a breakdown in neural connectivity and efficiency such that the same neural circuits are used for a number of different cognitive functions (Cabeza, 2002).

At present, the compensation view has the most support and this is taken to be the most convincing account of age-related reductions in lateralisation (Deselaar & Cabeza, 2005). Indeed, there is a great deal of evidence in support of this view (e.g., Cabeza, 2002; Cabeza et al., 1997; Cabeza et al., 2002; Reuter-Lorenz, 2002; Reuter-Lorenz & Lustig, 2005; Reuter-Lorenz, Stanczak, & Miller, 1999). However, the compensation and dedifferentiation mechanisms are not mutually exclusive, and, recently, Rajah and D'Esposito (2005) suggested that dedifferentiation may be the first stage of adapting to neurological changes in the brain. Once the brain has 'de-specialised', additional areas can be recruited, resulting in functional compensation.

Regardless of the reasons why, it would seem that with age, changes occur in hemispheric functioning and the HAROLD model provides a clear account of hemispheric processing in an ageing population. For this reason, the HAROLD model will be central to the predictions and interpretations of performance during categorical and coordinate VS processing tasks. Specifically, with respect to categorical and coordinate VS processing, it could be predicted that the associated hemispheric specialisations expected with younger adults would not be obtained with older populations, as hemispheric specialisations would have reduced, and older adults would instead show bihemispheric activation.

2.4. Right Hemi-Aging Hypothesis

Differential ageing is not only restricted to differences between the frontal and other brain lobes. The right hemi-aging hypothesis suggests that processes undertaken by the RH decline disproportionately with age compared to processes undertaken by the LH. Furthermore, it is suggested that this disproportionate decline is also accompanied by a reduction in RH specialisation. However, unlike the generalised slowing hypothesis and the HAROLD model, neurobiological evidence is limited and the right hemi-aging hypothesis relies mainly on behavioural data comparing verbal and VS cognitive functioning. The following sections will review these strands of evidence.

2.4.1. Verbal versus VS functioning.

It is widely accepted that language-based tasks are mainly processed in the LH, whereas VS tasks are predominantly processed in the RH. The right hemi-aging hypothesis states that cognitive functions involving RH processes are affected to a greater degree than cognitive functions associated with the LH (Dolcos et al., 2002;

Goldstein & Shelley, 1981). In this way, it is hypothesised that VS information should be more at risk from age-related decline than verbal information. In line with this, research reveals that VS tasks are especially vulnerable to age-related decline, and direct comparisons between VS and verbal tasks provide further support for the right hemi-aging hypothesis. For example, research has demonstrated significant age-related deficits in recalling spatial locations compared to recalling visual features, such as object, shape, or colour (Chalfonte & Johnson, 1996; Chen et al., 2003).

This selective decline in recall performance is further supported by research comparing information processing speeds. Lawrence et al. (1998) found, that over the life course (ages 18 - 90 years), processing speeds decreased to a greater extent for VS than verbal processing. The amount of time older adults needed for verbal processing increased linearly by approximately 50%. By contrast, VS processing increased by 500% (Lawrence et al., 1998). Similarly, Verhaeghen et al. (2006) found performance on VS tasks slowed by as much as three times more than performance on verbal tasks. Thus, although both VS and verbal cognitive processing speeds decrease with age, it would seem that VS functioning is affected to a greater extent.

Differences in verbal and VS ability can also be related to crystallised and fluid intelligence. Based on correlations from a series of WM span tasks, Haavisto and Lehto (2004) suggest that crystallised abilities are associated with verbal WM and fluid abilities with VSWM. Interestingly, Horn and Cattell (1967) found younger adults showed higher levels of fluid intelligence than older adults, whereas, older adults had higher crystallised intelligence. Thus, if verbal intelligence increases with age, this accounts for the observed superior performance on verbal compared to VS tasks in older adults. Moreover, Busch et al. (2005) suggest that fluid cognitive abilities are controlled by executive functions. Executive functions have been shown to be affected by age-related decline (Busch et al., 2005; Fernandez-Duque, Baird, & Posner, 2000; Lewis & Miller, 2007; Rypma, Prabhakaran, Desmond, & Gabrieli, 2001) and so, in turn, may affect performance for fluid cognitive abilities, such as some VS tasks.

2.4.2. Neurobiological evidence

Support for the right hemi-aging hypothesis can also be found in relation to neurobiological evidence. For example, Good et al. (2001) found a lower grey to white matter ratio in the RH compared to the LH. Similarly, Pujol et al. (2002) also found lower white matter volumes in the RH compared to the LH. With fewer neurons and less connective tissue available, the RH may be more sensitive to age-related neural changes which may cause more detrimental effects in RH processes. Rajah and D'Esposito (2005) also found that, in WM tasks, older adults had greater activation of the left dorsal PFC than the right dorsal PFC. The opposite was found for younger adults. This led them to suggest that older adults may under-recruit RH and over-recruit LH neural circuitry. In turn, this suggests a larger decline of functions lateralised to the RH (Rajah & D'Esposito, 2005).

The apparent decline in VS abilities in older adults may also, in part, be due to reductions in hippocampal volumes (Raz, 2004a). The hippocampus is a structure that has shown reduced activation and volume in older adults (Park et al., 2003). The hippocampus, and in particular, the right hippocampus, is a cognitive structure thought to be heavily involved in spatial memory (Kessels et al., 2001; Tang, 2003; Van Asselen et al., 2006). As such, it is unsurprising that VSWM tasks are differentially affected by age. However, it is difficult to infer a causal relationship between brain reduction and cognitive reduction given that brain reduction may cause cognitive reduction, or cognitive reduction may lead to brain reduction.

In summary, the evidence for the right hemi-aging model suggests that, with age, greater deficits may be found for cognitive functions associated with the RH. Thus, with respect to categorical and coordinate VS processing, it could be hypothesised that as coordinate VS processes are associated with RH specialisation greater age-related deficits may be found in coordinate compared to categorical cognitive tasks.

2.5. Evidence Against Age-Related Changes in Hemispheric Processing

The preceding sections have provided evidence to suggest that hemispheric processing changes with age; however, there are also studies that have found no differences in hemispheric specialisation between younger and older age-groups, nor any differential decline for RH-oriented tasks. For example, in a series of tasks assessing hemispheric specialisation Cherry, Hellige, and McDowd (1994) found no age-related differences in hemispheric processing. In the tasks, which included emotion processing (RH) and phonetic-linguistic processing (LH), both younger and older adults displayed the expected lateralisation. Similarly, Park et al. (2002) also found no evidence to suggest that cortical areas used by older adults in verbal and VS tasks were less specialised than those of younger adults.

With respect to differential ageing, there is some research which has found no evidence of a greater decline in VS compared to verbal functioning with increasing age (e.g., Kemps & Newson, 2006; Park et al., 2002; Parkin, Walter, & Hunkin, 1995). Behavioural studies comparing verbal and VS tasks are the main source of evidence in line with the right hemi-aging hypothesis, and the validity of these studies has been questioned (Desalaar & Cabeza, 2005). Specifically, it is suggested that comparisons between verbal and VS tasks are not reliable, since other factors (such as task demand) may affect the results. For example, VS tasks are often novel and complex and, thus, are more demanding processes than verbal tasks (Daselaar & Cabeza, 2004; Hellige, 1993). It is well documented that with age as task demands increase, performance decreases (Chen et al., 2003; Reuter-Lorenz et al., 1999; see also Stuart-Hamilton, 2006). Hence, if VS tasks are more complex than verbal tasks, it is unsurprising that this cognitive domain is affected by age to a greater extent. Indeed, in line with this, disproportionate effects of age have been shown to reduce when task demand associated with VS and verbal tasks has been controlled or equated (e.g., Kemps & Newson, 2006; Janowsky, Carper, & Kaye, 1995). In addition, research has shown that increased task demand is associated with bilateral activation in both younger and older adults; presumably more resources are recruited to facilitate processing (Reuter-Lorenz et al., 1999; Weissman & Banich, 2000). Older adults' cognitive resources are already limited, and consequently, they may show different patterns of processing at lower task demands than younger adults. This would, therefore, account for a difference in hemispheric lateralisation. Thus, hemispheric reduction found with older adults may be partly due to the cognitive demand associated with the task at hand.

It is clear that hemispheric processing in ageing populations is complex. As found in the categorical and coordinate literature, hemispheric specialisations are not clear cut, seem not to be consistent and seem to be particularly affected by task demand. This makes it difficult to interpret results found. The following section will summarise the literature reviewed with respect to cognitive ageing, before the implications of age for categorical and coordinate VS processes are considered in Section 2.7.

2.6. Cognitive Ageing: Summary

The preceding review demonstrated that cognitive processing changes with age, often affecting cognitive performance in a negative fashion. However, it would seem that older adults often use cognitive strategies to help counteract the effects of age. For example, older adults may respond more slowly to ensure better accuracy and cognitive resources are recruited bilaterally to help compensate for inefficient unilateral processing. Thus, it is clear that younger and older adults can differ in how they process information and perform in cognitive tasks.

The preceding review described two accounts of hemispheric ageing both of which predict age-related differences in hemispheric processing. These two hypotheses differ in their specific predictions, but while they are independent models, they may not be mutually exclusive (Desalaar & Cabeza, 2005; Dolcos et al., 2002). For example, LH and RH specialisations may reduce with age (HAROLD), however, reduction may be more pronounced for processes undertaken by the RH (right hemi-aging). It was also suggested that VS processing may be more susceptible to age-related decline than other cognitive domains. The reason for this, however, was not entirely apparent; VS processing may deteriorate because RH functioning declines at a faster rate than the LH, or it may be due to other factors such as the suggested increased cognitive demand required by VS tasks. As categorical VS processes are associated with the LH and low task demand and coordinate VS processes are associated with the RH and high task demand, age-related decline may be selective within the VS domain. Thus, categorical and coordinate VS processes provide a well-established framework from which the potential effects of age, in terms of hemispheric specialisation and differential age-related decline can be examined.

2.7 Implications of Ageing on Categorical and Coordinate VS Processing

To reiterate, the primary aim of this thesis is to investigate categorical and coordinate VS processing in younger and older adults. Thus far, the literature has considered categorical and coordinate VS processing dissociations mainly in relation to younger adults only. However, the preceding review demonstrated that both VS processes and patterns of hemispheric activation differ with age. Thus, given that categorical and coordinate VS processes are associated with different hemispheric specialisation this provides motivation for investigating cognitive ageing in relation to these processes. Specifically, systematic investigation of performance in categorical and coordinate tasks across age will provide insight into whether age-related decline for VS processing is selective and whether changes in hemispheric performance also occur with age. This next section focuses on the implications of ageing on the proposed categorical/coordinate VS dichotomy.

From the theories of cognitive ageing reviewed, very clear hypotheses can be made with respect to categorical and coordinate VS processing. The generalised slowing hypothesis suggests that with age, the speed at which information is processed decreases. In this way, it is expected that younger adults will be faster than older adults when making a spatial relation judgement. However, under the right hemi-aging hypothesis it is argued that RH processes decline at a faster rate than LH processes (see Dolcos et al., 2002). Specifically, language/verbal functioning is thought to be relatively preserved with increasing age (Haavisto & Lehto, 2004). Given that categorical VS processing has a strong association with language, it is reasonable to assume that language attributes might help to preserve categorical VS processing. Similarly, as the coordinate task is associated with RH processes, it could be hypothesised that coordinate VS processes will be disproportionately affected by age, providing differential age-related decline. The right hemi-aging hypothesis also suggests that there will be an overall deficit in older participants' ability to process stimuli initially presented to the RH. Thus, in terms of categorical and coordinate VS processing it could also be expected that older adults would perform much more poorly when the stimuli were presented to the RH.

The HAROLD model predicts that hemispheric specialisations reduce with age, in favour of bihemispheric activation. Thus, it could be argued that the predicted RVF-LH advantage for categorical VS processing and the predicted LVF-RH advantage for coordinate VS processing should be reduced in older compared to younger adults. Specifically, in terms of behavioural data, it could be predicted that no Task by Hemisphere (or VF, as visual half-field studies will be employed in this thesis) advantage would be found with older adults, because of bilateral recruitment.

In summary, it can be predicted that age may affect coordinate VS processes disproportionately to categorical VS processes, hemispheric specialisations may disappear, and this is likely to be more prominent for LVF-RH trials. However, to date, only two studies have directly assessed categorical and coordinate VS processing across age. Unsurprisingly, given the instability of categorical and coordinate hemispheric specialisations in younger adults, these studies provided inconsistent results. These two studies will be described in detail in the remainder of this section.

Bruyer et al. (1997) employed a visual half-field study in which participants had to make either an above/below categorical judgement or a near/far coordinate judgement regarding the location of a dot in relation to a bar. In Experiment 1, Bruyer et al. conducted the study with younger adults. With respect to the accuracy data, a Task by VF interaction showed that younger participants were more accurate in the categorical task when stimuli had been presented in the RVF-LH. In contrast, participants were more accurate in the coordinate task when the stimuli were presented in the LVF-RH. In Experiment 5, Bruyer et al. conducted the same study with older adults (mean age = 68 years old). In contrast to the younger adults, no Task by VF interaction was found for the accuracy data. Thus, Bruyer et al.'s results are in line with the pattern of findings predicted by the HAROLD model, and show a reduction in hemispheric specialisation.

Bruyer et al. (1997) also found age-related differences in relation to task. Specifically, in line with the right hemi-aging hypothesis, older adults made considerably more errors in the coordinate task compared to the younger adults than in the categorical task. That is, the discrepancy between errors made by the younger and older adults was much larger in the coordinate task than in the categorical task. Bruyer et al. concluded that this demonstrated that age-related decline was differential with the coordinate task being particularly at risk. The results from the accuracy data, therefore, suggest that Bruyer et al. found evidence consistent with both the HAROLD model and the right hemi-aging hypothesis.

However, the results from the RT data provide a contrasting pattern of results. Specifically, neither age-group showed the expected VF advantages, and the Task by Age-Group interaction showed a greater age-related deficit in the categorical task. That is, younger adults were much faster to make a categorical judgement than older adults; hence, there was a larger RT discrepancy between the two age groups in this task. Thus, in contrast to the accuracy data there was a disproportionate age-related deficit in categorical VS processing for speed of response.

In summary, the results of this study are difficult to interpret. The results suggest that age-related decline is differential; however, the direction of decline is unclear. Bruyer et al. (1997) concluded in favour of the accuracy data and suggested that, in line with the right hemi-aging hypothesis, there was a greater age-related deficit in coordinate VS processes. The accuracy data also suggested that with age hemispheric specialisations reduce. This study highlights the inconsistency in results obtained from this type of research.

The results reported by Bruyer et al. (1997) are also in contrast to Hoyer and Rybash (1992). Hoyer and Rybash (1992) conducted two types of categorical and coordinate task. In the original versions of the tasks, younger (mean age = 19 years old) and older (mean age = 69 years old) participants judged whether a dot was above or below a bar, or whether it was within 6 mm of the line (i.e., near/far task). For the modified versions of the tasks, younger and older adults were presented with a bar and two dots. The dots were located above or below the bar, and both the length of the bar and the distance between the dots was varied. In the modified categorical task, participants had to judge if the bar was above or below the two dots, and in the coordinate task, participants had to judge whether the bar could fit in between the two dots. Hoyer and Rybash modified the original tasks to try to reduce the chance that participants categorised the coordinate judgement, and to try to encourage participants to compute a quantitative distance judgement on each trial.

The key findings were that older adults were slower, and less accurate, to respond than younger adults and a LVF-RH advantage was found in the first block of the coordinate task only. There was no RVF-LH advantage for the categorical task. Importantly, these specialisations were similar in both age-groups; thus, Hoyer and Rybash (1992) found no evidence for the HAROLD model. In addition, in contrast to the right hemi-aging hypothesis, Hoyer and Rybash found no evidence to suggest that coordinate VS processes were more vulnerable to age-related decline. Instead, their results suggest that hemispheric specialisation is similar across age and age-related performance is similar across categorical and coordinate tasks.

More recently, a study by Laeng (2006) provided more insight into categorical and coordinate VS processing in older adults. Laeng (2006) conducted a study with patients with lesions in the parietal lobe that had been caused by stroke. The mean age of these patients was 63 years old. Participants were asked to complete three tasks. In the object relocation task, participants were shown pictures of 3-7 animals. After a short delay the picture was presented again, with two of the animals missing. The two missing animals and their mirror images were provided below the picture and the participants had to relocate the correct image back to the correct location. The relocated items were measured in terms of categorical and coordinate errors. A categorical error included participants relocating the mirror image picture, or providing the wrong relation between the two animals. A coordinate error was scored in terms of the distance displacement between the original location and the location of the relocated item.

In the stick task, participants were shown a pattern made from matchsticks, and after a short delay were asked to recreate the pattern. Again, categorical and coordinate errors were measured; a categorical error included the matchstick head pointing in the wrong direction whereas a coordinate error was considered to be when the angle of the matchsticks was greater or more acute. Laeng (2006) found that patients with LH damage made more categorical errors in both of these tasks than patients with RH damage, whereas patients with RH damage made more coordinate errors than patients with LH damage.

Finally, in the third task, participants were asked to complete the computerised study developed by Laeng (1994; see Section 1.3.3 for full description). Participants were shown pictures of one or two animals and after a short delay were asked to identify which of two pictures depicted the previously viewed picture. The alternative picture differed from the original in a categorical way (e.g., the animals were facing the other direction), a coordinate way (e.g., the distance between the two animals was changed), or both spatial relations had changed. Similar to the object location and matchsticks tasks, Laeng (2006) found that patients with LH damage were slower and made more errors when identifying categorical changes than patients with RH damage. In contrast, patients with RH damage made more errors and were slower to identify coordinate changes compared to patients with LH damage. Thus, older adults with damage to the LH had more difficulty with categorical VS processing, whereas participants with RH damage found coordinate VS processing more challenging. Importantly, in line with Hoyer and Rybash (1992), it seems that with age hemispheric specialisation for categorical and coordinate VS processes remain relatively intact.

In summary, the three studies described provide very different findings for categorical and coordinate VS in older adults. Hoyer and Rybash (1992) and Laeng (2006) suggest that VS specialisation is similar in younger and older adults, whereas Bruyer et al. (1997) did not. Similarly, Bruyer et al. (1997) found evidence of differential age-related decline, whereas Hoyer and Rybash (1992) did not. Thus, further research is required in order to determine if there are changes in the nature of categorical and coordinate VS processing with age, and specifically, if age-related decline affects these two processes differentially.

It is also important to note that Hoyer and Rybash (1992) highlight that there are issues regarding the type of cognitive processes involved in categorical and coordinate VS processing. Specifically, they, among others, have suggested that near/far coordinate tasks may utilise cognitive processes similar to those underlying categorical VS processes. The limitations of this task have been raised before (e.g., Banich &

Federmeier, 1999; Bruyer et al., 1997), and adaptations of the near/far task have been developed to account for the possible involvement of categorisation. These issues will be developed and discussed throughout the thesis.

2.8 Summary of Research Questions and Thesis Outline

Functional dissociation between categorical and coordinate VS processes has been widely studied in younger adults. In general, there is consensus that categorical VS processes are associated with RVF-LH advantages and coordinate VS processes are associated with LVF-RH advantages; although these advantages are relatively small. Chapter 1 identified three gaps in the existing categorical and coordinate literature. First, research is lacking in respect to older adult populations. This is surprising given that both VS processing and hemispheric specialisation (the main aspects of categorical and coordinate processes) are affected by age. Second, it seems that understanding of the cognitive processes underlying categorical and coordinate VS processes is not comprehensive. This too is surprising given that the aim of most categorical and coordinate research is to demonstrate that these two processes are qualitatively different; by using methodologies that examine cognition online, a more definitive conclusion would be drawn. Finally, on the issue of qualitative distinctions, it has recently been suggested that categorical and coordinate hemispheric specialisations reflect nothing more than differences in the amount of cognitive demand required by each task. Task demand has been shown to affect cognitive processing disproportionately in older than younger adults (Chen et al., 2003; Myerson, Emery, White, & Hale, 2003; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Verhaeghen, et al., 2006). Furthermore, age-related changes do not just occur in cognitive performance but increased cognitive demand also induces changes in hemispheric functioning (e.g., Cabeza, 2002; Cabeza et al., 1997; Cabeza et al., 2002; Desalaar & Cabeza, 2005; Dolcos et al., 2002; Reuter-Lorenz, 2002; Reuter-Lorenz et al., 1999; Reuter-Lorenz & Lustig, 2005). Task demand may, therefore, affect performance for older adults during categorical and coordinate VS processing differently to younger adults. Given that coordinate VS processing is inherently more demanding than categorical VS processing (and in line with the right hemi-aging model), this may contribute to greater age-related deficits for coordinate VS processes. These claims need further research.

Thus, the primary aim in this thesis was to investigate categorical and coordinate VS processing in younger and older adults. Specifically, this was with respect to the hemispheric advantages underlying these processes and in relation to whether age-related decline is differential across categorical and coordinate tasks. In addition, this thesis investigated the cognitive processes underlying categorical and coordinate VS processes and the affects of task demand. Ultimately the proposed research offers valuable insight into the change in the nature of processing with age and could provide better understanding into issues concerning cognitive ageing and cognitive processing of VS information. With this in mind there were three main research questions addressed throughout this thesis:

(1) How *do categorical and coordinate components of VS processing change with age*?
(2) How does task demand affect categorical and coordinate VS processes?
(3) How do the cognitive processes that underlie categorical and coordinate VS processing differ?

To achieve these research aims, four experiments will be conducted and reported in this thesis. Experiment 1 (see Chapter 3) will investigate hemispheric specialisations of categorical and coordinate VS processes in younger and older adults. Specifically, in a visual half-field study, younger and older participants will be required to make spatial relation judgements using a typical above/below categorical task and a near/far coordinate task. In addition, the processes underlying near/far spatial relation judgements will be questioned and a novel coordinate task developed and evaluated.

Given that it has recently been proposed that task demand affects the hemispheric advantages found for categorical and coordinate VS processes, Experiment 2 (see Chapter 4) will manipulate task demand and investigate whether the predicted advantages are still found. Experiment 3 (see Chapter 5) further examines task demand in WM tasks that examine categorical and coordinate VS processes. This will not only provide further insight into the importance of task demand but will also allow the assessment of whether categorical and coordinate hemispheric advantages generalise to higher-order cognitive tasks.

In Chapter 6, Experiment 4 examines the cognitive processes involved in categorical and coordinate VS processing through eye movement methodology. This will provide insight into the on-line cognitive processes underlying categorical and coordinate spatial relation judgements, and will allow direct examination of whether categorical and coordinate VS processes are qualitatively distinct. Finally, the General Discussion in Chapter 7 will summarise the results from all four studies and conclusions will be drawn.

Chapter 3
Hemispheric Specialisations for Categorical and Coordinate VS Processes and the Effects of Age

3.1. Introduction

As detailed in Chapter 1, Kosslyn and colleagues (Kosslyn 1987; Kosslyn et al., 1992; Kosslyn et al., 1989) hypothesised that spatial relations can be described by two independent VS processing systems. It is argued that categorical spatial relations are essentially verbal labels that describe broad directional relationships between objects, without specifying precise location details. In contrast, coordinate spatial relations indicate the precise position of an object (Kosslyn, 1987; Kosslyn et al., 1992). Kosslyn (1987) further suggested that categorical and coordinate VS processes are associated with different hemispheric specialisation. Specifically, the LH is suggested to be more efficient at computing categorical spatial relations whilst the RH is more efficient at computing coordinate spatial relations. Thus, it is argued that categorical and coordinate VS processes differ in the type of VS representation they provide, and in which hemisphere they are processed most efficiently.

To assess hemispheric advantages for categorical and coordinate VS processing, a stimulus is often briefly presented in the LVF or RVF for 100-200 ms. These stimuli are lateralised on screen and displayed so that they are presented initially to the RH or LH, respectively. Typically, a simple bar-dot paradigm is used, in which participants are presented with a horizontal bar and a dot located at varying distances above or below the bar (Hellige & Michimata, 1989; Kossyln et al., 1989). Participants are required to make a VS judgement regarding the location of the dot, in relation to the bar. Categorical judgements require an above/below discrimination, irrespective of distance, whereas coordinate judgements require evaluation of distance as being near or far. For example, in Hellige and Michimata's (1989) study, participants had to judge whether the dot was within (near) or further than (far) 2 cm from the bar. It is argued that support for Kosslyn's (1987) VS asymmetry theory is shown though a Task by Hemisphere interaction (or Task by VF interaction in the case of visual half-field studies), in which a RVF-LH advantage is expected for categorical VS processes and a LVF-RH advantage is expected for coordinate VS processes.

Hemispheric dissociation of categorical and coordinate VS processes has received a considerable amount of attention in younger adults (for reviews see Jager & Postma, 2003; Laeng et al., 2003); however, it has been largely overlooked with regards to ageing. This is surprising as with age VS processing declines and patterns of hemispheric activation change (see Chapter 2). As outlined in Chapter 2, the two main theories of hemispheric ageing predict different patterns of performance in lateralised tasks. To reiterate, in the HAROLD model (hemispheric asymmetry reduction in the old), Cabeza and colleagues (Cabeza, 2002; Cabeza et al., 2002; Cabeza et al., 1997) proposed that with age hemispheric specialisation declines in favour of bihemispheric processing. This is suggested to be some sort of compensation mechanism used to facilitate cognitive performance in older adults. Thus, in terms of behavioural data for categorical and coordinate VS processing, the HAROLD model predicts that the RVF-LH and LVF-RH advantages found in previous research with younger adults would disappear with an older group of participants.

By contrast, the right hemi-aging hypothesis suggests that processes undertaken in the RH decline at a faster rate than processes undertaken in the LH. Additionally, this differential decline should also be accompanied by a decline in RH processing. Thus, in terms of categorical and coordinate VS processing, the right hemi-aging model would predict a greater decline in coordinate VS processing and a greater reduction in the LVF-RH advantage for this VS process.

As reported in Chapter 2, to date, the existing empirical studies that have investigated categorical and coordinate VS processes in normal ageing have provided inconsistent results. For example, in line with the HAROLD model, Bruyer et al. (1997) found that the VF advantages displayed by younger adults disappeared in an older adult group. That is, there was no Task by VF interaction for the older adults, suggesting that with age one hemisphere was no longer efficient for successful computation of categorical and coordinate VS judgements. Bruyer et al. (1997) also found evidence of selective decline and concluded that coordinate VS processes were more susceptible to age-related decline. Thus, in terms of accuracy only, Bruyer et al.'s (1997) results were in line with both the HAROLD and the right hemi-aging hypotheses.

In contrast to both the HAROLD model and the right hemi-aging hypothesis, Hoyer and Rybash (1992) found a LVF-RH advantage for coordinate VS processes only, and no evidence of selective decline. In line with this, Laeng (2006) found that older patients with LH damage had performance deficits in a categorical task and older patients with RH damage had performance deficits in a coordinate task. Together, these studies suggest that LH and RH neural networks for categorical and coordinate VS processes, respectively, may still be specialised in older adults.

With the limited empirical research across age and the inconsistent results, categorical and coordinate VS processing needs further research in older age groups in order to assess how VS processing and the hemispheric advantages for those processes change with age. Consequently, in the current study, a younger and older adult group were recruited to participate in an above/below categorical task and a near/far coordinate task.

However, recall that in Chapter 1 it was shown that not all studies have found the predicted double-dissociation between Task and Hemisphere/VF (e.g., Banich & Federmeier, 1999; Hellige & Cumberland, 2000; Rybash & Hoyer, 1992; Sergent, 1991; Van der Ham et al., 2006; Wilkinson & Donnelly, 1999). For example, Sergent (1991) conducted a series of studies using stimuli similar to that used by Kosslyn et al. (1989), and had difficulty in replicating the results. Specifically, in three out of four experiments, Sergent (1991) found no Task by VF interaction (whereas Kosslyn et al., 1989, did). Furthermore, in Experiment 4, although a Task by VF interaction was found, only the LVF-RH advantage for the near/far task was significant. Indeed, as described in Chapter 1, a number of studies have only found a trend towards a RVF-LH advantage for categorical VS processes; however, in general, the trend is in the correct direction (e.g., Hellige & Michimata, 1989; Kosslyn et al., 1989; Sergent, 1991).

By contrast, some researchers have found a RVF-LH advantage for coordinate VS processes. For example, as described in Chapter 1, Slotnick et al. (2001) administered two categorical tasks and three coordinate tasks. For the categorical tasks, participants had to judge whether a dot was on or off a line contour of an irregular shaped blob, and whether a plus sign was to the right of a minus sign. For the coordinate tasks, participants had to judge whether a dot was within 2 inches of a line contour of an irregular shaped blob, judge whether a plus and minus sign were less than two inches apart, and judge whether two pairs of dots were the same distance apart. For each task, the distance of the probe (e.g., the dot/plus sign) from the reference item (e.g., the contour/minus sign) was varied. Importantly, for the coordinate tasks, the smaller the distance between the probe item and the reference point (in this case the 2 inch distance boundary) the more demanding the spatial judgement (Kosslyn et al., 1992). Interestingly, a LH advantage was found for all the categorical trials and for the coordinate trials in which the distance of the probe was greater than 1 inch from the reference item (i.e. the 'easier' trials). The only RH advantage found was in the most demanding of the three coordinate tasks (the paired squares task) and was for the trials in which the probe item was located closer than 1 inch from the reference item (i.e. the 'difficult' trials).

Some researchers have also reported that the LVF-RH advantage for coordinate VS processing is only present on initial trials and quickly disappears through the course of an experiment (Baciu et al., 1999; Hoyer & Rybash, 1992; Kosslyn et al., 1989; Rybash & Hoyer, 1992). One explanation for these findings is that, with practice, new spatial categories are developed to evaluate whether a coordinate distance condition has been met without having to measure the actual distance (Kosslyn et al., 1989). This proposal is consistent with the categorical-adjustment model (Huttenlocher et al., 1991). In this model, Huttenlocher et al. (1991) suggest that when fine-grain, coordinate spatial information is imprecise the spatial judgement is biased towards categorical input (see also, Haun, Allen, & Wedell, 2005; Postma et al., 2006; Van der Ham et al., 2007). This suggests that near/far types of coordinate task are susceptible to categorical influences.

To reiterate, it is argued that coordinate VS processes are associated with quantitative distance computations that are continuous in nature (Laeng et al., 2003). By contrast, when making a categorical judgement, an individual usually has to discriminate from a set of predetermined categories. These are mainly binary oppositions, such as left/right, above/below, in/out (Laeng et al., 2003). However, by asking participants to judge if a dot is *near* or *far*, participants are, essentially, being asked to judge a distance as belonging to one of two categories, and the precision element of the coordinate judgement may be lost.

Importantly, these results suggest that the near/far task only implicitly involves distance (e.g., Banich & Federmeier, 1999; Bruyer et al., 1997; Sergent, 1991), and it is not clear whether precise distance is computed on each trial. Furthermore, it seems reasonable to suggest that by requiring participants to judge distances into binary near/far categories, coordinate VS judgements could be made using similar discrimination processes as those used to make categorical spatial judgements.

For example, Kosslyn et al. (1989; Experiment 1 & 4) used a blob and dot stimulus in which the dots were located 0 mm, 1 mm, or 10 mm from the contour of the blob. For the near/far coordinate task, participants were asked to judge whether the dot was within 2 mm of the blob contour. As criticised by Sergent (1991), 0 mm from the contour means the dot is not away from the contour, automatically allowing a categorisation of 'on' and making it easy to judge as within 2 mm. Similarly, 10 mm is far enough away to be an obvious distance outside of 2 mm, and again, can be easily categorised as 'far'. Thus, it would seem that in this experiment, the majority of trials could be judged through the use of categorical discrimination (categories on and far), negating the need for quantitative distance estimation.

Additionally, Kosslyn et al. (1992) suggested that the closer the dot is located from the reference point, the more difficult it is to discriminate the regions to be related (e.g., above/below; near/far). For example, it is easier to tell apart two items if they are located 10 cm away from each other, than if they are 10 mm apart. Combined with the results reported by Slotnick et al. (2001) and others (e.g., Parrot et al., 1999; Parrot et al., 2000), it would seem that trials in which the probe item is located furthest from the critical reference distance may be particularly vulnerable to categorical influences.

The near/far task has been considered problematic (e.g., Banich & Federmeier, 1999; Bruyer et al., 1997; Hoyer & Rybash; Rybash & Hoyer, 1992; Sergent, 1991; Wilkinson & Donnelly, 1999). Consequently, some researchers have already tried to adapt the near/far task to make it more robust to metric distance computations and less at risk from categorical influences (e.g., Banich & Federmeier, 1999; Bruyer et al., 1997; Hoyer & Rybash, 1992). For example, as described in Chapter 2, Hoyer and Rybash (1992) developed a task in which participants had to judge whether a line fit in between two dots. Bruyer et al. (1997; Experiments 2 and 3) modified the coordinate task by including a more continuous measure for the coordinate response in which participants judged how far a dot was from a central point along an 8-point scale. However, the coordinate judgements were still not completely continuous as they were restricted to a limited number of responses, albeit 1 of 8.

Accordingly, in the current experiment, this motivated the development of a novel coordinate task in which the aim was to capture the continuous and quantitative nature of coordinate VS processes. To achieve this, participants were required to report the precise distance between the bar and the dot. That is, a task was designed using the same bar-dot stimuli that were employed during typical categorical and near/far tasks. Specifically, a horizontal bar and a dot, which was located above or below the bar at a distance of 1 to 8 cm away, were presented on a computer screen. Participants were required to estimate the distance between the bar and the dot. In this way, distance computation was explicitly required on each trial. Additionally, the judgement was kept continuous as participants were given no distance range. Henceforth, this task will be referred to as the distance quantification task.

To summarise, the effects of ageing have been largely overlooked with respect to categorical and coordinate VS processing. Furthermore, the existing literature demonstrates that there are inconsistencies in hemispheric dissociations of categorical and coordinate VS processes using typical above/below and near/far VS tasks. Specifically, it was suggested that the near/far coordinate task may rely on discrimination processes similar to those that underlie categorical VS processes. Accordingly, a novel distance quantification task was developed in which participants had to report the distance between the bar and the dot. If it is assumed that categorical VS processes are specialised to the LH and that coordinate VS processes are specialised to the RH, then VF advantages may provide some insight into the processes undertaken during the near/far task. There has been no investigation of categorical and coordinate VS processing using a methodology that requires precise distance computation and directly compares two coordinate tasks using the same stimuli. Thus, there were two main aims of the current study: one aim of the current study was to replicate previous research and investigate the VF advantages associated with a categorical above/below task, a coordinate near/far task, and a newly developed distance quantification task. The second aim was to investigate effects of age both in relation to hemispheric differences and differential age-related decline.

For the younger adults, it was predicted that a Task by VF interaction would be found. Moreover, it was predicted this would show a RVF-LH advantage for categorical VS judgements and a LVF-RH advantage for distance estimation. By contrast, it was predicted that no overall LVF-RH advantage would be found for near/far VS judgements. However, consistent with previous research it was anticipated that the distance of the dot from the bar may affect the advantage obtained in this task. For this reason, distance was added as a dependent variable to the analysis. Kosslyn et al. (1992) proposed that the nearer to the reference point, the more demanding the judgements. Accordingly, it was predicted that for the near/far coordinate task, a LVF-RH advantage would be found for the dots located nearest to the critical distance, whereas a RVF-LH advantage would be found for the dots located furthest from the critical distance.

For the older adults, given the inconsistency in the previous research two patterns of results were predicted: (1) consistent with Hoyer and Rybash (1992) and Laeng (2006), if hemispheric specialisation for categorical and coordinate VS processing remains with age, then it was predicted that the older adults would show the same VF advantages as the younger adults. However, (2) if hemispheric specialisation follows the pattern predicted by the HAROLD model, in line with Bruyer et al. (1997), no VF advantages would be expected for any of the VS tasks.

Without doubt, it was expected that the older adults would respond more slowly than the younger adults. However, again, the existing literature is not clear as to whether performance for categorical and coordinate VS processing declines equally with age. Thus, it was important to determine whether a Task by Age-Group interaction would demonstrate that age-related decline affects categorical and coordinate VS processes differentially. Again, two patterns of performance were predicted: (1) If performance in the older adult age-group replicates that reported by Hoyer & Rybash (1992), then no Task by Age-Group interaction will be obtained, and there will be no evidence of selective decline. Alternatively, (2) if age-related decline is differential, as suggested by the right hemi-aging hypothesis, it was anticipated that a Task by Age-Group interaction would reveal a greater age-related deficit for coordinate VS processes. Furthermore, this decline might be emphasised by a greater decline in the LVF-RH advantage.

Finally, in line with previous research it was hypothesised that participants would respond most quickly and accurately in the categorical task and that participants would take longer to respond and make more errors in the distance quantification task. It was also predicted that distance of the dot from the bar would affect performance. For the categorical and near/far task, it was predicted that participants would be faster and more accurate to respond to dots located furthest from the bar/critical distance. By contrast, for the distance quantification task, it was predicted that participants would be faster and more accurate to estimate smaller distances than larger distances.

3.2. Method

Participants

Sixty-four participants were recruited for this study; there were 28 younger participants who volunteered or were awarded course credits and 36 older adult, community-dwelling volunteers who were recruited through an Older Adult Database at the School of Psychology, University of Southampton. Participants were screened for normal or corrected-to-normal vision. As described in Chapter 1, individuals who are right-handed have a greater degree of hemispheric specialisation than those who are left-handed (Hellige, 1993). Thus, to avoid a handedness confound, only right-handed participants were recruited for this study. The degree of right-handedness was then assessed using the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). On this scale, handedness is scored from positive 100 to negative 100, where +100 is strongly right handed, and -100, is strongly left handed.

The older adults were also screened for cognitive impairments using the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). Five participants were excluded from the analysis as they scored below the cut-off of 26 on the MoCA (Nasreddine et al., 2005). An additional two participants were excluded from the analysis, as they did not complete the task due to technical difficulties with the computer: unwanted displays appeared during the task causing the computer programme to crash before the end of the tasks.

Table 3.1 displays the participant descriptives of each age-group. Age, gender, handedness, years of education and Predicted IQ were compared across age-groups in order to assess whether any age-group differences in performance could be due to differences in descriptive factors. The *p*-values in Table 3.1 show that older adults had significantly fewer years of formal education but had higher Predicted IQ scores than younger adults. No age differences were found for laterality or gender.

Table 3.1

Comparison of Participants' Descriptives across Age-Groups

	M, (SD), range		*p*
	Younger adults (*N* = 28)	Older adults (*N*=29)	
Age	19.89 (2.20), 18-27	72.10 (6.85), 60-87	.00*
Gender (M : F)	7 : 21	6 : 23	.47
Handedness (EHI)	88.41 (16.36), 36.80-100	90.82 (9.30), 76.50-100	.99
Years of Education	15.39 (2.04), 13-21	12.90 (3.27), 7-21	.00*
Predicted IQ	103.32 (6.77), 94-118	117.72 (8.31), 95-129	.00*
MoCA	N/A	27.90 (1.35), 26-30	-

Note. Age is provided in years. EHI = Edinburgh Handedness Inventory (Oldfield, 1971); a score of 100 = very strongly right-handed. MoCA = Montreal Cognitive Assessment (Nasreddine et al., 2005); scored out of 30, so that a high score = better cognitive performance. Years of education refers to how many years of formal school-education were received. Predicted IQ = National Adult Reading Test (Nelson & Willison, 1991); a high score = higher IQ. * = age-related differences $p < .01$.

Design and Materials

Each task was computerised and had been programmed using Presentation software. To ensure constant viewing conditions, participants used a chin rest and were seated 57 cm from a 15 inch computer monitor. The stimuli were a dot (0.5^o x 0.5^o) and a horizontal bar (4.4^o x 0.4^o). The stimuli were presented in black on a white screen, in the LVF or RVF. A fixation cross (0.5^o x 0.5^o) was presented in the centre of the screen. Ninety-six trials were presented for each VS task, of which 48 were in the RVF and 48 in the LVF. The edge of the horizontal bar was located at 3^o from the fixation cross.

Before the tasks began, participants were given the option of working in inches or cm. This was because older adults are more familiar with the imperial measurement system (inches) and younger adults with the metric system (cm). It was, therefore, anticipated that the different age-groups might prefer to work in different units. All younger participants chose cm, whereas all older adults, except four, chose to work in inches. Indeed, many of the older adults commented that they would only participate if they would be able to measure in inches, as they did not know the metric equivalent. It was argued that by allowing choice of unit, effects of unit conversion and computation would be diminished. That is, RT and accuracy would not be affected by participants having to convert their responses into their preferred unit, and any differences between the two age-groups would not have been a product of using unfamiliar units. The chosen unit was used for all three tasks.

The dot could appear at 1 of 8 distances away from the bar; these were positioned at 1 cm or ½ inch increments from the bar, with eight trials being above and eight trials below (see Figure 3.1). The first 4 dots above and below the bar fell within 4.5 cm/2 ¼ inches of the bar, and the remaining four dots were further than 4.5 cm/ 2 ¼ inches (i.e. within or outside 4.5^o).

The bar could appear in 1 of 3 locations in each VF; centrally or slightly above or below central (0.7^o); thus, each dot position was presented six times. In addition, in line with past research (e.g., Kosslyn et al., 1992; Parrot et al., 1999; Slotnick et al., 2001) the dot positions were classified by distance in relation to the reference point; 48 near and 48 far trials (see Figure 3.1). Note, in previous research these distance classifications were sometimes referred to as difficult and easy trials, respectively. For the categorical and distance quantification task, the positions *closest to the bar* were considered the 'near' trials. For the near/far task, 'near' trials were defined as those *closest to the designated critical distance* (the 4.5 cm boarder indicated by the dashed line in Figure 3.1). However, please note that these near/far labels relate to the distance variable only and the near/far responses reported by the participants referred to the dot in relation to the bar. That is, participants were to respond near when the dot was located at a distance smaller than 4.5 cm.

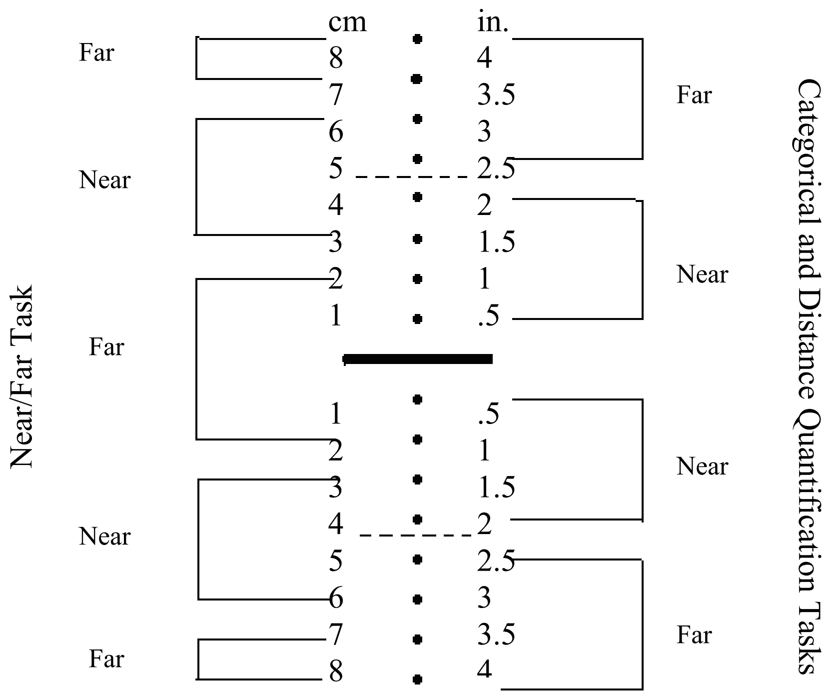


Figure 3.1. The positions in which the dots (•) could appear in relation to the bar (▬) and their distance from the relevant reference point for each task; (- - -) shows the critical 4.5 cm distance boundary from the bar. Left hand side shows near/far distinction for near/far task; Right hand side shows near/far distinction for categorical and distance quantification tasks. cm = centimetre distances; in. = inch distances.

Bar-dot stimuli were presented in a fixed, pseudo-random order; all three tasks presented the stimuli in the same order, and all participants received the stimuli in the same order. There were no more than three consecutive trials in either VF. All tasks used the same stimuli, and only differed in the VS judgement required. Consistent with previous studies, the categorical task, required an ‘above’ or ‘below’ judgement; the near/far task required a ‘within 4.5 cm’ or ‘outside 4.5 cm’ judgement and the distance quantification task required a distance estimation.

Practice Trials

Participants were given practice trials before the administration of each task. For the categorical and near/far tasks, participants completed two blocks of practice trials, whereas in the distance quantification task, participants completed the second block of practice trials only.

The first block of practice trials, consisting of eight trials, involved familiarisation with which keys to press. In the categorical practice trials, the words ‘above’ or ‘below’ were displayed centrally on screen and participants had to press the corresponding key. For the near/far task, the words ‘within 4.5 cm/2 ¼ inches’ or ‘outside 4.5 cm /2 ¼ inches’ were displayed centrally on screen and participants had to press the corresponding key.

The second practice block allowed familiarisation with the actual stimuli. Participants were presented with eight trials; four in each VF. Within each VF, two of the trials showed the dot above the bar, and two below, additionally, two were located within 4.5 cm/2 ¼ inches and two outside this distance. For the categorical and near/far tasks participants had to press the key corresponding to whether the dot was above/below or near/far. For the distance quantification task, participants were asked to press a key and verbally report the distance of the dot from the bar. For the practice trials only, participants received feedback when they made an incorrect response. That is, participants were told that they were incorrect and the correct response was specified to them.

Procedure

Each trial within each task consisted of the same sequence of events. A central fixation cross appeared on a blank screen. After 300 ms, ‘ready?’ appeared above the cross. Participants indicated that they were ready to begin by pressing a key on a RB-620 response box with the index finger of their left (non-dominant) hand. Following a 250 ms blank screen, a centrally displayed fixation cross appeared for 200 ms before a bar and dot stimulus pair were flashed on the screen for 150 ms, in the LVF or RVF. The stimulus then disappeared and the screen remained blank until a response was made.

For the categorical and near/far tasks, participants indicated their response by pressing one of two keys on the response box (located next to each other). Consistent with Hoyer and Rybash (1992), responses were made using the index and middle finger of their right (dominant) hand. For the distance quantification task, participants pressed a button when they were ready to give an estimate (this recorded RT) and then verbally gave their distance estimation. As soon as a button was pressed, a mask screen appeared for 300 ms.

Although ideally the response modes should be kept constant, a verbal response was used in the distance quantification task in order to encourage participants' to use decimal numbers (e.g., 2.5 cm) as well as whole integer estimates (e.g., 1, 2 cm). That is, it was thought that participants would be more likely to provide decimal numbers if they reported their estimate verbally than if they had to type the estimate in manually. This was important as it further emphasised the continuous aspect of the distance quantification task. The mask comprising of many bars and dots was presented to prevent any carry-over from trial to trial.

Participants were given verbal instructions before each task began, and a set of eight practice trials, for which they received feedback. The categorical task was always administered second and the order of near/far and distance quantification tasks were counterbalanced. Following testing, the EHI (Oldfield, 1971), and NART (Nelson & Willison, 1991) were administered to all participants. The older adults were also administered the MoCA (Nasreddine et al., 2005).

3.3. Results

The data were compared across age-group, task, hemisphere and distance. With respect to the distance variable, Kosslyn et al. (1992) argued that for the categorical and near/far tasks, the closer the dots were located to the reference point to which they were related (i.e. the bar and critical boundary, respectively) the more difficult the spatial relation judgement. To examine this, previous research has collapsed across distance to make two groups; *near* (the dots located nearest to the reference point) and *far* (the dots located furthest from the reference point). Thus, to be consistent with previous research, distance was divided into near and far. For the categorical and distance quantification task 'near' refers to the dots located nearest to the bar. For the near/far task, 'near' refers to the dots located nearest to the 4.5 cm critical distance.

Education and Predicted IQ

As the younger and older participants differed in number of years of formal education and Predicted IQ, it was important to examine whether these differences could account for any age-related performance differences. However, before Predicted IQ and years of education could be added as covariates to an ANCOVA, it was first important to ensure that a relationship existed between the potential covariates (i.e. Predicted IQ and education) and the dependent variables (i.e. RT and accuracy). As such, correlations were conducted. As shown in Table 3.2, Predicted IQ correlated with RT in all three tasks. Specifically, higher Predicted IQ was associated with longer RTs. According to Pallant (2001), as years of education did not correlate with the dependent variables, it would be inappropriate to include this variable as a covariate as this would serve to reduce the sensitivity of the results (see also Howitt & Cramer, 2001).

Table 3.2

Correlations between Years of Education, Predicted IQ, RT and ER

	r (p)	
Task	Predicted IQ	Education
	RT	
Categorical	.47** (.00)	-.19 (.15)
Near/far	.48** (.00)	-.04 (.77)
Distance	.28* (.04)	-.04 (.78)
	ER	
Categorical	.01 (.92)	-.21
Near/far	-.09 (.50)	.05 (.71)
Distance^	.16 (.23)	-.18 (.18)

Note. Predicted IQ = Predicted IQ from National Adult Reading Test (Nelson & Willison, 1997). Education refers to the number of years of formal education attended. ** correlation = $p < .01$; * correlation = $p < .05$. N = 57. Distance = distance quantification task. ^ = ER in the distance quantification task refers to the absolute error difference.

Interestingly, older adults had higher Predicted IQs than the younger adults, but had slower RTs. These results were not as expected as longer RTs are usually associated with lower intelligence levels (see Stuart-Hamilton, 2006; see also Nebes et al., 2006). As such, it is very unlikely that differences in Predicted IQ would account for any potential differences found in performance across the tasks. Nevertheless, to confirm this, Predicted IQ was centred (as recommended by Cohen, Cohen, West, & Aiken, 2003) and added into a 2 (Task) x 2 (Age-Group) ANOVA as a covariate.

The RT data showed the same patterns of results were found when Predicted IQ was included as a covariate and when it was not. Importantly, the main effect of Age-Group remained, $F(1, 54) = 4.21$, $p < .05$, suggesting that differences between groups were not affected by differences in IQ. Instead, it would seem that whilst there are differences in Predicted IQ across the age-groups, these differences were not related to differences in performance observed in the current experiment. Accordingly, in the following analyses, Predicted IQ was not added as a covariate.

Accuracy

For the categorical and near/far coordinate task there was no ambiguity concerning what constituted an error. For the distance quantification task, however, it was less obvious how to categorise a response as erroneous, as the task was designed to emphasise decision responses that were continuous rather than discrete. As such, accuracy in the above/below and near/far tasks was analysed independently from accuracy in the distance quantification task.

Categorical and Near/Far Tasks: Percentage Error Rates

The distributions of percentage ERs were not normally distributed. However, as ANOVA is a robust statistical method, for the purposes of assessing whether there were differences in accuracy across age-groups, a 2 (Task) x 2 (VF) x 2 (Distance) x 2 (Age-Group) ANOVA was conducted. All comparisons were confirmed with non-parametric equivalent tests, and unplanned multiple comparisons were Bonferroni corrected.

There was a main effect of Task, $F(1, 55) = 92.91$, $p < .01$ (see Table 3.3). As predicted, participants made fewer errors in the categorical task compared to the near/far task, suggesting that participants found the categorical task easiest. There was also a main effect of Distance, $F(1, 55) = 259.60$, $p < .01$, in which participants made fewer errors when the dot was located far from the reference point compared to when it was near to the reference point. However, the Task x Distance interaction, $F(1, 55) = 254.52$, $p < .01$, showed the effect of Distance was driven by the near/far task, $t(56) = 17.27$, $p < .01$, and not the categorical task, $t(56) = .47$, *ns*. As predicted, participants made more errors when judging a dot location that was near to the critical boundary in the near/far task (see Table 3.3).

Finally, the main effect of Age-Group, $F(1, 55) = 5.62$, $p < .05$, demonstrated that overall younger adults ($M = 6.92$, $SD = 4.20$) responded more accurately than the older adults ($M = 9.56$, $SD = 4.20$). No other main effects or interactions were significant, Fs < 1.56.

Table 3.3

Percentage of Errors made by Participants as a Function of Task and Distance

Distance of dot from reference	*M* % (*SD*)		
	Categorical	Near/far	Total
Near	2.89 (2.60)	23.79 (10.55)	13.31 (5.33)
Far	2.66 (2.78)	3.69 (8.33)	3.16 (4.26)

Distance Quantification Task: Estimates

As stated previously, the distance quantification task was designed to emphasise decision responses that were continuous rather than discrete. Thus, before accuracy was assessed it was first important to establish whether participants were using a continuous response scale and were not treating the decision as discrete (i.e. did they use a range of estimates). The frequencies by which different estimates were given were examined (see Appendix for plot of *t*-values). These analyses showed that when participants estimated the distance between the bar and dot in cm, they used a range from .5 to 12 cm (often using .5 cm increments; see Figure A1). When participants estimated the distance between the bar and dot in inches, they used a range from .5 to 5 inches (often using .25 inch increments; see Figure A2). This suggests that participants were not treating distance estimates as a discrete decision.

With respect to accuracy in this task, rather than set an arbitrary error criterion (e.g., .5 cm/inches, 1 cm) to compare performance across the two age-groups, accuracy was assessed using the estimate data. Given that the younger and older adults differed in the units they used, it was first necessary to convert the estimate data into one unit (i.e. cm) so that the estimates were comparable. To do this, the inch estimates were converted to cm (by multiplying by 2.54), and absolute mean difference scores were calculated. This was done by subtracting the actual distance (in cm) from the estimate (in cm), and taking the absolute difference. The mean absolute difference scores were then subjected to a 2 (VF) x 8 (Distance) x 2 (Age-Group) ANOVA. Multiple comparisons were Bonferroni corrected.

Figure 3.2 shows the absolute difference scores for each age-group as a function of VF and distance. There was a main effect of Distance, $F(7,385) = 24.32$, $p < .01$. This showed that accuracy decreased with distance; however, there were no significant differences when Bonferroni corrected. There was also a main effect of VF, F (1, 55) =

15.14, $p < .01$. Importantly, participants were more accurate in estimating distance when the stimuli were presented in the LVF-RH ($M = .97$ cm difference, $SD = .50$) than in the RVF-LH ($M = 1.06$ cm difference, $SD = .54$). However, the interaction between VF and Age-Group, $F(1, 55) = 6.49$, $p < .01$, demonstrated that the LVF-RH advantage was driven by performance of the older adults, $t(28) = 4.43$, $p < .01$, and not the younger adults, $t(27) = .62$, *ns.* There was no main effect of Age-Group, $F(1, 55) = 1.18$, *ns,* suggesting that younger and older adults were equally accurate in estimating the distance between a bar and a dot. No other interactions were significant, $F < 1.80$.

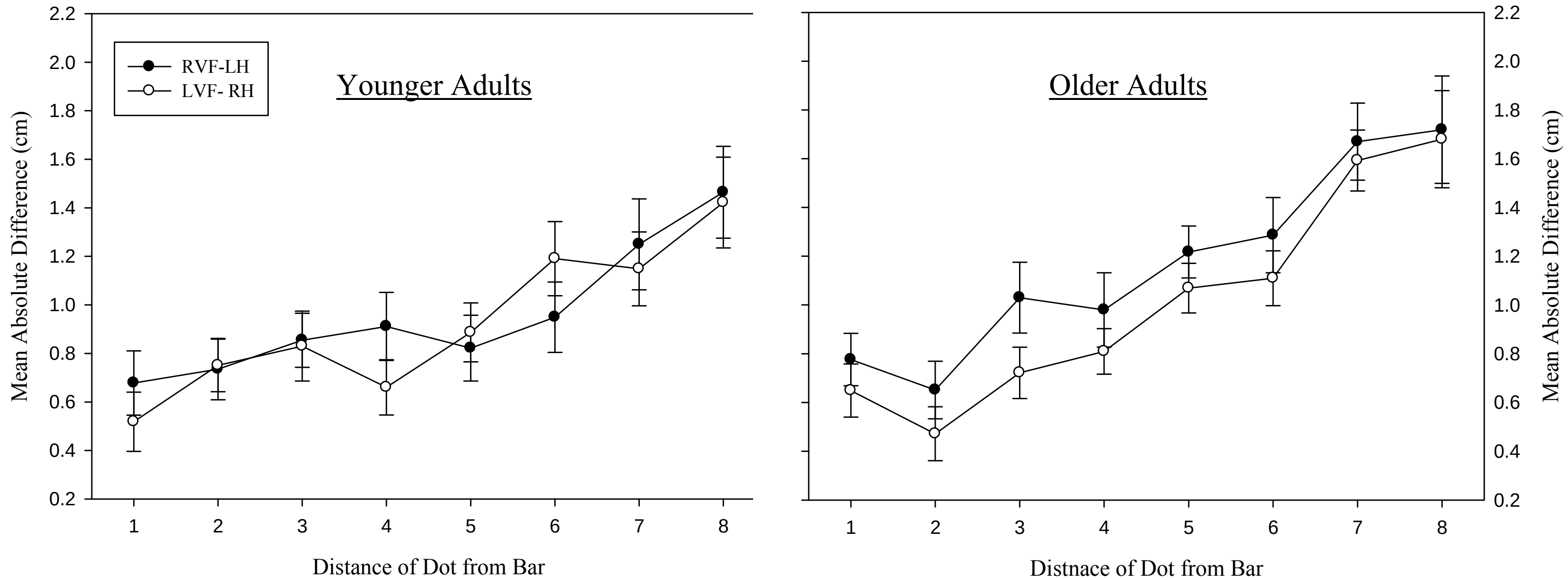


Figure 3.2. Mean absolute difference scores (with standard error bars) of each distance for LVF-RH and RVF-LH trials.

Note. Lower scores = more accurate estimations.

Response Times

For the categorical and near/far tasks only correct RTs were included in the analysis. For the distance quantification task, in order to reflect the continuous nature of the estimation response, all RT trials were analysed. For each participant outliers were trimmed. A datum point was considered an outlier if it was plus or minus 3 *SD* from the individuals mean; as such, 4% of the data were excluded. Although the data were found to deviate from the normal distribution, the analyses showed the same results when using data that had been log transformed, as well as when checked by non-parametric tests. For ease of interpretation, therefore, the data reported in Figures and Tables show original RT means. However, statistical analyses were conducted using the log transformed RT scores. Any unplanned multiple comparisons were Bonferroni corrected.

A 3 (Task) x 2 (VF) x 2 (Distance) x 2 (Age-Group) ANOVA was conducted. The Task x VF interaction was significant, $F(2, 110) = 18.69$, $p < .01$. Consistent with the predictions, the key findings showed a RVF-LH advantage for categorical processing, $t(56) = 3.71$, $p < .01$, and a LVF-RH advantage for estimating distance, $t(56) = -3.50$, $p < .01$. There was also a LVF-RH advantage for near/far VS judgements, $t(56) = -2.14$, $p < .05$ (see Figure 3.3). This was not in line with the predictions.

There was no Task x VF x Age-Group interaction, $F(2, 110) = .06$, *ns*, suggesting that the effects of VF for categorical and coordinate VS processes remain with age. This was confirmed with separate ANOVAs and with pairwise comparisons conducted with each age-group. There was a Task x VF interaction for both age-groups, (younger adults, $F(2, 54) = 8.47$, $p < .01$; older adults, $F(2, 56) = 5.38$, $p < .01$). In addition, for each age-group there was a RVF-LH advantage for the categorical task, *t*s > 1.96, *p*s < .06 (although this was only a trend for the older adults), and a LVF-RH advantage for the distance quantification task, *t*s > 2.23, *p*s < .03. Interestingly, neither age-group showed a significant advantage for the near/far task, *t*s < 1.74, *p*s > .09.

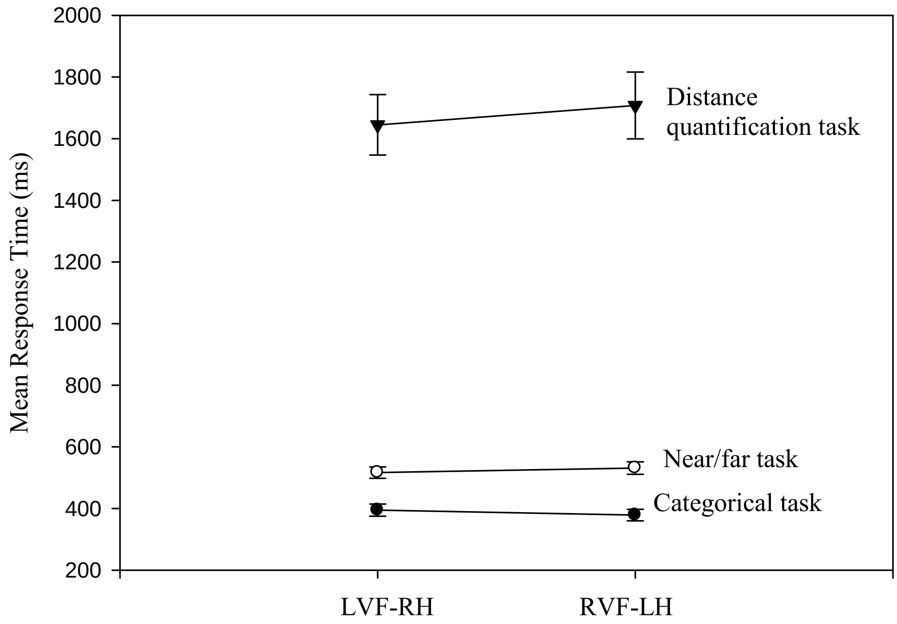


Figure 3.3. Mean RT (and standard error) for all tasks (categorical, near/far and distance quantification) across LVF-RH and RVF-LH trials.

In line with both Bruyer et al. (1997) and Hoyer and Rybash (1992), there was a main effect of Age Group, $F(1, 55) = 18.76$, $p < .01$. Younger adults ($M = 756.42$ ms, $SD = 273.48$) were faster to respond than older adults ($M = 962.57$ ms, $SD = 273.49$). Thus, processing speed declined with age.

Main effects were also found for Task, $F(1, 55) = 250.18$, $p < .01$, and Distance, $F(1, 55) = 59.25$, $p < .01$. In line with the predictions, participants responded fastest in the categorical task and slowest in the distance quantification task, all *t*s > 8.39, *p*s < .01, suggesting that participants found the categorical task easiest and the distance quantification task most difficult. Participants also responded fastest to the trials in which the dot was located furthest from the bar ($M = 841.67$ ms, $SD = 266.49$) compared to when the dots were located near to the bar ($M = 877.31$ ms, $SD = 289.23$).

There were interactions between Task and Distance, $F(2, 110) = 38.63$, $p < .01$, and Distance and Age-Group, $F(1, 55) = 10.69$, $p < .01$, which were qualified by a three-way interaction between Task, Distance and Age-Group, $F(2, 110) = 3.09$, $p < .05$. Figure 3.4 shows that there was no effect of distance in the categorical task for either age-group, *t*s < 1.56. In addition, in the near/far task both age-groups were faster to respond to trials in which the dot was located furthest from the critical distance compared to nearest the critical distance, *t*s > 7.01, *p*s < .008. However, for the distance quantification task, the younger adults were faster to estimate distance when the dots were located near to the bar, $t(27) = 5.91$, $p < .008$, whereas there was no effect of distance for the older adults, $t(28) = 1.13$, *ns.*

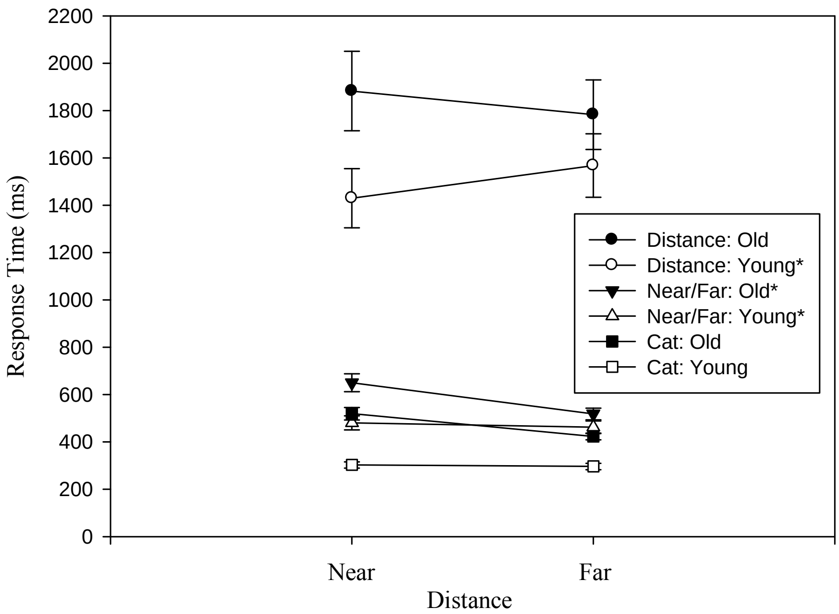


Figure 3.4. Mean RTs (and standard errors) for all tasks (categorical, near/far and distance quantification) as a function of distance (near and far) and age-group. Circles = distance quantification task, triangles = near/far task and squares = categorical task. Open shapes = younger adults; filled shapes = older adults. * = $p < .008$.

There was also an interaction between VF and Distance, $F(1, 55) = 6.18$, $p < .05$, which revealed an overall LVF-RH advantage for responses to dots located near to the bar, $t(56) = -2.76$, $p < .025$. There was no difference between VFs for dots located far from the bar, $t(56) = .87$, *ns*. There were no other significant main effects or interactions, all *F*s < 2.45.

3.4. Discussion

The current experiment investigated how younger adults and older adults processed three different VS judgements; a categorical above/below judgement, a coordinate near/far judgement, and distance estimation in a newly developed coordinate task. Importantly, a Task by VF interaction was obtained. In line with the predictions, the key finding was that there was a RVF-LH advantage for categorical VS judgements and a LVF-RH advantage for distance estimation. There was also a significant LVF-RH advantage for near/far VS judgements, but only when data was collapsed across age-groups. The results can be interpreted to provide support for Kosslyn's (1987) hemispheric asymmetry theory. With respect to age, the HAROLD and right-hemi-aging hypotheses were assessed. The key findings showed that, although processing speed changed, VF advantages were similar across age. Furthermore, there was no evidence that coordinate VS processes were more vulnerable to age-related decline. Thus, the results reported here are not in line with the HAROLD model or right hemi-aging hypothesis.

Consistent with the predictions, participants made fewest errors and were fastest to respond in the categorical task, made more errors and took longer to respond in the near/far task, and took longest to respond in the distance quantification task. This suggests that participants found making above/below decisions easiest and estimating distance in the distance quantification task most difficult.

With respect to hemispheric specialisation, in line with the predictions, the study reported here shows preferential categorical performance, at least in terms of faster RTs, for trials presented in the RVF. It is argued that the LH is more involved in categorical VS processes because of the association between the generation of spatial categories and language; categorical spatial relations are, essentially, spatially descriptive words and so are language oriented (Carlson & Van Deman, 2004; Hartley et al., 2001; Kosslyn, 1987; Landau & Jackendoff, 1993; Noordzij et al., 2008). Thus, the RVF-LH advantage found for this task is in line with the theory of LH specialisation for categorical VS processing. In addition, this is the only study to have found a RVF-LH advantage with both younger and older adults. Thus, the current results indicate that, in line with Laeng (2006), hemispheric specialisations underlying categorical VS processing remain relatively intact with age, at least in terms of processing speed.

Interestingly, participants showed no effect of distance in the categorical task. This finding has been reported in previous work (e.g., Sergent, 1991; Wilkinson & Donnelly, 1999), and may be the result of ceiling performance. That is, accuracy in this task was near perfect. As such, there may be no effect of distance because the overall task demands were sufficiently low that all trials could be responded to quickly and accurately.

A LVF-RH advantage, in terms of speed of response and in the accuracy of estimates, was found with the novel distance quantification task. That is to say, not only were participants faster to make distance estimations when the stimuli were presented in the LVF-RH, but they were also more accurate in their estimations. The distance quantification task was designed to reflect the continuous nature of coordinate spatial relations, and to ensure distance was explicitly computed on every trial. This was achieved by asking participants to estimate distance on each trial. Thus, this finding is consistent with the theory of RH specialisation for coordinate VS processing. Furthermore, again, this suggests that the RH specialisation underlying coordinate VS processing when precise distance was required remains intact with age.

The results obtained in the near/far task were more difficult to interpret. Separately, neither age-group showed an overall advantage in this task. When the analyses were collapsed across age-groups, a LVF-RH advantage was found. This suggests that the non-significant findings for the younger and older adults separately may have been due to a lack of power. Therefore, this finding provided some support for Kosslyn's (1987) theory that the RH specialises in processing near/far coordinate spatial relations. However, the limited evidence of a LVF-RH advantage in the near/far task, in the context of a clear advantage with the newly developed task, was consistent with the view that the distance of the dot from the bar may not have been explicitly measured on every trial, and on some trials (especially when the dot was located far from the bar), the near/far judgement could be reconstructed according to categorical boundaries (see Huttenlocher et al., 1991). Indeed, participants were faster to respond to dots located furthest from the critical 4.5 cm boundary. According to Kosslyn et al. (1992), the closer two items to be related are the more difficult it becomes to discriminate between them, hence a longer time is needed to make a judgement.

Alternatively, it could be that the nearer a dot was located to the critical distance a longer RT was needed, because the distance of that dot from the bar was actually being computed. That is, the distances of dots located furthest from the critical distance could have been judged using a discrimination process that does not require precise distance computation, whereas, as the distance of the dot gets closer to the critical distance (i.e. 4.5 cm/2 ¼ inches), these discrimination processes may become more difficult, and participants then may have to start computing distance in order to accurately judge them as near or far. However, given that participants responded over 1000 ms slower on average when estimating distance compared to when making a near/far judgement, it is unlikely that these two tasks utilise the same cognitive processes. Instead, the findings suggest that near/far VS judgements probably do not explicitly require the computation of distance.

It is important to note, however, that it is difficult to make inferences about the cognitive processes underpinning each cognitive task as perceptual visual half-field studies are limited with respect to the degree of insight they provide into the nature and time course of categorical and coordinate VS cognitive processes. This is an issue that will be investigated in more detail in Experiment 4 (see Chapter 6).

The key finding in terms of VF advantages and age is that no significant differences were found between younger and older adults. Thus, in contrast to the HAROLD model, these results can be interpreted to show that hemispheric advantages for categorical and coordinate VS processing remains intact with age.

Consistent with Bruyer et al. (1997) and Hoyer and Rybash (1992), older adults were slower to make a VS judgement than younger adults. This overall decline in processing speed was not surprising and is consistent with the theory of generalised slowing with age (Salthouse, 1996). Older adults take longer to process information and make appropriate responses. In contrast to the predictions, no Age-Group by Task interaction was obtained with the RT data. This suggests that there was no differential age-related slowing in processing speed for any of the three tasks. Furthermore, there were no significant differences in accuracy rates between the two age-groups, suggesting that younger and older adults are equally good at computing spatial relations.

In summary, this chapter set out to replicate previous research and investigate the VF advantages associated with a categorical above/below task, a coordinate near/far task, and a newly developed distance in younger and older adults. The first key finding was that effects of VF do not change with age, and both younger and older adults demonstrated a RVF-LH advantage for categorical VS judgements, and a LVF-RH advantage for distance estimation. In addition, neither age-group showed a significant advantage for the near/far task, although collapsed across age-groups a LVF-RH was found. The second key finding was that age-related decline was not selective across tasks. Specifically, coordinate VS processes were not disproportionately affected by age-related decline.

In conclusion, the findings reported in this chapter are in line with Kosslyn's (1987) theory of hemispheric specialisation for categorical and coordinate VS processes. However, the results from this study are not in line with the HAROLD model, demonstrating that patterns of lateralisation found in younger adults for VS processing remain in older adults. The results are also inconsistent with the right hemi-aging hypothesis.

It is important to consider alternative reasons as to why VF differences were found between tasks. For example, some researchers have found that hemispheric advantages for categorical and coordinate VS processes appear only under specific experimental conditions. Recall that Slotnick et al. (2001) found a RH advantage for coordinate VS processes only when task demand was sufficiently high, and a LH advantage for easy tasks. Thus, it cannot be ruled out that the LVF-RH advantage for the distance quantification task and the RVF-LH advantage for the categorical task were obtained because different task demands. This is an important issue and will be further investigated in Experiment 2.

Consequently, two important research questions have emerged from Experiment 1 and need to be addressed. First, how robust is the LVF-RH advantage found in the distance quantification task? The distance quantification task presented in this chapter reflects the continuous nature of coordinate VS judgements. It is clear that further task refinement, reliability and validation are required; nevertheless, it seems that employing a task that requires precise distance computation is a promising way forward if clarity and consistency are to be found in this field. Second, how does task demand affect the associated hemispheric specialisations for categorical and coordinate VS processes? The results showed that there were differences in task demand between the categorical above/below task, the near/far coordinate task and the distance quantification task. Accordingly, in the following chapter, task demand will be manipulated in order to assess whether task demand affects processing of categorical and coordinate VS information presented in different VFs.

Chapter 4

The Importance of Task Demand in Relation to Hemispheric Specialisation and VS Processes

4.1. Introduction

Previous research has argued that categorical and coordinate VS processes are qualitatively distinct VS cognitive functions (see Chapter 1). These processes are suggested to be computed more efficiently by different neural networks that are specialised in the LH and RH, respectively (e.g., Kosslyn et al., 1992). However, hemispheric specialisations tend to be particularly sensitive to task demand. For example, recall that Slotnick et al. (2001) found LH advantages for all categorical judgements and low demand coordinate judgements. A RH advantage for coordinate judgements was found only under high task demands. These results replicated those reported by Parrot et al. (1999). Specifically, Parrot et al. conducted a near/far coordinate task in which the dot was located in 1 of 6 locations away from the bar. A LVF-RH advantage was found for trials in which the dot was located nearest to the critical value only. The closer the dots were to the critical distance the more difficult it was for participants to judge as near or far (see Kosslyn et al., 1992). A RVF-LH advantage was found for all other dot locations. Accordingly, this has led some researchers to propose that the hemispheric advantages found for categorical and coordinate VS tasks may be driven by differences in task demand rather than differences in the type of spatial judgement per se (e.g., categorical or coordinate; Martin et al., 2008; Oleksiak et al., 2009; Parrot et al., 1999; Sergent, 1991; Slotnick et al., 2001).

The importance of task demand in determining hemispheric specialisation has received further support in two recent empirical papers. Specifically, Van der Lubbe et al. (2006) and Martin et al. (2008) suggested that hemispheric specialisations associated with categorical and coordinate VS judgements may not represent qualitative differences in cognitive processing but quantitative differences. For example, Martin et al. (2008) suggested that categorical and coordinate VS processes are located at opposing ends of a continuous spatial code. Specifically, Martin et al. postulated that categorical and coordinate information is processed along the same cognitive networks, and differ only in the amount of general cognitive resources required. These general cognitive resources are suggested to include VS attention and executive functioning, both of which are thought to be predominantly RH oriented functions (Martin et al., 2008; Wager & Smith, 2003). According to Martin et al. (2008), the increased VS attention and executive functioning required for coordinate VS judgements causes greater activation of the RH which in turn leads to the RH advantage observed for this process.

In the previous experiment a RVF-LH advantage was obtained for the categorical task, a LVF-RH advantage was obtained for the distance quantification task, and no significant LVF-RH advantage was obtained for the near/far coordinate task, at least for each age-group independently. However, the tasks differed in cognitive demand. Participants made very few errors in the categorical task, suggesting that above/below VS judgements were particularly easy. By contrast, estimating precise distance required much longer average RTs and participants made a greater number of errors, suggesting that this task was particularly demanding. The results from the near/far task were more mixed. Similar to performance in the categorical task, for the trials in which the dot was located furthest from the critical distance, participants responded relatively quickly and with minimal errors. In contrast, participants made more errors and took longer to respond in the trials in which the dot was located near to the critical distance. Importantly, however, the time taken and errors made were much shorter and lower than that in the distance quantification task. Thus, differences in task demand may go some way to explaining the patterns of performance observed.

If the above/below categorical task was particularly easy, indicating very low cognitive demand, then this may have contributed to the RVF-LH advantage displayed by this task. Similarly, if the distance quantification task was particularly demanding, then this may explain why a clear LVF-RH advantage was found in this task and not in the near/far coordinate task. Consequently, it is important to establish whether the RVF-LH advantage in the categorical task and the LVF-RH advantage in the distance quantification coordinate task found in the previous chapters were simply due to differences in task demand.

With this in mind, the aim of the current study was to investigate whether task demand was important in obtaining hemispheric specialisation for above/below and distance quantification judgements. The primary objective was to develop a new experimental paradigm in which the task demand associated with the typical above/below categorical task was increased, and the task demand of the distance quantification task, developed in Experiment 1, was decreased.

One way to achieve greater task demand in the categorical task was to increase the number of categories in which the dot could be located so that the categorical decision was no longer binary. Accordingly, in the current experiment, the number of categories in which the dot could be located was doubled, to four, to include above, below, left and right spatial categories. Left/right spatial relations were employed because previous work has extended to methodologies requiring left/right judgements, and found the associated RVF-LH advantage (Kosslyn et al., 1989; Slotnick et al., 2001).

For the distance quantification task, the number of distances in which the dot could be located was decreased from eight to two. It is important to note that by reducing the number of distances to two does not fundamentally change this task, in that a distance judgement on a continuous scale was still required. Specifically, participants were not told that there were only two distances, nor were they told the range of distances (see Appendix; Figures A3 and A4). Instead, participants were simply asked to estimate distance as accurately as possible. Furthermore, given the effects of distance reported in the previous chapter, by having at least two distances meant that distance could be included as a dependent variable. The distances were 2 cm and 5 cm. Again, as it was anticipated that older adults would prefer to work in inches rather than cms, an inch version of the task was also designed. To be comparable to the cm version, the distances used were 1 inch and 2 inches.

To incorporate these task parameters, a novel box paradigm was developed. In the box paradigm, participants were first presented with a dot located inside a box for 25 ms. A box was used rather than horizontal or vertical bar in order to keep the stimulus, initially, perceptually ambiguous with respect to which bar the judgement about the dot would be made. After 25 ms, three sides of the box disappeared, leaving one remaining box bar and the dot for 125 ms. Consistent with Experiment 1, this meant that the stimuli were presented for a total time of 150 ms.

It was anticipated that by using this novel box paradigm, the categorical task would be more demanding and the distance quantification coordinate task would be less demanding than reported in Experiment 1. Specifically, it was predicted that participants would respond more slowly and less accurately in the categorical box task than the previous above/below task. It was also predicted that participants would respond more quickly and more accurately in the distance quantification box task than the distance quantification task developed in Experiment 1.

On the assumption that task difficulty in the box paradigm tasks was manipulated, the data from the box paradigm tasks will then be analysed to evaluate whether changes in task demand affect the patterns of performance across VFs. If the VF advantages found in Experiment 1 were due to the type of task being performed (i.e. categorical or coordinate) then it was predicted that a RVF-LH advantage would be found for the categorical task and a LVF-RH advantage for the distance quantification task. However, if, instead, task demand drives the hemispheric specialisations then differences in hemispheric specialisation would be found. Specifically, a LVF-RH advantage would be predicted for the categorical task, and no advantage was predicted for the distance quantification task. Thus, a Task by VF interaction was expected, but the directions of the advantages were not clear.

With respect to distance, it was predicted that for the categorical task, participants would be faster and more accurate to respond to dots located furthest from the bar. By contrast, for the distance quantification task, it was predicted that participants would be faster and more accurate to estimate the smaller distance than the larger distance. Thus, given the cross-over in results, this should manifest as a Task by Distance interaction.

The final aim of the study was to investigate younger and older adults' performance using the box paradigm. Consistent with previous work (e.g., Bruyer et al., 1997; Hoyer & Rybash, 1992; see also Experiment 1) it was predicted that younger adults would respond more quickly than older adults. In terms of ERs, it was anticipated that older adults would make more errors in the categorical task than the younger adults, especially given the increased task demand. For the distance quantification task, older adults were expected to be more accurate at estimating distance than the younger adults. It was also predicted that both age-groups would show the same patterns of VF advantage, and that age-related slowing would not affect processing in the categorical and distance quantification tasks differentially.

4.2. Method

Participants

Fifty-nine participants were recruited for this study; there were 28 right-handed younger participants who volunteered or were awarded course credits and 31 older adult, community-dwelling volunteers were recruited through an Older Adult Volunteer Database at the School of Psychology, University of Southampton. Participants were screened for normal or corrected-to-normal vision and were assessed for handedness using the EHI (Oldfield, 1971). The older adults were also screened for cognitive impairments using the MoCA (Nasreddine et al., 2005). Two older adults were excluded from analysis due to scores on the MoCA being lower than the cut-off of 26/30 (Nasreddine et al., 2005). One additional older adult was also excluded, due to complaints that the stimuli could not be seen properly.

Table 4.1 displays the participants' descriptives of each age-group. Age, gender, handedness, years of education and Predicted IQ were compared across age-groups in order to assess whether any age-group differences in performance could be due to differences in descriptive factors. The *p*-values in Table 4.1 show whether differences were found across age-groups. Consistent with Experiment 1, older adults had significantly higher Predicted IQ scores than younger adults, however, no age differences were found for gender, laterality or years of education.

Table 4.1

Comparison of Participants' Descriptives across Age-Groups

	M, (SD), range		*p*
	Younger adults (N=28)	Older adults (N= 28)	
Age	19.21 (.92), 18-21	67.11 (7.17), 57-84	.00*
Gender (M:F)	7:21	9:19	.27
Handedness (EHI)	88.26 (16.34), 36.8-100	93.28 (13.19), 41.2-100	.12
Years of Education	14.64 (.87), 13-16	15.18 (3.42), 10-25	.38
NART Predicted IQ	101.93 (4.78), 90-113	120.25 (8.33), 91-129	.00*
MoCA	-	28.14 (1.53), 26-30	-

Note. Age is provided in years. EHI = Edinburgh Handedness Inventory (Oldfield, 1971); a score of 100 = very strongly right-handed. MoCA = Montreal Cognitive Assessment (Nasreddine et al., 2005); scored out of 30, so that a high score = better cognitive performance. Years of education refers to how many years of formal school-education were attended. Predicted IQ-NART = National Adult Reading Test (Nelson & Willison, 1991); a high score = higher IQ. * = age-related differences $p < .01$.

Design and Materials

Each task was computerised and had been programmed using Presentation software. To ensure constant viewing conditions, participants used a chin rest and were seated 57 cm from a 15 inch computer monitor. Participants were given the option of working in inches or cm. All younger participants chose cm, and the majority of the older participants (18/28) chose inches.

The stimuli were a dot (0.5^o x 0.5^o) and a box (7^o x 7^o). During the presentation of the box, three sides of the box would disappear, leaving one remaining bar (0.5^o x 7^o; see Figure 4.1). This would be the bar against which the judgement in relation to the dot was made, and will be referred to as the box-bar stimulus. The stimuli were presented in black on a white screen, in the LVF or RVF.

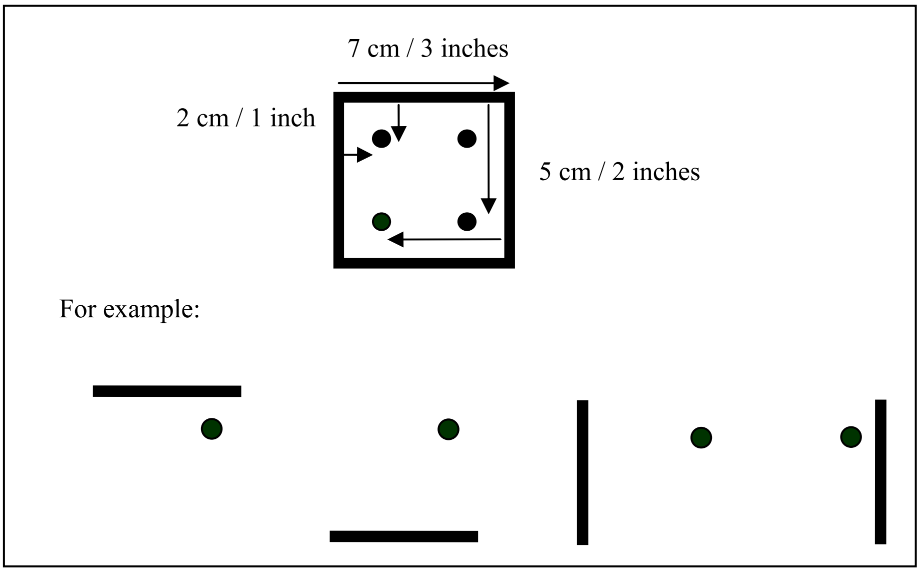


Figure 4.1. Figure to show range of stimuli. Top: initial box seen by participants, and the possible four positions in which the dot could be located (although only one dot was displayed per trial). Bottom: examples of the stimuli after three sides of the box had disappeared (from left to right: categorical task: dot below, above, right, left; distance quantification task; 2 cm, 5 cm, 5 cm, 2 cm from bar; or 1 inch, 2 inches, 2 inches, 1 inch).

Both tasks consisted of 96 trials, of which 48 were in the RVF and 48 in the LVF. The edge of the box was located at 3^o from the fixation cross. The dot could appear at 1 of 4 locations within the box; these were positioned 2 cm x 2 cm across from the corners of the box. Thus, for each box-bar position, the dot either appeared 2 cm or 5 cm away (1 or 2 inches; see Figure 4.1). In each VF, the box could appear in 1 of 3 locations; centrally and 0.7 above and below central. All four dots were presented with all four box-bars (top, bottom, left and right; see Figure 4.1). Each box-bar-dot position was seen twelve times in each VF; four times at each of the three box position. In both tasks, stimuli were presented in a fixed, pseudo-random order and appeared in one VF or at either distance on no more than 3 consecutive trials.

In the categorical task, participants were required to decide whether the dot was located *above, below, left,* or *right* of the box-bar. Participants indicated their response by pressing one of two keys on the keyboard (located next to each other), using the index and middle finger of their right (dominant) hand. To reduce RT lags, participants were trained to press key ‘b’ when making an above or left response, and key ‘n’ when making a below or right response.

For the distance quantification task, participants were required to estimate the distance between the dot and the box-bar. Participants indicated their estimate by typing in a number (in inches or cm) on the keyboard, using their right (dominant) hand. RT was recorded when the first key was pressed. Once participants had finished typing in their estimate, they pressed enter. This recorded their actual estimate, and signalled for the mask to be displayed.

Practice Trials

Participants were required to complete two blocks of practice trials before the experimental trials were started. The first block consisted of 16 trials and involved familiarisation with which keys to press. In the categorical practice trials, the words ‘above’, ‘below’, ‘left’ or ‘right’ were displayed centrally on screen and participants had to press the corresponding key. For the distance quantification task, numbers were displayed in figure format (i.e. 1, 2, 9 etc) and participants had to type in the corresponding number. For example, if the number 2 was presented on screen participants had to press number 2 on the key-pad.

The second practice block allowed familiarisation with the actual stimuli. Participants were presented with 16 trials in which the dot appeared with each of the box-bar configurations (e.g., at each categorical position and at each distance) in each VF. For both practice blocks, participants received feedback for incorrect responses. That is, participates were told when they were incorrect and the correct category or distance was specified to them.

Procedure

Both tasks used the same stimuli, and only differed in the VS judgement required. Each trial within each task consisted of the same sequence of events (see Figure 4.2). A central fixation cross appeared on a blank screen. After 300 ms, ‘ready?’ appeared above the cross. Participants indicated they were ready to begin by pressing the space bar on a Standard English keyboard with the index finger of their left (non-dominant) hand. Following a 250 ms blank screen, a centrally displayed fixation cross appeared for 200 ms. A box and dot were then presented in the LVF or RVF for 25 ms. Three sides of the box then disappeared, leaving one remaining box-bar and the dot, and this remained on screen for 125 ms. The stimulus then disappeared and the screen remained blank until participants pressed a response button. As soon as a button was pressed, a mask screen, comprised of many bars and dots, appeared for 300 ms. Consistent with Experiment 1, the mask was presented in order to prevent carry-over from trial to trial. Participants were given verbal instructions and practice trials before each task began. The tasks were counterbalanced.

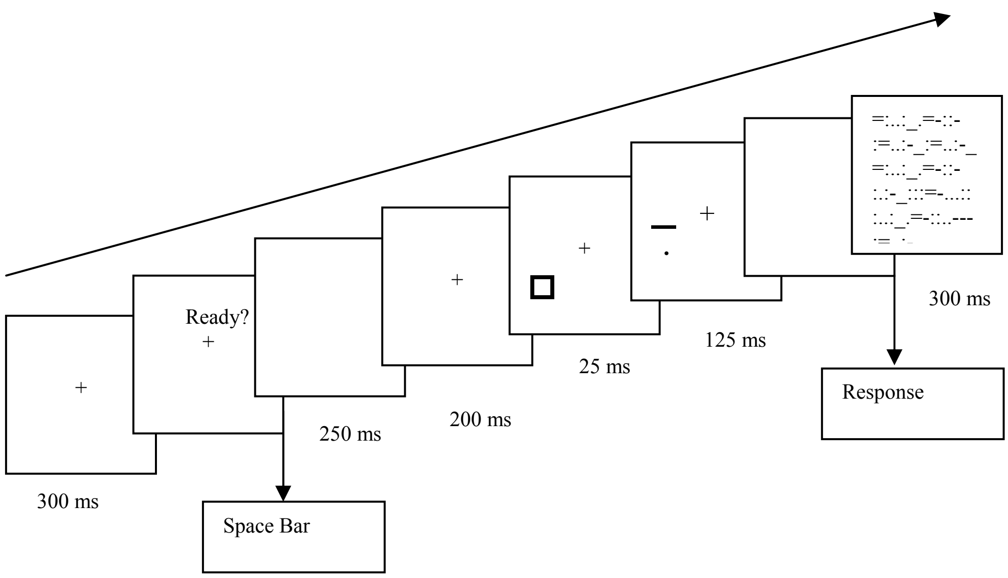


Figure 4.2. Figure to show the sequence of events that constituted a trial.

4.3. Results

The data were analysed in two stages. In Section 4.3.1 task demand was assessed in relation to the tasks employed in the previous experiments, and in Section

4.3.2 the tasks developed for the current experiment were analysed with respect to VF and distance.

4.3.1. Results: Comparisons to Experiment 1

Group Comparisons

Table 4.2 shows the comparisons of each age-groups' descriptive across Experiment 1 and Experiment 2. As shown in Table 4.2, there were no differences in descriptives between the two groups of younger adults. For the older adults, differences were found in age and education. The older adults in Experiment 1 had a higher mean age and had fewer years of formal education than those who participated in Experiment 2.

Table 4.2

Comparisons of each Age-Groups' Descriptives across Experiments

	M (SD)		*p*	*M (SD)*		*p*
	Younger adults			Older adults		
	Experiment 1	Experiment 2		Experiment 1	Experiment 2	
Age	19.89 (2.20)	19.21 (.92)	.60	72.10 (6.85)	67.11 (7.17)	.00*
Gender (M:F)	7:21	7:21	.50	6:23	9:19	.25
Handedness	88.41 (16.36)	88.26 (16.34)	.71	90.82 (9.30)	93.28 (13.19)	.11
Education	15.39 (2.04)	14.64 (.87)	.46	12.90 (3.27)	15.18 (3.42)	.00*
Predicted IQ	103.32 (6.77)	101.93 (4.78)	.61	117.72 (8.31)	120.25 (8.33)	.13
MoCA	-	-	-	27.90 (1.35)	28.14 (1.53)	.48

Note. Age is provided in years. Handedness is assessed by the Edinburgh Handedness Inventory (Oldfield, 1971); a score of 100 = very strongly right-handed. Years of education refers to how many years of formal school-education were received. Predicted IQ is assessed by the National Adult Reading Test (Nelson & Willison, 1991); a high score = higher IQ. MoCA = Montreal Cognitive Assessment (Nasreddine et al., 2005); scored out of 30, so that a high score = better cognitive performance. *p*-values refer to comparisons of participants' descriptives across experiments. * = $p < .01$.

Given that across the two experiments the older adults groups differed in age and education, correlations were computed in order to assess whether age and education should be added as covariates to the analysis. As shown in Table 4.3, for the older adults, as age increased, the time taken to estimate distance decreased, and as the number of years of formal education increased, the time taken to make a categorical judgement increased. These findings were opposite to what would be expected; that is, normally with age RT increases, whereas RT decreases as education levels increase.

Table 4.3

Correlations between Age, Years of Education, RT and ER for each Age-Group across Experiments

	r (p)			
	Categorical task		Distance quantification task	
	RT	ER	RT	ER
	Younger adults[a]			
Age	-.17 (.21)	-.17 (.22)	-.14 (.32)	-.21 (.13)
Education	-.17 (.21)	.10 (.45)	-.13 (.33)	-.25 (.06)
	Older adults[b]			
Age	-.13 (.34)	-.25 (.06)	-.27* (.04)	-.03 (.83)
Education	.37** (.01)	-.005 (.97)	.23 (.08)	.01 (.97)

Note. Education refers to the number of years of formal education attended.
* = correlation $p < .01$. [a]N = 56; [b]N = 57.

As age and education did not correlate with ER performance, an ANCOVA was not conducted with the ER data, as the sensitivity of the analyses would be reduced (see Pallant, 2001 or Howitt & Cramer, 2001). However, as education and age differed between older adults only, and given that these variables correlated with RT for older adults only, an ANCOVA was conducted with the older adult age-groups. Specifically, to assess whether differences between Experiments 1 and 2 were affected by differences in age and education, a 2 (Task) x 2 (Experiment) ANCOVA was conducted on the older adults data with age and education included as covariates. Again, as recommended by Cohen et al. (2003), the continuous covariate measures were first centred.

Importantly, the main effects of Task and Experiment and the Task x Experiment interaction still remained significant in the ANCOVA, Fs > 41.26, ps < .01. Thus, it seems reasonable to suggest that different patterns of performance found between Experiments were not due to differences in age and education in the older adult groups. The following analysis examines, in detail, the differences in performance across Experiments.

Accuracy

In line with Experiment 1, the accuracy of the categorical and distance quantification tasks were analysed separately using 2 (Experiment) x 2 (Age-Group) ANOVAs. Experiment and Age-Group were both between-subjects variables. For the categorical task accuracy was assessed using percentage error rate. For the distance quantification task, accuracy was assessed using absolute differences scores between the estimate and the actual distance. Any unplanned multiple comparisons were Bonferroni corrected.

Categorical Task: Percentage Error Rates

There was a main effect of Experiment, $F(1, 109) = 16.92$, $p < .01$, which demonstrated that, overall, participants made fewer errors in Experiment 1 ($M = 2.78\%$ errors, $SD = 2.04$) than in Experiment 2 ($M = 9.24\%$ errors, $SD = 11.62$). This suggests that the box paradigm categorical task was more challenging than making judgements in relation to a horizontal bar only. There was no main effect of Age-Group, or an interaction, $F < .37$.

Distance Quantification Task: Estimates

There was a main effect of Age-Group, $F(1, 109) = 13.94$ $p < .01$, which demonstrated that, overall, younger participants ($M = .63$ cm difference, $SD = .37$) were more accurate in their estimations than older adults ($M = .99$ cm difference, $SD = .36$). There was also a main effect of Experiment, $F(1, 109) = 7.77$ $p < .01$, which demonstrated that participants were more accurate at estimating distance in Experiment 2 ($M = .67$ cm difference, $SD = .52$) than in Experiment 1 ($M = .94$ cm difference, $SD = .51$). This suggests that participants found estimating distance easier when there were only two distances to be judged (Experiment 2) compared to when there were 8 distances to be judged (Experiment 1). There was no Experiment x Age-Group interaction, $F(1, 109) = 1.24$, *ns*.

Recall, that in the introduction it was suggested that by decreasing the number of distances to be estimated from eight to two would not fundamentally change the nature of this task (i.e. would not make this task a categorical, discrete decision). In order to confirm that participants did not treat this task as a discrete decision, in line with Experiment 1, estimate response distributions were plotted, and the frequencies by which participants gave a particular distance estimate were examined (see Appendix for plot of *t*-values). Again, these analyses showed that when participants estimated the distance between the bar and dot in cm, they used a range from 1 to 9 cm (see Figure A3). When participants estimated the distance between the bar and dot in inches, they used a range from 1 to 4 inches (and also gave .5 inch estimates; see Figure A4). This suggests that participants were using a continuous scale to estimate distance in the box-paradigm distance quantification task.

Response Times

The RT data were subjected to a 2 (Task) x 2 (Experiment) x 2 (Age-Group) ANOVA. Age-Group and Experiment were between-subject factors. There were main effects of Task, $F(1, 109) = 404.57$, $p < .01$; Experiment, $F(1, 109) = 62.90$, $p < .01$; and Age-Group, $F(1, 109) = 62.53$, $p < .01$. These demonstrated that participants were faster to respond in the categorical tasks compared to the distance quantification tasks, highlighting that estimating distance was more challenging than judging spatial categories. Participants were also faster to respond in Experiment 1 than in Experiment 2. This suggests that overall the box paradigm was more challenging than making judgements in relation to a horizontal bar only. Finally, as expected younger adults were faster to respond than older adults.

Importantly, there was a Task x Experiment interaction, $F(1, 109) = 113.18$, $p < .01$. As illustrated in Table 4.4, for the categorical task, participants were faster to respond in Experiment 1 compared to Experiment 2, $t(111) = 11.87$, $p < .025$. In line with the ER data, this suggests that both younger and older adult participants found the box paradigm categorical task in Experiment 2 more demanding than the categorical task in Experiment 1. In contrast, for the distance quantification task, although numerically both younger and older participants were faster to estimate distance in Experiment 2 than in Experiment 1, this was not significant, $t(111) = .97$, *ns*. There was also an interaction between Task and Age-Group, $F(1, 109) = 6.77$, $p < .05$. This showed that there was a larger age-related difference in the categorical tasks, $t(111) = 5.07$, $p < .025$, than in the coordinate tasks, $t(111) = 3.60$, $p < .025$.

Table 4.4

Mean RT across Task, Experiment and Age-Group

Task	Experiment 1	Experiment 2
	M RT (*SD*) ms	
	Younger adults	
Categorical	299.49 (69.78)	671.79 (174.14)
Distance Quantification	1498.48 (684.03)	1155.70 (247.23)
	Older adults	
Categorical	471.18 (147.31)	1267.62 (425.47)
Distance Quantification	1832.54 (824.73)	1698.76 (505.33)
	Total	
Categorical	386.84 (143.86)	969.70 (440.59)
Distance Quantification	1668.44 (770.76)	1427.23 (480.03)

Summary

One of the primary aims of this experiment was to increase task demand in the categorical task and decrease task demand in the distance quantification task. The results demonstrate that by increasing the number of categorical positions from 2 to 4 task demand was increased. This was reflected in increased RTs and ERs in Experiment 2 using the box paradigm task compared to the simple binary above/below categorical task used in Experiment 1.

For the distance quantification task, the number of distances to be judged were decreased from eight to two. In line with the predictions, participants were more accurate to judge distance in Experiment 2 than in Experiment 1. Furthermore, although not statistically significant, participants were also faster to make a distance estimate in Experiment 2 compared to Experiment 1. Together, these results suggest that it is more difficult to judge distance as the number of different distances to judge increases.

In summary, it would seem that increasing the number of spatial categories task demand successfully increased in the box-paradigm categorical task, and decreasing the number of distances to be judged successfully decreased task demand in the box-paradigm distance quantification task.

4.3.2. Results: Comparison of the tasks used in Experiment 2

The following analyses were conducted on the data from the tasks reported in this experiment only (i.e. the box paradigm tasks).

Predicted IQ

Consistent with Experiment 1, younger and older adults differed in Predicted IQ; older adults had higher Predicted IQs than younger adults. Correlations showed that Predicted IQ correlated with RT in the categorical task, $r(56) = .50$, $p < .01$, and in the distance quantification task, $r(56) = .41$, $p < .01$. However, as Predicted IQ increased so did RT. As argued in Experiment 1, it is unusual that higher IQs would lead to slower RTs. Consequently, it was suggested that differences in Predicted IQ were unrelated to differences in age-related performance and consistent with Experiment 1, Predicted IQ was not included in the analyses a covariate.

Accuracy

Consistent with Experiment 1, accuracy for the categorical and distance quantification task was analysed separately. For the categorical task accuracy was assessed using percentage error rates. For the distance quantification task, accuracy was assessed using absolute differences scores between the estimate and the actual distance. The accuracy data were not normally distributed, however, for the purpose of assessing VF and Age-Group interactions, separate 2 (VF) x 2 (Distance) x 2 (Age-Group) ANOVAs were conducted. Age-Group was a between subjects variable. All comparisons were confirmed with non-parametric equivalents, and any unplanned multiple comparisons were Bonferroni corrected.

Categorical Task: Percentage Error Rates

There were main effects of VF, $F(1, 54) = 4.80$, $p < .05$, and Distance, $F(1, 54) = 5.49$, $p < .05$. Participants made fewer errors when the stimuli were presented in the LVF-RH ($M = 8.63\%$ errors, $SD = 11.78$) compared to the RVF-LH ($M = 9.86\%$ errors, $SD = 12.04$). In addition, participants made fewer errors when judging dots located near to the bar ($M = 8.52\%$ errors, $SD = 12.15$) compared to far from the bar ($M = 9.97\%$ errors, $SD = 11.75$). This suggests that the closer the dot was located to the bar, the more difficult it was to make a spatial relation judgement. There were no other main effects or interactions, Fs < 2.18.

Distance Quantification Task: Estimates

There was a main effect of Distance, $F(1, 54) = 4.14$, $p < .01$. Participants made more accurate estimations when judging dots located near to the bar ($M = .57$ cm difference, $SD = .73$) compared to far from the bar ($M = .78$ cm difference, $SD = .72$). This suggests that the closer the dot was located to the bar, the easier it was to make a distance judgement. Interestingly, there was also a main effect of Age-Group, $F(1, 54) = 10.91$, $p < .01$, which showed that younger adults ($M = .46$ cm difference, $SD = .52$) more accurately estimated distance than the older adults ($M = .89$ cm difference, $SD = .52$). There were no other main effects or interactions, *F*s < .72.

Response Times

For the categorical task, the correct RT data were used. Consistent with Experiment 1, for the distance quantification task all RT data points were analysed. In both tasks, data were trimmed for outliers (plus or minus 3 *SD*s of the individuals mean); in this way 5% of the data were excluded. The distance quantification data were not normally distributed and variance differed between the age-groups. To account for this, the data were log-transformed (Cornelissen & Kooijmn, 2000; Tabachnick & Fidell, 1996). Data analysis was conducted on the log-transformed scores, but for ease of interpretation raw scores are reported in the Figures and Tables. Unplanned multiple comparisons were Bonferroni corrected; otherwise planned comparisons were conducted.

A 2 (Task) x 2 (VF) x 2 (Distance) x 2 (Age-Group) ANOVA was conducted. Age-Group was a between subjects variable. There were main effects of Age-Group, $F(1, 54) = 58.80$, $p < .01$, and Task, $F(1, 54) = 101.12$, $p < .01$. These findings showed that younger adults ($M = 913.72$ ms, $SD = 303.04$) were faster to respond than older adults ($M = 1483.19$ ms, $SD = 303.04$), and, overall, participants were faster to respond in the categorical task ($M = 969.70$ ms, $SD = 440.59$) compared to the distance quantification task ($M = 1427.23$ ms, $SD = 480.03$). This demonstrated that estimating distance was more cognitively demanding than judging categorical locations.

However, there was a larger age-related difference between RT in the categorical task, $t(54) = 6.86$, $p < .01$, than in the distance quantification task, $t(54) = 5.11$, $p < .01$. This was qualified by a Task x Age-Group interaction, $F(1, 54) = 8.74$, $p < .01$ (see Figure 4.3). Thus, in contrast to the right hemi-aging hypothesis, age-related decline was more pronounced for categorical VS processes than for distance quantification VS processes.

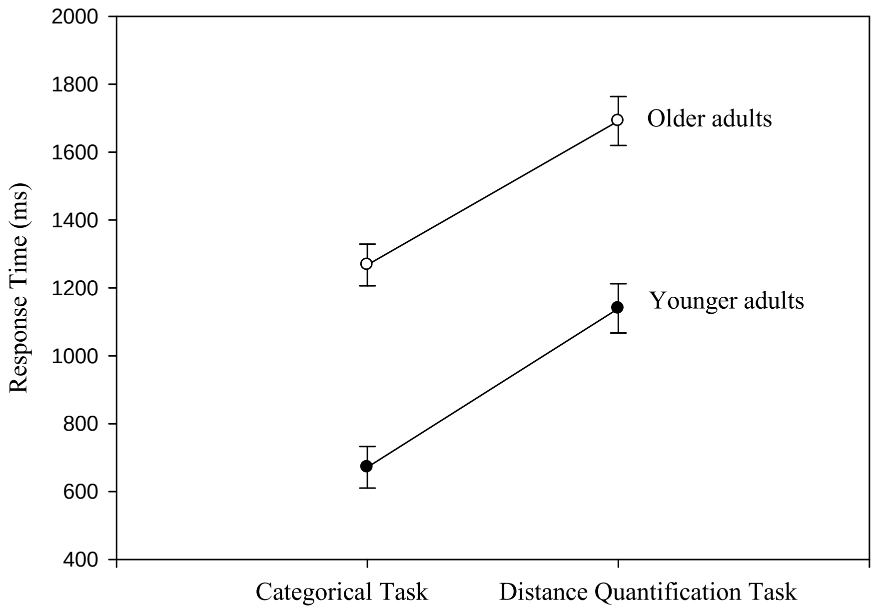


Figure 4.3. Mean RT (and standard error bars) as a function of Task and Age-Group.

As predicted, there was also a main effect of Distance, $F(1, 54) = 67.61$, $p < .01$, which showed that participants were faster to respond to the near trials compared to the far trials. In contrast to the predictions this effect was shown for both the categorical and distance quantification task (see Table 4.5). The effect of distance, however, was greater in the distance quantification task, $t(55) = -8.84$, $p < .01$, compared to the categorical task, $t(55) = 3.00$, $p < .01$. This was reflected in the Task x Distance interaction, $F(1, 54) = 28.49$, $p < .01$.

Distance also interacted with VF, $F(1, 54) = 33.55$, $p < .01$, in which there was a LVF-RH advantage for trials in which the dots were located near to the bar, $t(55) = -5.46$, $p < .025$, and a RVF-LH advantage for trials in which the dots were located far from the bar, $t(55) = 4.12$, $p < .025$.

Table 4.5

Mean RTs across Task and Distance

Task	Near	Far
	M (SD) ms	
Categorical	947.96 (431.70)	991.44 (456.69)
Distance Quantification	1317.75 (469.99)	1536.70 (513.15)
Total	1132. 86 (205.52)	1264.07 (232.52)

Importantly, the Task x VF interaction was significant, $F(1, 54) = 5.77$, $p < .05$, and demonstrated an overall LVF-RH advantage in the distance quantification task, $t(55) = -2.59$, $p < .01$, and no overall hemispheric advantage in the categorical task, $t(55) = 1.45$, *ns*. At face-value, this provides partial support for Kosslyn's (1987) VS asymmetry theory, at least in terms of processing of precise distance. However, as illustrated in Figure 4.4, the 4-way interaction between Task, VF, Distance and Age-Group, $F(1, 54) = 3.97$, $p < .05$, indicated a different result. No other main effects or interactions were found, *Fs* < 1.63.

In order to explore the four-way interaction between Task, VF, Distance and Age-Group, the categorical and coordinate tasks were analysed separately. For the coordinate task, as described in the overall analysis, there was a main effect of VF, $F(1, 54) = 6.65$, $p < .05$, and a main effect of Distance, $F(1, 54) = 76.92$, $p < .01$, showing that participants were faster to respond when the dot was located in the LVF and near to the bar. There was also a VF x Distance interaction, $F(1, 54) = 15.78$, $p < .01$, in which the overall LVF-RH advantage was driven by performance for dots located near to the bar, $t(55) = 4.64$, $p < .025$. This was found with both the younger and older adults, *ts* > 2.70. No VF advantage was found when the dot was located far from the bar, $t(55) = 1.54$, *ns*.

For the categorical task, as described previously, there was a main effect of Distance, $F(1, 54) = 8.94$, $p < .01$, which demonstrated that participants were faster to respond to the dots located near to the bar. There was also a VF x Distance interaction, $F(1, 54) = 23.35$, $p < .01$, and a VF x Distance x Age-Group interaction, $F(1, 54) = 3.92$, $p < .05$. A RVF-LH advantage was found for the categorical trials in which the dot was located far from the bar, $t(55) = 4.00$, $p < .025$, whereas there was a LVF-RH advantage for the categorical trials in which the dot was located near to the bar, $t(55) =$

2.73, $p < .025$. However, the RVF-LH advantage was only significant with the younger adults, $t(27) = 4.52$, $p < .0125$, and not with the older adults, $t(27) = 1.40$, *ns*. Both younger and older adults showed a trend towards a LVF-RH for the dots located near to the bar ts > 1.83, ps < .08.

Thus, it would seem that the distance of dot from the bar affects the patterns of VF advantages observed. Furthermore, the results for the box paradigm tasks show that younger and older adults process categorical stimuli presented in the LVF and RVF differently. These effects are illustrated in Figure 4.4.

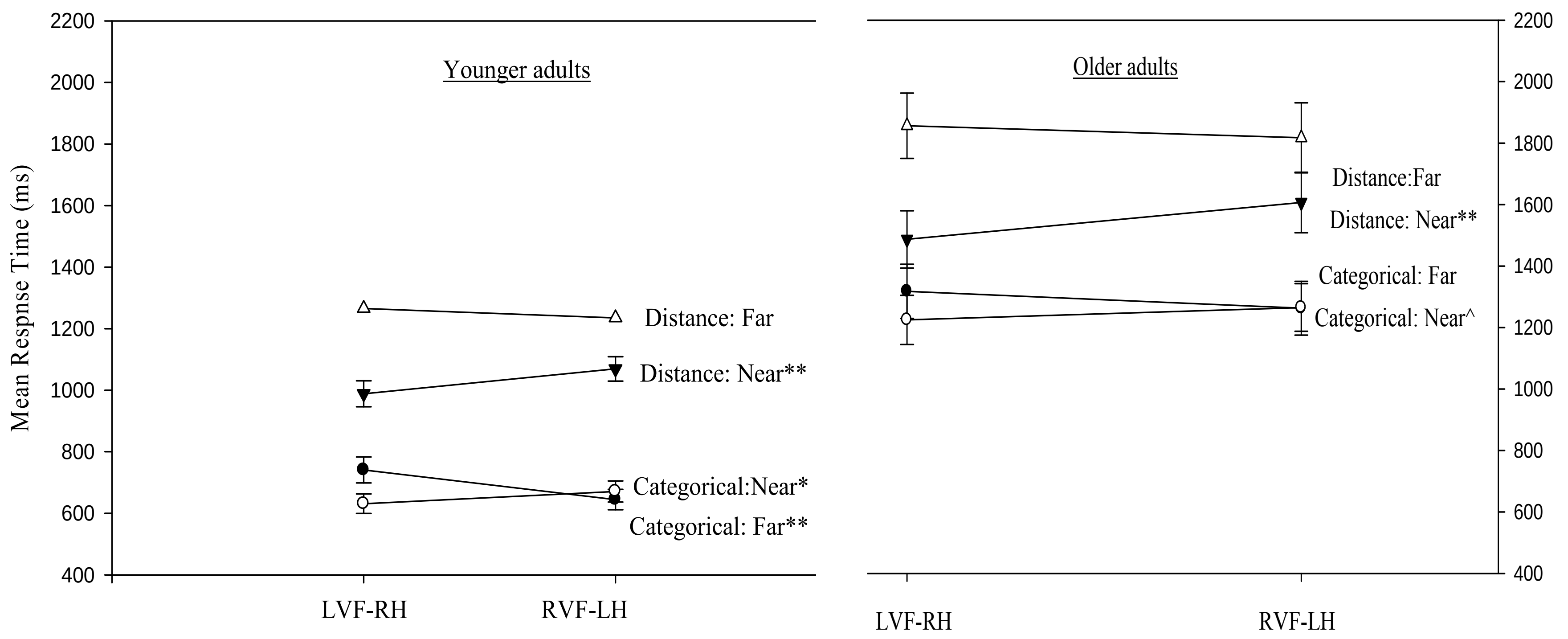


Figure 4.4. Mean RT (with standard error bars) stratified by task and distance across LVF-RH and RVF-LH trials. Categorical and Distance refer to the categorical and distance quantification tasks and near and far refer to the distance of the dot away from the bar. The younger adults RTs are displayed in the left panel and the older adults RTs are displayed in the right panel. ** $p < .01$; * $p < .05$; ^ $p = .08$.

4.4. Discussion

There were two aims for the current experiment. The main aim was to investigate the importance of task demand in obtaining VF advantages for categorical and distance quantification coordinate VS processes. The second aim was to investigate whether changes in task demand differentially affected age-related performance for these VS processes. From the pattern of results observed it seems that performance differed depending on the distance of the dot from the bar. Furthermore, patterns of performance were different for the younger compared to the older adults, and in contrast to the right hemi-aging hypothesis, greater age-related decline was found in the categorical task. The results will be discussed in relation to the aims and objectives set out in the introduction.

One of the primary objectives of this experiment was to manipulate the task demand associated with categorical and distance quantification judgements. In the categorical task this was achieved by increasing the number of categorical locations from 2 to 4. Longer RTs and higher percentage ERs indicated that the participants in Experiment 2 found the categorical task more demanding than the participants in Experiment 1. For the distance quantification task, the number of distances to be judged was reduced from 8 to 2. Differences in estimate accuracy and RT showed that participants were faster and more accurate to judge distance in Experiment 2. This suggests that estimating distance is more challenging when there are a greater number of different distances to be judged. However, even though task demand was increased in the categorical task and decreased in the distance quantification task, estimating distance was still more difficult than judging relative positions, as evidenced by longer RTs.

Interestingly, in contrast to Experiment 1, the changes in task demand in the box paradigm caused differential age-related decline to be found across tasks. Consistent with previous research (Bruyer et al., 1997; Hoyer and Rybash, 1992; Salthouse, 1996) older adults were found to respond more slowly than younger adults. This was true in both the categorical and distance quantification tasks; therefore, with age, the time it takes to make a response increases, regardless of the type of VS judgement being made. However, in contrast to the right hemi-aging hypothesis a larger age-related deficit in RT was found in the categorical compared to the distance quantification task. This finding in the RT data was also reported by Bruyer et al. (1997), and suggests that for the current tasks categorical VS judgements may be more susceptible to age-related decline, at least in terms of speed of processing. Thus, when considering RT data only, in contrast to the right hemi-aging hypothesis coordinate VS processes were not found to be more vulnerable to age-related decline. It is important to note, however, that with respect to accuracy, older adults in the current experiment were less accurate at judging distance than the younger adults. Despite this, as accuracy data were not comparable across tasks, it is difficult to ascertain whether this finding is in line with the right-hemi aging hypothesis. That is, it is difficult to determine whether there would be a Task x Age-Group interaction. Furthermore, given that some older adults estimated distance in inches, it is difficult to know the extent to which the difference in unit contributed to the age-related differences in distance estimation.

An additional aim of this experiment was to investigate VF effects in the categorical and distance quantification box paradigm tasks. Specifically, there were two key findings with respect to VF advantages. First, a Task by VF interaction was found. A LVF-RH advantage was found for the distance quantification VS task, indicating that the RH is more efficient at processing precise distance estimations. This, therefore, replicates the results for the distance quantification task in Experiment 1, providing some validation for this task. However, in contrast to Experiment 1, there was no overall hemispheric advantage for the categorical task. At face value this result provides partial support for Kosslyn's (1987) theory of categorical and coordinate hemispheric asymmetry. However, the results were more complex than this, and effects of VF differed across distance in both tasks.

For the distance quantification task, the overall LVF-RH advantage found was driven by the trials in which the dot was located nearest to the bar. The same pattern of performance was found with both younger and older adults. For the categorical task, differences in performance were found with respect to VF, distance and age-group. Specifically, the younger adults showed a RVF-LH advantage for the categorical trials in which the dot was located far from the bar and a trend towards a LVF-RH advantage for the categorical trials in which the dot was near to the bar. This pattern of performance was also found with older adults; however, there were no significant differences for the older adults. Thus, in line with the HAROLD model, these findings can be taken to suggest that the hemispheric advantages for categorical VS judgements that were found with the younger adults reduced with age (Cabeza, 2002). Furthermore, it seems that the lack of an overall RVF-LH advantage in the categorical task was masked by different performance at the two distances.

Recall that it is suggested that increased cognitive demand (and in particular, attentional and executive resources) induces RH specialisations (Martin et al., 2008; Van der Lubbe et al., 2006; Wager & Smith, 2003). Recall also that Kosslyn et al. (1992) suggested that, for categorical judgements, the further apart two items to be related the easier the decision-making process. Thus, it could be argued that task demand could account for the perceived shift from a RVF-LH advantage for the *easy* categorical trials to the LVF-RH advantage for the *difficult* categorical trials in the younger adults. These results are in line with the continuous spatial code hypothesis and with the idea that differences between categorical and coordinate VS processes are quantitative and not qualitative (Martin et al., 2008).

However, in contrast to the predictions, participants made categorical judgements faster and more accurately when the dot was located near the bar compared to when it was located far from the bar. The RT and ER data, therefore, suggest that categorical judgments were easier when the dot was located near to the bar. Consequently, these findings were not in line with the theory that increased task demand (in terms of increased RT and ER) induces LVF-RH advantages.

A similar pattern of performance was found for the distance quantification task; participants were faster and more accurate at judging distance when the dot was located near to the bar. In addition, a LVF-RH advantage was found for these trials. It was unusual that participants responded to the dots located near to the bar more quickly in both tasks, and that a LVF-RH advantage should be found for these trials. One post-hoc account is that these results may be due to attentional processes. Specifically, it is easier to allocate attention to one small spatially constrained area than a large area or two different areas. Thus, it would be easier to allocate attention to the bar and dot when the dot was located near to the bar compared to when the dot was located far from the bar (see also the eye movement data in Experiment 4, Chapter 6). Why it would be easier to do this when stimuli appear in the LVF-RH is less clear.

In summary, task demand was successfully manipulated and different patterns of performance were found in relation to the distance of the dot from the bar and with respect to which VF the stimuli were presented. However, the results found in this experiment were not as clear cut as one would ideally wish. Also, given that the results have not been replicated, the degree to which the effects are robust is perhaps questionable. For example, some of the results were not predicted and have not been found previously. In addition, it is not entirely clear what is responsible for the unexpected findings, and this makes it difficult to interpret the pattern of results found. Therefore, the results found in the current experiment should be treated with a degree of caution.

Experiments 1 and 2 have studied categorical and coordinate VS processing using simple visuoperceptual tasks; however, as detailed in Chapter 1, categorical and coordinate VS processes have also been examined in mental imagery tasks and memory tasks. With this in mind, the following experiment will incorporate a memory component into the categorical and coordinate tasks. This will allow the effects of task demand to be further assessed and will also provide insight into how age affects WM processes when making categorical and coordinate VS judgements.

Chapter 5

Working Memory for Categorical and Coordinate VS Processes

5.1. Introduction

Experiments 1 and 2 investigated categorical and coordinate VS processing in younger and older adults during relatively simple visuoperceptual tasks. In general, the same patterns of performance were found with both age-groups, although VF advantages were not always significant for the older adults. However, categorical and coordinate VS processing has also been examined in cognitive domains other than visuoperception, such as mental imagery and WM.

To date, research investigating WM for categorical and coordinate VS processes is limited; few studies have been conducted and results are not consistent. Furthermore, there has been no published data investigating WM for categorical and coordinate VS processes across age. Accordingly, the aim of this experiment was to investigate WM for categorical and coordinate VS processes in both younger and older adults. This will allow for greater insight into WM for categorical and coordinate spatial relation judgements with younger adults, but will also extend the literature to older age-groups.

Working memory is involved in encoding, storage, maintenance and transformation of information (Baddeley, 1998). Specifically, WM temporarily keeps information *active* or *on-line*, and is, essentially, the amount of cognitive resources available to process information. As described in Chapter 2, WM is suggested to be comprised of three critical components; the central executive, the phonological loop and the visuospatial sketchpad (VSS). It is within the VSS that VS information is processed, and typical tasks involving visuospatial working memory (VSWM) include location learning tasks such as remembering recently displayed positions in a grid or matching an upright to a rotated letter.

Researchers have already applied the paradigm of categorical and coordinate VS processing to the spatial memory domain (Kessels, Kappelle, et al., 2002; Martin et al., 2008; Postma et al., 1998; Slotnick & Moo, 2006; Van der Ham et al., 2007; Van der Lubbe et al., 2006). One way to assess WM for categorical and coordinate VS processes is to employ a match-to-sample design. In a typical match-to-sample task, participants are presented with two stimuli sequentially and are asked to make some sort of same/different judgement. That is, participants are shown Stimulus 1 and, after a delay, are then shown Stimulus 2. In this way, participants have to keep the representation of

Stimulus 1 *on-line* in WM, so that when Stimulus 2 is encoded the two representations can be compared and a judgement made. Importantly, this type of experimental design allows stimuli to be lateralised, and so effects of VF presentation still can be assessed.

As described in Chapter 1, Van der Lubbe et al. (2006) assessed the time course of brain activity for VSWM during categorical and coordinate spatial relation judgements using ERP methodology. To do this they used a match-to-sample bar-dot task. Participants were presented with a bar and a dot, centrally on screen, for 150 ms. After a delay of 2500 ms, a second bar-dot presentation was displayed in the LVF or RVF for 150 ms. Participants were required to judge if the two bar-dot stimuli were the same or different. For the categorical task this was a relative positional judgement (e.g., whether both dots were above/below the bar). For the coordinate task, participants had to compare the actual distance. With respect to the ERP data, source analysis showed that the stimuli shown in the LVF and RVF did initially activate areas in contralateral hemisphere. However, beyond this they found no evidence of greater activation in the LH for categorical VS processes nor did they find greater activation of the RH for coordinate VS processes. By contrast, a LVF-RH advantage was found in the coordinate task for both RT and ER, but no significant differences were found in the categorical task.

Van der Ham et al. (2007) also employed a match-to-sample bar-dot task. In this study, participants were presented with a cross and dot located in one quadrant of the cross (i.e. top left, top right, bottom left, or bottom right). The dot was positioned on the 45 degree angle line from the centre of the cross and could appear at 1 of 4 distances away from the centre of the cross. The first stimulus was presented in the centre of the screen, and the second stimulus was lateralised for 150 ms. The retention interval between the presentations of the two stimuli was varied at 500 ms, 2000 ms, and 5000 ms. In the categorical task, participants had to judge if the dot was in the same quadrant and in the coordinate task if the dot appeared at the same distance away from the centre of the cross. A Task by VF interaction was found only at the shortest retention interval, and this showed that participants were faster to make categorical responses when the stimulus was presented in the RVF-LH. Participants were also faster to make coordinate judgements when the stimulus was presented in the LVF-RH, however, this was not statistically significant.

In summary, using match-to-sample tasks, these two studies both found Task by VF interactions. This could be interpreted to show that VF advantages for categorical and coordinate processes generalise to WM tasks. However, as with much of the research in this field, the predicted double-dissociation was not found. As such, further research is required to clarify the results.

With respect to ageing, no studies have investigated WM for categorical and coordinate spatial relation judgements in younger and older adults. However, recently, Bullens and Postma (2008) investigated the development of categorical and coordinate VS processes during WM tasks with children and younger adults. Bullens and Postma showed participants two pictures of an animal (or two animals) sequentially. The first picture stimulus was presented for 750 ms, and after a delay of 500 ms, the second picture stimulus was shown for 100 ms in the LVF or RVF. Participants aged 6-8, 10-12, or over 18 years old judged whether the second picture was the same or different to the first.

Bullens and Postma (2008) analysed their data using signal detection theory (SDT). Briefly, SDT is a method that can be used to explore whether differences between tasks or between populations are underpinned by true differences in visual perceptual processing or whether they can instead be explained by differences in the decision criterion or bias. Specifically, a measure of sensitivity and response bias is calculated. Sensitivity refers to how well an individual can correctly identify a change in spatial relation (i.e. respond different when the stimuli are different), while also taking into consideration how often a change in spatial relation is incorrectly identified (i.e. respond different when stimuli are actually the same). Response bias refers to how often an individual makes a particular response. For example, if an individual responded 'different' on the majority of trials, they would be biased to responding 'different'.

Bullens and Postma (2008) found that the adults (over 18 year olds) demonstrated an overall LVF-RH advantage for detecting changes in spatial relations. However, this advantage was not found with the youngest group of children, suggesting that hemispheric specialisation for processing VS information develops with age. Bullens and Postma (2008) also found that discrimination sensitivity for changes in spatial relations improved with age; the older children and adults were better able to detect spatial changes than the younger children. Furthermore, all participants were more biased to respond same than to respond different, and this was more prominent in the older children and adults. Bullens and Postma (2008) attributed these differences in performance to different stages of maturity of the frontal lobes, especially in the prefrontal cortex (PFC; see also Aine et al., 2006).

It is well established that WM declines with older age, and VSWM is especially vulnerable (e.g., Hartley et al., 2001; Jenkins et al., 2000; Lawrence et al., 1998; Mitchell et al., 2000; Myerson et al., 2003; see also Chapter 2). There are many contributing factors to the decline in WM. For example, with age, neurons become less efficient at transmitting information; this is due to neuronal loss, shrinkage, and particularly, a thinning of the myelin sheath, and a decrease in the number of connections made between neurons (see Chapter 2). As a result, the number of cognitive resources available for processing information reduces, as does the speed by which information is processed. In turn, as described in Chapter 2, with reduced time and resources available to consolidate information that has been encoded, the chance that the information will be kept active in WM also decreases. In addition, WM is associated with frontal lobe activation, especially in the PFC, and activation of the frontal lobes is considered to change greatly with age (see Chapter 2). Indeed, the HAROLD model specifically suggests that activation patterns in the PFC become less lateralised, due to compensatory strategies or dedifferentiation. These patterns (bihemispheric activation) are also found in younger children (e.g., Moses et al., 2002; see also Reese and Stiles, 2005). Thus, Bullens and Postma's (2008) finding that sensitivity to detect spatial changes increases with age, as does the likelihood of responding same, indicates that changes may also occur as age progresses into older adulthood. Specifically, given that WM has a large affect on age-related performance it is likely that under WM task demands greater age-related differences will be found, both in terms of differential VS processing and hemispheric advantages and also in terms of sensitivity to changes in spatial relations.

The aim of the current experiment (Experiment 3) was to investigate categorical and coordinate VS processes during a WM task in younger and older adults. To achieve this aim, a match-to-sample WM task was employed to assess WM for categorical and coordinate VS processes. Specifically, participants were presented sequentially with two bar-dot stimuli and were required to make a same/different judgement. In line with Laeng and Peters (1995), participants had an unlimited time to view Stimulus 1, and Stimulus 2 was lateralised and presented for 150 ms. The second bar-dot stimulus was presented after a delay of 2000 ms.

For the younger adults it was predicted that a RVF-LH advantage would be found for the categorical task and a LVF-RH advantage in the coordinate task. For the older adults, given the known changes in PFC activation, and the involvement of frontal networks in WM tasks, it was anticipated that no significant advantages would be found. Thus, a three-way interaction was expected between Task, VF and Age-Group.

What was not clear was whether age-related decline would be differential. Although the literature suggests that coordinate VS processing should be more vulnerable to age-related decline, so far this has not been found. However, given the known age-related deficits during WM tasks, it may be that under WM task demands, coordinate VS processes would be affected by age to a greater extent than categorical VS processes. Thus, it was hypothesised that this study would provide evidence in favour of both the HAROLD and right hemi-aging hypotheses.

The match-to-sample task design also allowed the data to be analysed using SDT. That is, participants' sensitivity and response bias can be examined to gain further insight into how younger and older adults process and detect changes in spatial relations. Consequently, in light of the results reported by Bullens and Postma (2008), it was predicted that younger adults would be faster and more sensitive to detect changes in spatial relations than older adults. In addition, it was anticipated that younger adults would show an overall LVF-RH advantage in terms of sensitivity. However, like the youngest children in Bullens and Postma's study, it was anticipated that the overall LVF-RH advantage would not be present for the older adults. It was also anticipated that participants would be biased to responding 'same', and that this would be stronger in the younger adults than in the older adults.

5.2. Method

Participants

Twenty five right-handed younger adults volunteered or were awarded course credits for participating in this study. A total of 28 right-handed, community-dwelling older volunteers were recruited through an Older Adult Volunteer Database held by the School of Psychology. Participants were screened for normal or corrected-to-normal vision and were assessed for handedness using the EHI (Oldfield, 1971). The older adults were also screened for cognitive impairments using the MoCA (Nasreddine et al., 2005). Three older adults were excluded from analysis due to scores on the MoCA being lower than the cut-off of 26/30 (Nasreddine et al., 2005). One additional older adult was excluded from the analysis, as their ER data suggested that they were performing below chance.

Table 5.1 shows the descriptive measures of each age-group. To examine whether there were any differences in these measures, comparisons were made across age-groups. In line with Experiment 1, comparisons showed that older adults had significantly fewer years of formal education, but had greater Predicted IQ scores than younger adults. No age differences were found for gender or handedness.

Table 5.1

Comparison of Participants' Descriptives across Age-Groups

	M, (SD), range		*P*
	Younger adults	Older adults	
Age	19.64, (1.44), 18-24	70.38, (7.26), 60-85	.00**
Gender (M:F)	7:18	10:14	.38
Handedness	87.85, (14.41), 36.8-100	93.56, (9.71), 66.67-100	.11
Education	14.68 (1.60), 11-19	13.23, (2.58), 10-20	.02*
Predicted IQ	102.64, (8.00), 90-123	119.63, (5.65), 105-128	.00**
MoCA	-	28.04, (1.30), 26-30	-

Note. Age is provided in years. EHI = Edinburgh Handedness Inventory (Oldfield, 1971); a score of 100 = very strongly right-handed. MoCA = Montreal Cognitive Assessment (Nasreddine et al., 2005); scored out of 30, so that a high score = better cognitive performance. Years of education refers to how many years of formal school-education were attended. Predicted IQ-NART = National Adult Reading Test (Nelson & Willison, 1991); a high score = higher IQ. ** = age-related differences, $p < .01$; * = age-related differences, $p < .05$.

Design and Materials

Each task was computerised and had been programmed using Presentation software. To ensure constant viewing conditions, participants used a chin rest and were seated 57 cm from a 15 inch computer monitor. The stimuli were a dot (0.5 x 0.5 cm) and a bar (5 x 0.5 cm). The stimuli were presented in black on a white screen. A fixation cross (0.5 x 0.5 cm) was presented in the centre of the screen. The tasks used a match-to-sample design.

The dot could appear in 1 of 3 positions in relation to the bar; these were at 2 cm, 3 cm, or 4 cm away, and could be above or below the bar. During each trial, two bar-dot stimuli were shown. The first stimulus presentation always appeared in the centre of the screen and the second was either in the LVF or RVF. For the second presentation the edge of the bar was located at 3^o from the fixation cross.

Both tasks consisted of 96 trials; of which the second stimulus appeared in the RVF for 48 trials and in the LVF for 48 trials. The six bar-dot stimuli were seen eight times as the first stimulus, and were paired once with each of the other distances (above and below) and twice with the same distance stimuli. That is, when the dot was 2 cm away from the bar, this was paired once with distances 3 and 4 cm (both when the dot was above and below the bar in the LVF or RVF) and twice with stimuli that were 2 cm away from the bar (above and below in the LVF or RVF); similarly, the 3 cm distance between the dot and bar was paired twice with the 3 cm distance stimuli and the 4 cm distance with that of the 4 cm distance.

Bar-dot stimuli were presented in a fixed, pseudo-random order. For both tasks there were no more than three consecutive trials (a) in either VF, (b) at any one distance – for either first or second stimuli presentations, and (c) for either judgement – same or different. The two tasks presented the stimuli in a different order, but for each task all participants received the same order of presentation.

In both tasks participants were required to judge whether two sequential bar-dot presentations were the same or different. In the categorical task, the participants were asked to judge whether the dot appeared in the same or different categorical location in relation to the bar, regardless of distance. For example, the trial was to be judged as *different* if the dot appeared above the bar in one presentation and below the bar in the other presentation. In the coordinate task, participants were required to judge if the stimuli were the same or different distance from the bar; that is, the stimuli were to be judged as *different* if they appeared at different distances from the bar, regardless of whether they appeared above or below. To make a response, participants pressed one of two keys, using their dominant hand: 'b' = same, 'n' = different.

Pilot Study

A pilot study was conducted in which the dots were located 2, 5 and 8 cm from the bar. This was in order to assess that participants were measuring distance in the coordinate task. The ER was very low (near to ceiling), and feedback from participants suggested that the distances were so distinct that the distances of the dot did not have to be measured and instead could be judged using relative size. That is, it was extremely easy to group (or 'categorise') the distances into big, medium and small. It became evident that if participants were to measure distance, the distance between the three dot locations would have to be reduced. Accordingly, the distances were changed, so that they differed by 1 cm (2, 3 and 4 cm). The percentage ER increased, and subsequent pilot participants reported paying close attention to the distances.

Practice Trials

Participants were required to complete two blocks of practice trials before the administration of each task. Both tasks used the same practice trials. The first practice block, consisting of 16 trials, involved familiarisation with which keys to press: The words 'same' and 'different' were displayed on screen, in either the LVF or the RVF and participants were required to press the corresponding key. The second practice block allowed familiarisation with the actual stimuli. Participants were presented with eight trials, consisting of a combination of paired bar-dot stimuli in which the dot was located above or below the bar at a distance of 1 cm or 10 cm away from the bar. These were presented in a random order and participants were given feedback if they made an incorrect response. That is, participants were told whether the response should have been same or different.

Procedure

Both tasks used identical stimuli, only differing in the spatial judgement made. Each trial within each task consisted of the same sequence of events (see Figure 5.1). A central fixation cross with the word 'ready?' appeared on screen. Participants indicated they were ready to begin by pressing the space bar on a Standard English keyboard with the index finger of their non-dominant hand. A bar-dot stimulus was then presented centrally. Participants could view this stimulus for as long as they required, and indicated they were ready by a second press of the space bar. The participants then saw a mask, comprised of many of bars and dots, for 1550 ms. The mask was presented after Stimulus 1 to ensure that any low level visual effects associated with Stimulus 1 would not carry-over to Stimulus 2. Following the mask, there was a blank screen for 250 ms. A fixation cross then appeared for 200 ms. This was to ensure that participants' attention was orientated towards the centre of the screen. The second bar-dot stimulus was then presented for 150 ms in the LVF or RVF. The bar-dot stimulus then disappeared and participants then made a ‘same’ or ‘different’ response. As soon as a response was made, the ‘ready?’ screen was displayed and the next trial began.

Participants were given verbal instructions and practice trials before each task began. The tasks were counterbalanced. After completing the tasks, the EHI (Oldfield, 1971), NART (Nelson and Willison, 1997) and MoCA (Nasreddine et al., 2005) were administered.

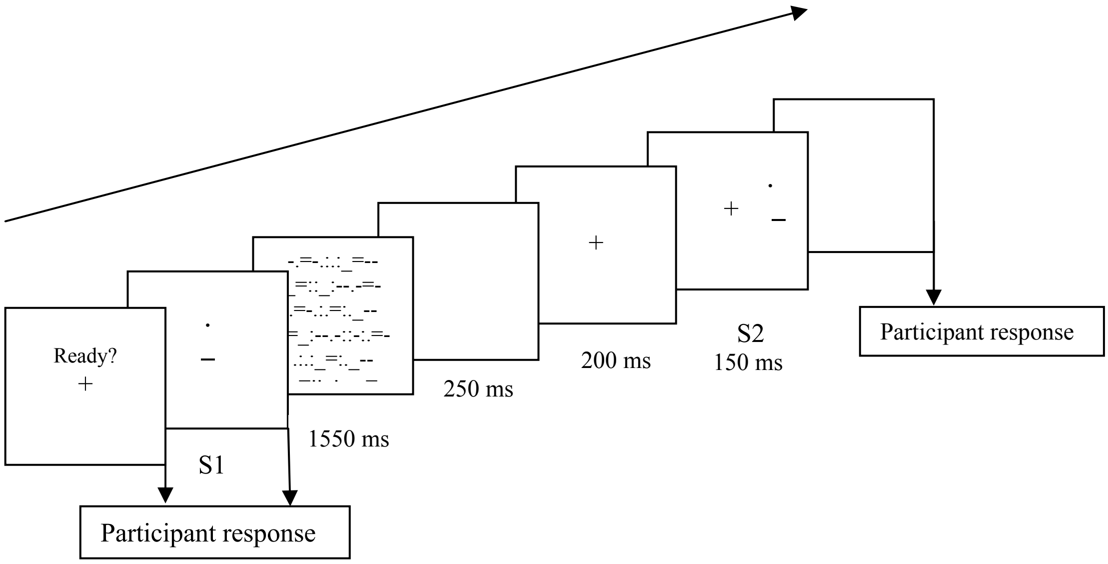


Figure 5.1. Figure to show the sequence of events that constituted a trial. S1 = Stimulus 1 (sample); S2= Stimulus 2 (match).

5.3. Results and Discussions

5.3.1. Percentage Error Rate and Response Time Data: Results

Predicted IQ and Years of Education

Consistent with Experiment 1, younger and older adults differed in Predicted IQ and years of education; older adults had fewer years of formal education, but despite this had higher Predicted IQs. Years of education and Predicted IQ were not found to correlate with RT or ER. Thus, consistent with the previous experiments and as recommended by Pallant (2001), Predicted IQ and education were not included in the analyses as covariates.

Percentage Error Rates

The distributions of percentage ERs in the categorical task were not normally distributed. However, consistent with the previous chapters, for the purposes of assessing whether there were differences in accuracy across age-groups, a 2 (Task) x 2 (VF) x 2 (Age-Group) ANOVA was conducted. All comparisons were confirmed with non-parametric equivalent tests.

There were main effects of Task, $F(1, 47) = 195.74$, $p < .01$, and VF, $F(1, 47) = 7.01$, $p < .01$. These showed that participants made fewer errors in the categorical task (M = 5.15% errors, SD = 5.97) compared to the coordinate task (M = 19.68% errors, SD = 7.32), and also made fewer errors when the stimuli were presented in the LVF-RH (M = 11.65% errors, SD = 5.83) compared to the RVF-LH (M = 13.17% errors, SD = 6.07). No other main effects or interactions were significant, Fs < 2.64.

Response Times

The RT data referred to the time taken to make a same/different judgement regarding Stimulus 2 in comparison to Stimulus 1. Presumably, this reflected the time needed to encode Stimulus 2, retrieve the representation of Stimulus 1 from WM and to make a comparative judgement. In both tasks, only RT data from correct responses were analysed. The data were also trimmed for outliers (plus or minus 3 *SD*s of the individuals mean); in this way 5% of the data were excluded. The coordinate data did not follow the normal distribution. As such, the mean RT data scores were transformed (Cornelissen & Kooijmn, 2000; Tabachnick & Fidell, 1996), and subjected to a 2 (Task) x 2 (VF) x 2 (Age-Group) repeated measures ANOVA. Age-Group was a between subjects design and Task and VF were within subjects. Data analysis was conducted on the log-transformed scores, but for ease of interpretation raw scores are reported in the Figures and Tables. Any unplanned multiple comparisons were Bonferroni corrected.

There was a main effect of Task, $F(1, 47) = 15.76$, $p < .01$. Participants responded faster in the categorical task (M = 796.12 ms, SD = 216.55) compared to the coordinate task (M = 893.11 ms, SD = 216.71). This indicated that participants found it easier to retrieve a representation of a categorical spatial relation from memory and to compare this with a second spatial relation, than a coordinate spatial relation. There was also a main effect of Age-Group, $F(1, 47) = 21.34$, $p < .01$. In line with the previous experiments and the theory of generalised slowing younger adults responded faster (M = 725.78 ms, SD = 192.55) than the older adults (M = 964.98 ms, SD = 151.66).

As predicted there was a three way interaction between Task, VF and Age-Group, $F(1, 47) = 4.01$, $p < .05$. This showed a difference in the effect of VF between the two age-groups in the categorical task. Specifically, as illustrated in Figure 5.2, for the younger adults there was a RVF-LH advantage for the categorical task, $t(24) = 2.56$, $p < .05$, whereas there was a trend towards a LVF-RH advantage for older adults, $t(23) = -1.86$, $p = .08$. No VF advantages were found in the coordinate task for either age-group, *t*s < 1.

The RVF-LH advantage found with younger adults for categorical spatial relation judgements is in line with the predictions made. This suggests that VF advantages for categorical information generalise from visuoperceptual tasks to WM tasks, at least for younger adults (see Experiments 1 and 2). In contrast, a trend towards the opposite advantage was found with the older adults. This was not in line with the predictions made. The age-related difference suggests that younger and older adults may process categorical information from the two VFs differently.

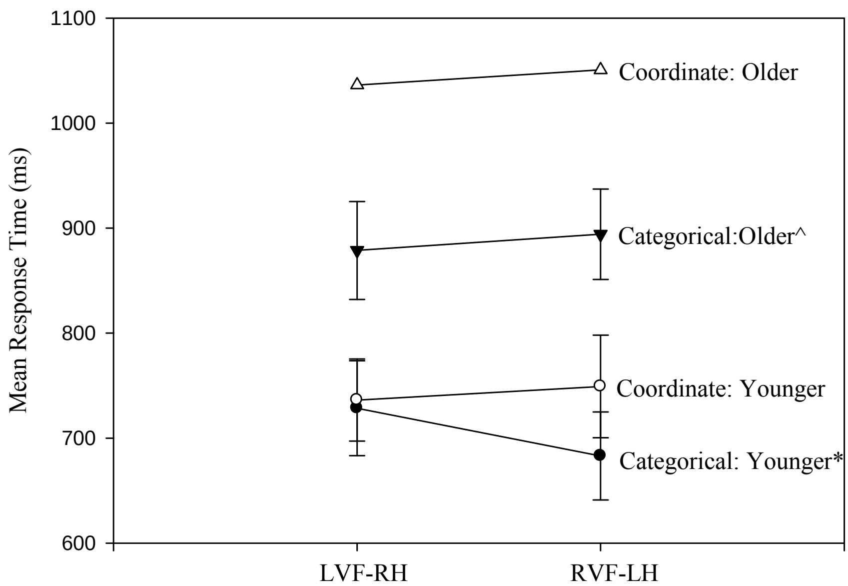


Figure 5.2. Mean RT (and standard error bars) across LVF-RH and RVF-LH trials as a function of task and age-group. Younger and older refer to the different participant age groups. * = $p < .05$; ^ = $p = .08$

The advantages found in the categorical task, also seemed to drive the VF x Age-Group interaction, $F(1, 47) = 4.47$, $p < .05$, in which there was a numerical RVF-LH advantage for the younger adults, and a LVF-RH advantage for the older adults;

however, these advantages were not significant, *t*s < 1.73. No other main effects or interactions were found, *Fs* < 2.14.

Time Spent Encoding Stimulus 1

Participants could view Stimulus 1 for as long as they wanted; not only was this in line with Laeng and Peters (1995) but it also meant that any age-related deficits found were not due to older adults having insufficient time to encode Stimulus 1. A 2 (Task) x 2 (Age-Group) ANOVA was conducted to investigate whether there were differences in encoding time across Task and Age-Group.

There was a main effect of Age-Group, $F(1, 47) = 23.97$, $p < .01$, in which younger adults spent significantly less time encoding Stimulus 1 than the older adults (see Table 6.2). Thus, in line with the generalised slowing hypothesis, older adults take longer to encode and process information. There was a main effect of Task, $F(1, 47) = 15.04$, $p < .01$, which showed that participants spent more time viewing the stimuli in the coordinate task, compared to the categorical task (see Table 5.2). These results suggest that it was easier to encode and store a representation of a categorical spatial relation in WM than a coordinate spatial relation. The Task x Age-Group interaction was not significant, $F(1, 47) = .13$, *ns*.

Table 5.2

Average Time Taken to Encode Stimulus 1 as a Function of Task and Age-Group

	M (*SD*) ms		
Task	Younger adults	Older adults	Overall Task
Categorical	786.58 (445.45)	1334.18 (611.53)	1054.79 (595.74)
Coordinate	961.46 (449.09)	1742.64 (721.47)	1344.08 (711.28)
Overall Age	874.02 (491.63)	1538.41 (495.09)	

As differences were found between the two tasks and age-groups, it is important to assess whether the time spent viewing Stimulus 1 affected processing speed for the subsequent stimulus and response. Time spent encoding Stimulus 1 correlated with the time taken to respond to Stimulus 2 (*r*s > .53, *p*s < .01), hence, time spent encoding Stimulus 1 was added as a covariate to the analyses. The results show that when time spent encoding Stimulus 1 is controlled for, the age-groups still differed in the time spent making a same/different response in the coordinate task, $F(1, 46) = 12.25$, $p < .01$, but not in the categorical task, $F(1, 46) = 2.39$, *ns*. That is, older adults were slower to make a coordinate same/different response than younger adults. Thus, older adults required more time to successfully encode categorical and coordinate spatial relations in WM, but additionally required more time to retrieve and utilise coordinate spatial relation information.

It is also worth noting that when age-group was controlled for, a relationship between the time spent encoding Stimulus 1 and RT for making a same/different response was found for the coordinate task, $F(1, 46) = 5.56$, $p < .05$, and the categorical task, $F(1, 46) = 6.49$, $p < .01$. These findings suggest that regardless of age there are individual differences in the time it takes to encode and respond to VS information, and participants who encoded S1 relatively quickly were also faster to encode S2 and make a response.

5.3.2. Percentage Error Rate and Response Time Data: Discussion

In the current study, the RT and ER data were analysed to investigate categorical and coordinate VS processing during a WM task across younger and older adults. The key findings were that the younger adults displayed a RVF-LH advantage in the categorical task only and there was limited evidence for differential age-related decline.

The current study investigated WM for categorical and coordinate VS processes. Specifically it was suggested that participants were required to keep an encoded representation of a spatial relation on-line for a short period of time before comparing it to a second encoded representation. As expected, in accordance with the generalised slowing hypothesis, older adults took longer to encode Stimulus 1 than the younger adults. Older adults were also found to take longer to make a same/different response. However, this age-related difference was found to diminish for categorical spatial judgements when the time taken to encode Stimulus 1 was taken into consideration. By contrast, it would seem that older adults require more time to successfully retrieve coordinate information from WM and make a comparative distance judgement. Although this could be taken as evidence in support of the right-hemi aging hypothesis, it is more likely that this finding instead shows an effect of task demand, especially given that there was no evidence of a LVF-RH advantage for the coordinate task, for either age-group, or a Task x Age-Group interaction.

It has been suggested that older adults find tasks in which to-be-remembered information is manipulated or transformed in some way, particularly challenging (Logie, 1995; Van Gerven, et al., 2007; Vecchi & Cornoldi, 1999). As such, it must be considered that the different orientations at which the dot could appear in relation to the bar could serve to add additional cognitive demand to the coordinate task. That is, it might have been more difficult for participants to compare two distances in the WM task for coordinate VS processes when the dot was located at different orientations in both stimulus presentations compared to when the stimuli appeared at the same orientation or if they were making a categorical decision. Thus, it could be hypothesised that older adults' performance would be particularly slow when the orientation of the dots in Stimulus 1 and Stimulus 2 were different in the coordinate task, and this may have contributed to the age-related decline found for the coordinate task when RT for Stimulus 1 was controlled.

To assess whether orientation affected performance, data were collapsed across VFs and a 2 (Task) x 2 (Orientation) x 2 (Age-Group) ANOVA was conducted. In line with the above analysis, a main effect was found for Age-Group, $F(1, 47) = 28.08$, $p < .01$, and Task, $F(1, 47) = 18.76$, $p < .01$. There was also a main effect of Orientation, $F(1, 47) = 5.16$, $p < .05$. This showed that, overall, participants were faster to make a response when the dots in the two stimuli were presented at the same orientation from the bar ($M = 859.50$ ms, $SD = 192.37$) compared to when they appeared in opposite orientations ($M = 883.69$, $SD = 213.41$). Thus, in both tasks, it seems that it was easier to judge a spatial relation when the dots were located at the same orientation.

A difference of orientation was found in the coordinate task for the older adults, $t(23) = 3.23$, $p < .01$, and no differences were found in the categorical task or for the younger adults, *t*s < 1.40. Thus, it seems that older adults found same/different judgements regarding coordinate spatial relations particularly challenging when the dot appeared at different orientations on both stimulus presentations, and this effect is likely to be driving the difference found between the age-groups when RT for Stimulus 1 had been controlled in the coordinate task. However, despite these comparisons, and in contrast to expectation, there was no Task x Orientation interaction, no Orientation x Age-Group interaction, nor was there a Task x Orientation x Age-Group interaction, *F*s < 1.59.

With respect to VF effects, again, the results were not clear cut. The younger adults' data replicated the results reported by Van der Ham et al. (2007), and a RVF-LH advantage was found for the categorical task. This finding also replicates the results of the previous experiments and suggests that, for younger adults, RVF-LH specialisation for categorical judgements probably generalises from simple visuoperception tasks to WM tasks.

For the older adults, there was no significant VF advantage for the categorical task, although they did show a trend towards a LVF-RH advantage. The opposite advantages found between age-groups in the categorical task are in contrast to the results of Experiments 1 and 2, in which effects of VF were in the same direction in both age-groups. In addition, neither age-group showed a VF advantage for the coordinate task. As with the unexpected findings in Experiments 1 and 2, it is not entirely clear as to why the direction of the advantage in the categorical task should differ between the age-groups or what caused the lack of a LVF-RH advantage for coordinate VS processes. Furthermore, the question still remains as to what cognitive processes underlie same/different categorical and coordinate spatial relation judgements, and more specifically, it is unclear whether the same cognitive processes can be used to make categorical and coordinate spatial relation judgements.

5.3.3. Sensitivity and Bias: Results

As discussed in the introduction, the same/different, match-to-sample paradigm employed in this experiment allowed a measure of sensitivity and response bias to be calculated. Accordingly, using SDT as an additional analysis to the RT analyses may provide a more insightful assessment of how younger and older adults make categorical and coordinate spatial relation judgements. Specifically, SDT facilitates an analysis of whether differences between tasks or between populations are underpinned by true differences in visual perceptual processing or whether they can instead be explained by differences in the decision criterion or bias (or both). In a typical SDT paradigm, participants are asked to determine whether or not a signal is present amongst a background of noise. In the current task, a signal trial is defined as one in which there is a change in spatial relation between Stimulus 1 and Stimulus 2 and a noise trial is defined as one which does not involve a change in the spatial relation between Stimulus 1 and Stimulus 2.

Importantly, SDT assumes that the decisions upon which same/different spatial relation judgements are made can be represented along a continuum, and formed in terms of two distributions: one distribution for the signal, and a second distribution for the noise. Typically these two distributions will overlap and so a participant will not be able to determine whether or not a stimulus is a signal or noise based on the strength of the stimulus information alone. To resolve this problem, the participants insert a threshold, or criterion (*c*), between the two distributions (see Figure 5.3). If the strength of the signal from the stimulus exceeds this criterion then the participant generates a signal response; different. Conversely if the strength of the signal does not exceed this criterion then the participant generates a noise response; same.

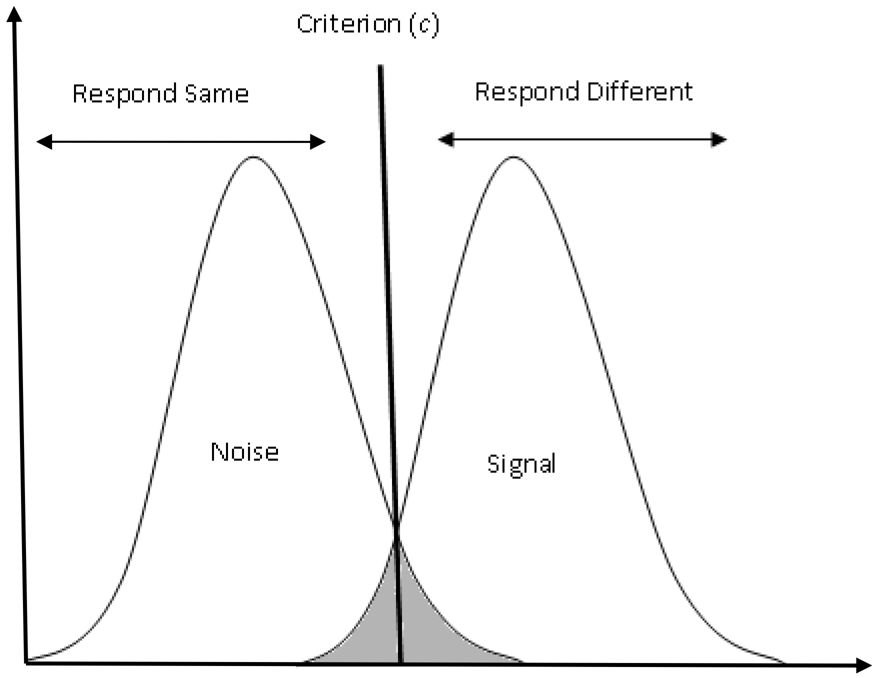


Figure 5.3. Diagram to show how participants distinguish between signal and noise. The shaded area, where the noise and signal distributions overlap, show situations in which the stimuli are confusable can be identified as signal or noise. Anything to the right of the criterion will be reported as different and anything to the left of the criterion will be reported as same.

By considering responses in this way it is possible to classify four different response categories (see Figure 5.4.). For this study, a *hit* occurs when a change in spatial relations is correctly identified (i.e. report different when stimuli are different); a *miss* occurs when a change in spatial relation is present but is not reported (i.e. report same when stimuli are different); a *false alarm* occurs when a change in spatial relation is reported, but is not present (i.e. report different when stimuli are the same) and a *correct rejection* occurs when no change in spatial relation is correctly identified (i.e. report same when stimuli are the same).

		Correct response	
		Same	**Different**
Participant Response	**Same**	Correct Rejection	Miss
	Different	False alarm	Hit

Figure 5.4. Diagram to show the four possible responses generated using signal detection theory.

The position that the participant places the criterion determines the proportion of hits and false alarms that the participant makes. If the participant positions the criterion to the left of the distribution then they will generate more hits but also more false alarms. Alternatively, if the participant positions the criterion further to the right of the distribution they will generate fewer false alarms but also fewer hits. Given that the response that the participant generates is dependent both on the strength of the signal from the stimuli and also on the position at which they place the criterion, it is important to consider these influences separately so as to determine whether or not there are true differences in VS processing between tasks and age-groups.

For this study, perceptual sensitivity (indexed by the SDT parameter *d'*) is defined as the ability of the participant to detect whether there was a change in the spatial relations between the two stimuli while also taking into consideration how often a spatial relation is incorrectly identified. To calculate *d'* the following formula was used (see Macmillan & Creelman, 2005):

$$2z\{0.5[1+\sqrt{(2z\{0.5[z(\text{hit rate})-z(\text{false alarm rate})]\}-1)}]\}$$

For this study, the hit rate was the proportion of trials in which the participants responded ‘different’ to trials in which the two stimuli differed in spatial relations (either in a categorical or coordinate fashion). The false alarm rate was the proportion of trials in which the participants responded ‘different’ to trials in which the spatial relations were actually the same (see Table 5.3 for hit rates and false alarm rates). A higher value of *d'* indicates higher levels of perceptual sensitivity, in that individuals can discriminate between noise and signal more effectively

The criterion, *c*, refers to the bias towards generating a particular response. For example, participants may be more likely to respond 'different' than same. Accordingly, *c* is described in relation to how conservative an individual is in making their responses. If an individual is conservative, the critical threshold required before a 'different' response will be made is high. Conversely, if an individual is more liberal, the critical threshold is much lower and a different response is reported more frequently. To calculate *c* values, the following formula was used (see Macmillan & Creelman, 2005):

$$-.5[z(\text{hit rate}) + z(\text{false alarms})]$$

In this study, a *c* value of 0 indicated a 'neutral' criterion; that is, participants were unbiased. A value of *c* that is below 0 indicated that the participant was biased towards responding 'different' rather than 'same' and a value of *c* above 0 indicated that the participant was biased towards responding 'same' rather than 'different'. The *d'* and *c* scores are displayed in Table 5.4.

Hit rates, false alarm rates, *d'* and *c* were all analysed in separate 2 (Task) x 2 (VF) x 2 (Age-Group) repeated measures ANOVAs, with Age-Group being a between subjects factor. To reiterate, it was predicted that younger adults would be more sensitive to detecting changes in spatial relations and that there would be an interaction between VF and Age-Group, showing an overall LVF-RH advantage for younger adults but no VF advantage for older adults. In addition, it was argued that if differences in *d'* were found between Task and Age-Groups, this would indicate that there were differences in the perceptual processing of the stimuli. In the same way, if differences in *d'* were found between Task and VF then this would provide evidence to support the theory that different types of VS information displayed in the LVF-RH and RVF-LH are processed differently. If differences are found in *d'* only, it can be concluded with some certainty that the effect is driven by perceptual differences. However, if *c* changes as well, then this means that there is also something going on with the decision-making.

Hit rates

The only significant effect found was for Task, $F(1, 47) = 183.66$, $p < .01$. As shown in Table 5.3., participants correctly identified more changes in categorical spatial relations than coordinate spatial relations, suggesting that it was easier to detect changes in categorical spatial relations than coordinate spatial relations. There were no other main effects or interactions, Fs < 2.04.

False alarm rates

The false alarm rates showed main effects of Task, $F(1, 47) = 33.00$, $p < .01$, and VF, $F(1, 47) = 3.90$, $p < .05$. Overall, participants made more false alarms in the coordinate task, and when the stimuli were presented in the RVF (see Table 6.3). However, there was a Task x VF x Age-Group interaction, $F(1, 47) = 6.14$, $p < .05$. As shown in Table 5.3., similar to the results reported by Bullens and Postma (2008), younger adults made more false alarms for categorical trials presented in the RVF-LH, $t(24) = -2.11$, $p < .05$. In contrast, there was a trend towards older adults making more false alarms for coordinate trials presented in the RVF-LH, $t(23) = 1.95$, $p < .06$. However, these were not significant when Bonferroni corrected. There were no other main effects or interactions, Fs < 1.61.

Table 5.3

Hit Rates and False Alarm Rates as a Function of Age-Group and Task

	Hit rates (*M, SD*)		False alarm rates (*M, SD*)	
	LVF	RVF	LVF	RVF
		Categorical Task		
Younger adults	.94 (.06)	.94 (.06)	.06 (.05)	.10 (.09)
Older adults	.95 (.06)	.95 (.05)	.05 (.06)	.07 (.07)
		Coordinate Task		
Younger adults	.78 (.10)	.75 (.12)	.19 (.11)	.16 (.11)
Older adults	.77 (.10)	.76 (.12)	.13 (.13)	.17 (.11)

Sensitivity data

Table 5.4 shows the *d'* values for younger and older adults as a function of task and hemisphere. There was a main effect of Task, $F(1, 47) = 201.04$, $p < .01$, which showed that participants were more sensitive to spatial changes in the categorical task compared to the coordinate task. In line with the previous results, this suggests that categorical VS processing was easier than coordinate VS processing. There was also a main effect of VF, $F(1, 47) = 11.62$, $p < .01$, which showed a LVF-RH advantage. Thus, in line with Bullens and Postma (2008), participants were more sensitive to detecting changes in spatial relations when Stimulus 2 was presented in the LVF-RH.

Additionally, consistent with the previous analyses, there was a Task x VF x Age-Group interaction, $F(1, 47) = 4.10$, $p < .05$. Further comparisons showed that there were trends towards younger adults being more sensitive to changes in categorical trials presented in the LVF-RH, $t(24) = 2.52$, $p < .05$, and older adults being more sensitive to spatial changes in LVF-RH coordinate trials, $t(23) = 2.59$, $p < .05$. However, again these effects were not significant when Bonferroni corrected. Thus, in contrast to the predictions, older adults were not less sensitive to changes in spatial relations than younger adults, nor did they show a lack of sensitivity for trials in which the stimuli were presented to the LVF-RH. No other main effects or interactions were found *F*s < 1.87.

Table 5.4

Sensitivity (d') and Response Bias (c) as a Function of Age-Group and Task

	d' (*M, SD*)		*c* (*M, SD*)	
	LVF	RVF	LVF	RVF
		Categorical Task		
Younger adults	3.95 (.56)	3.73 (.69)	-.01 (.23)	-.11 (.23)
Older adults	4.18 (.67)	4.05 (.71)	-.02 (.13)	-.04 (.19)
		Coordinate Task		
Younger adults	2.55 (.63)	2.55 (.65)	.07 (.30)	.17 (.27)
Older adults	2.81 (.64)	2.51 (.55)	.29 (.36)	.16 (.29)

Response Bias

The *c* values are shown in Table 6.4. Again, there was a main effect of Task, $F(1, 47) = 11.62$, $p < .01$. Participants were more conservative in their responses in the coordinate task and more liberal in the categorical task. That is, participants were more likely to respond 'same' in the coordinate task and 'different' in the categorical task. This suggests that the criterion level was shifted more to the left for categorical VS judgements and more to the right for coordinate VS judgements.

There was also a interaction between Task, VF and Age-Group, $F(1, 47) = 11.62$, $p < .01$. Interestingly, this was caused by a trend in older adults being biased towards responding 'different' for coordinate trials presented in the LVF-RH, $t(24) = -2.49$, $p < .05$, although this did not reach significance when Bonferroni corrected. This may go some way in explaining the older adults' LVF-RH advantage found in the coordinate task, and will be discussed in Section 6.3.4 below. No other main effects or interactions were found *F*s < 2.32.

5.3.4. Sensitivity and Bias: Discussion

There were three aims of conducting analyses using SDT. First, *d'* and *c* were analysed to investigate whether true differences in processing underpinned categorical and coordinate VS judgements. Second, it was of interest to determine whether there were true differences in processing of information presented in the LVF or RVF. Finally, it was also of interest to determine whether, with age, there were changes in ability to detect differences in categorical and coordinate spatial relations. The key findings were that differences in *d'* were found with respect to Task and VF. In addition, *d'* and *c* did not change with age.

With respect to task differences, both younger and older adults were able to detect more spatial changes in the categorical task compared to the coordinate task. Participants made more hits and fewer false alarms in the categorical task, whereas in the coordinate task participants made fewer hits and more false alarms. Not only did this further highlight that categorical VS judgements were easier than coordinate VS judgements, but the effect also suggested that, in this task, categorical and coordinate VS judgements were underpinned by differences in the type of cognitive processes that were engaged. However, it is important to note that there were also differences in *c* and participants were more liberal in the categorical task and more conservative in the coordinate task. Thus, it would seem that decisional criteria also contributed to the differences found.

One possible explanation for the differences in *c* may be due to the perceived task demand. Recall that SDT assumes that the participant creates two different distributions, one for the signal and one for the noise. If the distributions of the noise and signal were located further apart in the categorical task than in the coordinate task, then participants could be more certain that any accrued neural activation did represent a difference between the strength of the signal and not in the noise. To cope with the uncertainty of whether the accrued neural activation represented a difference in the coordinate task, it would seem that the participants adopted a more conservative criterion. By contrast, it would seem that for the categorical task, participants were overconfident in their ability to detect relative changes which led to a bias towards reporting a difference.

Inconsistent with the predictions, younger adults were not found to be more sensitive to detecting changes in spatial relations than older adults. Instead, younger and older participants correctly identified a similar number of changes in spatial relations, and made a similar number of false alarms. Thus, this study found that discrimination sensitivity does not change with older age.

In line with Bullens and Postma (2008), an overall LVF-RH advantage was found with the *d'* data. That is, participants were better able to detect changes if Stimulus 2 was presented in the LVF-RH. More specifically, participants made more false alarms regarding stimuli presented in the RVF-LH. This suggests that different encoding strategies may have been used to process information presented in the LVF-RH compared to the RVF-LH. Moreover, this finding could be interpreted to reflect that the processes undertaken by the RH are different to those undertaken by the LH, and is in line with the idea that the RH is more involved in processing VS information.

Effects of VF were found to interact with age and task; younger adults were marginally better at detecting categorical spatial changes presented in the LVF-RH, and the older adults detected more coordinate spatial changes for stimuli presented in the LVF-RH. It would seem that for the younger adults this may have occurred because more false alarms were made when judging categorical spatial relations when the stimuli were presented in the RVF-LH. Older adults were more biased to make a 'different' response in the LVF-RH trials of the coordinate task; thus, the likelihood that a change in coordinate spatial relations was correctly identified increased. However, hit rates and false alarm rates are positively correlated and so as the chance of the number of hits increases so does the chance of making false alarms. In this way, it would be expected that older adults would reduce in sensitivity for these trials. However, as shown by the false alarm data, older adults actually made fewer false alarms for these LVF-RH coordinate trials than for the RVF-LH coordinate trials, hence, increasing the sensitivity of the response. This suggests that older adults used different processes to encode coordinate information presented in the LVF-RH and RVF-LH, as well as different decision criteria.

In summary, the findings from the *d'* data suggest that participants process categorical or coordinate spatial relation judgements differently. Furthermore, participants also processed spatial information more accurately when the stimuli were presented in LVF. Differences in processing were also found between the age-groups as a function of Task and VF. However, as with the RT data, it is difficult to explain the different effects of VF. Furthermore, it is intriguing as to why the findings from the RT and SDT analyses were not consistent. The findings from the different analyses will now be compared and evaluated.

5.3.5 Evaluation of differences in ER, RT and SDT results

The results from the RT, ER and SDT data were not consistent in all respects. This raises the question of how the conflicting data can be interpreted? Signal detection theory can only be applied to certain experimental methodologies. The same-different, match-to-sample methodological approach employed in the current chapter allowed SDT to be carried out. Analyses using SDT were conducted as an alternative to analyses of ER and RT data. Importantly, it is suggested that percentage ERs and RTs cannot distinguish perceptual differences (i.e. differences in processing strategies) from decisional differences, whereas SDT can. This is done by taking into account how often a change in spatial relation is incorrectly identified (a false alarm) as well as how often a change in spatial relation is correctly identified (a hit). In this way, it is suggested that SDT facilitates analysis of whether differences between tasks or different participant populations are underpinned by differences in processing or by differences in decisional criteria. By contrast, RT and ER data show relative advantages and longer RTs and higher ERs are suggested to be indicative of more cognitively demanding processing. Indeed, it is suggested that RT is directly related to the difficulty of discrimination between signal and noise (Verghese, 2001). Thus, arguably, the SDT analyses should be more informative than both the ER and RT data.

The results showed that participants were more sensitive to detecting changes in categorical spatial relations than coordinate spatial relations. Similarly, participants took longer to make a response and made more errors regarding coordinate spatial relations compared to categorical spatial relations. However, as reported previously, differences were also found across tasks for *c*, and participants were more liberal in the categorical task and more conservative in the coordinate task. These findings suggest that categorical and coordinate VS processes are different, and that generating a same/different response with respect to distance is more difficult than generating a same/different response with respect to relative location. Furthermore, as described in

Section 5.3.4, it seems that to compensate for this, participants adopt a more conservative decisional criteria, presumably to try to reduce the chance that differences were mistakenly reported.

Interestingly, no differences were found across age-groups using the SDT and ER analyses, whereas the RT analyses showed older adults were much slower processing information than the younger adults. This suggests that for the current tasks, although older adults take longer to process information, the cognitive processes utilised are similar for both age-groups and ability to detect changes in spatial relations remain intact. Thus, converged together these findings provide greater insight into the processing that occurs when judging categorical and coordinate spatial relations in younger and older adults.

With respect to VF differences, there was a trend towards younger adults being more sensitive at detecting changes in categorical spatial relations when the stimuli were presented in the LVF-RH, whereas they showed a RVF-LH advantage for categorical VS processing in terms of perceptual speed. Interestingly, a trend was also found for younger adults to make more false alarms in the categorical task, when stimuli were presented in the RVF-LH. It could be that younger participants were faster to respond to categorical trials in which the stimulus was presented in the RVF-LH, but that this was at a cost to the accuracy of detecting a spatial change. However, the correlations were not significant ($r < -.04$). Interestingly, if RT data only had been used as the dependent measure, it would have been concluded that participants were more efficient and effective at processing categorical spatial relations when the stimuli were presented in the RVF-LH. However, the SDT analyses showed that this finding likely reflects changes in the criterion as well as perceptual processing and although participants may have been faster to respond to RVF trials, they were not more accurate when doing so, leading to an increase in the false alarm rates.

For the older adults, it would seem that the trend towards a LVF-RH advantage for detecting coordinate spatial relations may have been underpinned by different VS encoding processes being undertaken for stimuli presented in the LVF-RH and RVF-LH, as well as by differences in the decision criteria. By using the RT and percentage ER data only, this would have been missed. It is important to note, however, that the differences in *d'* and false alarm rates across task, VF and age-groups were not significant when Bonferroni corrected, and so it is possible that the marginal differences found were a product of chance.

In summary, RT is suggested to be directly related to the difficulty of discrimination between signal and noise; presumably the closer the noise and signal distributions the more difficult the discrimination (Verghese, 2001). In much the same way, percentage ERs can also provide information on the difficulty of the processes involved. Using ER and RT as a dependent measure does provide some useful information in the current experiment; however, ER and RT cannot distinguish perceptual differences in processing and differences in decisional criteria.

In conclusion, the results demonstrate the importance of using measures that are independent of response bias so that it is certain that effects found are driven by differences in processing strategy rather than decisional criteria. It seems that when methodologies permit the data to be analysed using SDT, this should be done in addition to more traditional ER and RT analyses and the use of converging statistical methods leads to greater insight with respect to underlying cognitive processes.

5.4. Chapter Summary

The aim of this chapter was to explore WM for categorical and coordinate spatial relations in younger and older adults. There were two key findings: The first key finding showed that, consistent with previous research (e.g., Bruyer et al., 1997; Hoyer & Rybash, 1992), older adults were slower to respond than younger adults. However, discrimination sensitivity did not decline with age. Furthermore, there was no compelling evidence of differential age-related decline. Thus, with age, processing speed reduces; however, ability to detect spatial relations remains intact. This occurs regardless of the type of VS judgement made. The second key finding was that RT, *d'* and *c* data showed a three-way interaction between Task, VF and Age-Group. However, these interactions patterned differently. Again, this highlights that effects of VF in categorical and coordinate VS processing are not robust.

Most empirical work focuses on the functional dissociation between categorical and coordinate VS processes with regard to VF (and hemispheric) differences. However, it appears that this type of research yields inconsistent results, and although the predicted VF advantages have been found, it seems that these advantages are never clear cut, and are difficult to replicate. This makes it very difficult to interpret the results, especially when ageing is thrown into the mix. Furthermore, VF and hemispheric processing provides very limited insight into the cognitive processes underlying categorical and coordinate VS processing. As described in the Section 5.3.5., converging statistical methodologies (SDT, RT and ER analyses) provided further insight into the processes involved in making a categorical or coordinate VS judgement; however, the question still remains as to exactly how participants make a categorical or coordinate VS judgement. To address this, the following chapter will investigate the moment-to-moment cognitive processes underlying categorical and coordinate VS processes, by employing eye-tracking methodology.

Chapter 6
Categorical and Coordinate VS Processing: Evidence from Eye Movements

6.1. Introduction

As described throughout this thesis, categorical and coordinate hemispheric asymmetry has received a considerable amount of attention. To reiterate, it is argued that hemispheric dissociation shows two independent processing systems; however, this is not necessarily the case, and different neural networks do not necessarily demonstrate qualitatively different cognitive processes. Furthermore, recently it has been proposed that the hemispheric specialisations obtained for spatial relation judgements may simply reflect quantitative differences in the cognitive demands associated with the different tasks (Martin et al., 2008; Van der Lubbe et al., 2006). Categorical and coordinate VS judgements have received little examination using methodologies that provide on-line, moment-to-moment measurements of cognitive processing (for ERP study see Van der Lubbe et al., 2006). Thus, the extent to which cognitive processes underlying different types of spatial relation judgements are qualitatively different is not clear.

Eye movement recording techniques provide a valuable tool for investigating on-line cognitive processes (Liversedge & Findlay, 2000; Rayner, 1998). Using eye movements as a performance measure thereby provides insight into the cognitive processes underlying visual cognitive perception. Specifically, eye movement research has significantly increased understanding of the cognitive processes involved in reading, visual search and scene perception (e.g., Castelhano, Mack & Henderson, 2009; Castelhano & Rayner, 2008; Rayner, 1998; Rayner & Castelhano, 2007).

Eye movement behaviour is characterised by patterns of saccades and fixations. During a fixation, visual information is encoded (see Findlay & Gilchrist, 2003). Accordingly, fixation duration has been suggested to reflect the relative difficulty of cognitive processing, and complexity of encoding is associated with longer fixation durations, as well as increased fixations and saccades (Kramer & McCarley, 2003; Liversedge & Findlay, 2000; Rayner, 1998). Furthermore, it has been clearly shown that patterns of eye movements differ depending on the type of task being undertaken (e.g., Castelhano et al., 2009; Yarbus, 1967). Thus, it seems reasonable to assume that differential patterns of eye movements might be found for tasks requiring different types of spatial relation judgements. Accordingly, in the current experiment, eye movements associated with categorical and coordinate VS judgements were examined to investigate how differential patterns of eye movement behaviour reflect different underlying cognitive processes. To date, there are no published studies that have examined eye movements during categorical and coordinate VS processes. The present study, therefore, provides a novel experimental approach, as well as a rich dataset that, potentially, may be useful in dissociating different types of VS processing.

To briefly recap, categorical tasks typically require a binary above/below decision based on the position of a dot in relation to a bar, irrespective of distance. Categorical judgements, therefore, require discrimination between two possible predetermined patterns (Martin et al., 2008). In contrast, coordinate VS judgements require some sort of distance judgement, and are suggested to use a more continuous scale (Laeng et al., 2003).

However, throughout the thesis, it has been argued that the extent to which precise computation of distance is necessary for near/far judgements is unclear (Banich & Federmeier, 1999; Hoyer & Rybash, 1992; Sergent, 1991; see also Chapters 3 and 4). To be more specific, it is not known whether a precise distance must be computed on each trial before it is categorised as near or far (Banich & Federmeier, 1999; Hoyer & Rybash, 1992). If precise distance is not computed on every trial, near/far judgements may be based on predetermined patterns similar to those underpinning categorical VS processes. Thus, the cognitive processes underlying above/below and near/far VS judgements may not be qualitatively different. By contrast, the distance quantification task developed in Experiment 1, explicitly required participants to report the distance between a bar and a dot. Accordingly, the judgement was on a continuous rather than a discrete scale and it was argued that the computation of a precise distance was necessarily required on every trial.

The aim of the current experiment was to record eye movements directly to assess the cognitive processes underlying the three VS tasks employed in Experiment 1; a categorical above/below task, a near/far task, and a distance quantification task. More specifically, the aim was to determine whether differential patterns of eye movements reflected qualitatively distinct underlying cognitive processes. In this way, the near/far and distance quantification tasks could be compared to determine whether both appear to require precise distance computation.

In line with Experiment 1, participants were presented with a bar and a dot located above or below the bar at 1 of 8 distances away from the bar. These stimuli were presented on the left or right hand side of the computer screen. However, in contrast to

Experiment 1, in the current study, the stimuli were presented for an unlimited viewing time. This was in order to encourage participants to make an eye movement to the stimuli. Recall that when eye movements are made directly to fixate a stimulus, the stimulus is presented bilaterally to both visual hemi-fields, and, arguably, neither hemisphere has initial access to the presented information (Hellige, 1993). Thus, this study moves away from categorical and coordinate hemispheric specialisation and lateralisation was not included in the analysis as a dependent variable. Furthermore, the analyses will consider each of the eight distances as a dependent variable rather than collapsing the distance into near/far categories. This will allow for a more detailed comparison across distance and tasks.

In line with Kosslyn (1987), it was predicted that for all three tasks attention (and the eyes) would most likely orient towards a reference point – either the bar or the dot – before a judgement regarding the location was made. Furthermore, given that in visual half-field studies stimuli are only presented for ~150 ms, it seems reasonable to suggest that spatial relation judgements could be made without a saccade to the reference point. Thus, it was anticipated that parafoveal judgements (i.e. judgements in which participants did not make a saccade to the stimulus) might be made on some occasions, and that this would occur more frequently in the above/below task, less often in the near far task and very infrequently in the distance quantification task.

It was also predicted that processing associated with categorical judgements would be qualitatively distinct from processing associated with distance quantification judgements. As such, it was anticipated that patterns of eye movements during these two tasks would be different. For the categorical task, it was predicted that above/below responses would be made rapidly, would require fewer fixations on the stimuli and that participants would make few errors. It was also predicted that the number and duration of fixations would remain relatively constant as the distance of the dot from the bar increased. Thus, in line with Experiment 1, no effect of distance was expected.

For the distance quantification task, given the explicit requirement to form a precise distance judgement, it was predicted that this judgement would be particularly cognitively demanding. Accordingly, it was anticipated that participants would make a relatively large number of fixations on the bar-dot stimuli in this task. Specifically, it was anticipated that eye movements would necessarily reflect distance measuring behaviours; such as counting out the distance or making repeated saccades between the bar and dot corresponding to the two end points of the distance to be estimated (i.e.

alternately fixating the bar and the dot). Consistent with the previous experimental results (see Experiments 1 and 2), it was also anticipated that estimate accuracy would decrease as a function of distance. Furthermore, if distance computation was more difficult for longer distances than for shorter distances then it was expected that participants would make more and longer fixations when computing larger distance estimations than when making shorter distance estimations. Therefore, a difference in performance across distance was expected in that number and duration of fixations would increase linearly with distance.

Finally, for the near/far task, it was anticipated that patterns of eye movements would differ depending on the distance of the dot from the critical distance. More specifically, it was predicted that trials in which the dot was located furthest from the critical distance would resemble performance in the categorical task. That is, judgements would be made quickly and with few fixations on the stimuli. By contrast, the dots located closer to the critical distance were anticipated to be more difficult, and it was expected that participants would take longer to make responses in these trials. However, a critical question for such trials concerns whether increased RTs simply reflect more difficult discrimination processes, or instead, processes associated with distance estimation. If increased RTs reflect distance estimations, then performance (in terms of eye movements) should be comparable to that observed at similar distances (of the dot in relation to the bar) in the distance estimation task, and patterns of eye movements would reflect counting out the distance or making a number of saccades alternately to fixate the bar and the dot. Alternatively, if increased RTs reflect discrimination processes, then fixations and saccades in the near/far task should be substantially reduced relative to those observed in the distance quantification task, and few patterns reflecting counting behaviours would be observed.

6.2. Method

Participants

Ten right-handed, younger participants volunteered or were awarded course credits for participating in this study. Participants were screened for normal or corrected-to-normal vision. All participants were right-handed with an overall mean Laterality Quotient of 93.65 (*SD* =9.85; assessed using the EHI; Oldfield, 1971). Participants were aged between 18-28 years (*M* = 21.40, *SD* = 3.03). There were 3 males and 7 females. Participants had an average 16.80 years of education (*SD* = 3.49), and a mean Predicted IQ (as assessed by the NART; Nelson & Willison, 1991) of 104.70 (*SD* = 8.34).

Design and Materials

The design of this study was similar to that in Experiment 1 except that each task was programmed using Experiment Builder software, and eye movement data were recorded using the EyeLink 1000 eye tracking system. Participants viewed the screen binocularly, but only the movements of the right eye were recorded. To ensure constant viewing conditions, participants used a chin rest and were seated 57 cm from a 24 inch computer monitor. The stimuli consisted of a dot (0.6^o x 0.6^o) and a horizontal bar (5.8^o x 0.5^o). The stimuli were presented in black on a white screen. A fixation cross (0.5^o x 0.5^o) was presented in the centre of the screen. Ninety-six trials were presented for each VS task, of which 48 stimuli were presented in the RVF and 48 in the LVF. The edge of the horizontal bar was located at 3.5^o from the fixation cross.

In line with the previous chapters, all participants made distance judgements in cm. The dot appeared at 1 of 8 distances away from the bar; these were positioned at 1 cm (1^o) increments from the centre of the bar, with eight trials being above and eight trials below. The first four dots above and below the bar fell within 4.5 cm (4.5^o) of the bar, and the remaining four dots were further than 4.5 cm. Interest areas (6.4^o x 1^o) were set around each distance region in which the dot could be located, above and below the bar. An interest area was also set around the bar (6.4^o x $.9^o$).

The bar could appear in 1 of 3 possible locations in each VF; centrally and slightly above and below central (0.7^o), thus, each dot position was presented six times. In all three tasks the stimuli were presented in a fixed pseudo-random order and appeared in the same VF in no more than three consecutive trials.

All tasks used the same stimuli, and only differed in the spatial judgement being made. Consistent with previous studies, for the categorical task, participants were required to decide whether the dot was located ‘above’ or ‘below’ the bar; for the near/far task participants were required to judge whether the dot was ‘within’ or ‘further than’ 4.5 cm of the bar; and for the distance quantification task participants were asked to estimate the distance between the bar and the dot (in cm).

Practice Trials

Participants were required to complete practice trials before the administration of each task. Participants were presented with eight trials; four above, four below; four within, four outside; and once at each distance from 1-8. The stimuli were presented centrally on the screen, and participants were given feedback for incorrect responses. That is, participants were told when they were incorrect and the correct spatial relation (above/below, near/far or the distance of the dot from the bar) was specified to them.

Procedure

Before the start of each task, participants' eye movements were calibrated and validated for accuracy. Participants viewed a series of nine dots, presented in a random order in three rows at the top, middle and bottom of the screen. Only accuracy levels of .30 or below were accepted. Re-calibration occurred throughout the experiment, as necessary.

Each trial within each task consisted of the same sequence of events. A black dot with a white centre appeared in the centre of the screen. Participants were told to stare at the white centre of the dot. Once the participant was staring at the centre of the screen the trial started. The word, 'ready?' appeared centrally on the screen. Participants indicated they were ready to begin by pressing a space bar with the index finger of their left (non-dominant) hand. A centrally displayed fixation cross appeared for 200 ms, followed by a blank screen (shown for 300 ms). The central fixation cross was then displayed again for a further 200 ms. A bar and dot stimulus then appeared, in either the LVF or RVF. The stimulus remained on the screen until the participant made a response.

For the categorical and near/far task, participants pressed one of two keys, 'b' or 'n', (located next to each other), using the index and middle finger of their right (dominant) hand. The 'b' key denoted 'above', or 'within' and the 'n' key denoted 'below' or 'outside', for the two tasks. As soon as a response was made, the screen went blank for 300 ms, before a new trial began.

For the distance quantification task, when the stimulus appeared on the screen, participants were required to press the space bar when they were confident that they had an estimate for the distance between the bar and the dot. This recorded RT. Participants then typed in their distance estimate using the number pad on the right hand side of a keyboard (the numbers 0-9 and the period, in case they wanted to use a decimal in their response). They then pressed the enter key also located in the number pad. This recorded the estimate. Following a 300 ms blank screen, a new trial began.

Participants were given verbal instructions and practice trials before each task began. In line with Experiment 1, the categorical task was always administered second and the order of the near/far and distance quantification tasks was counterbalanced. Following testing, the EHI (Oldfield, 1971) and NART (Nelson & Willison, 1997) were administered to all participants.

6.3. Results

6.3.1. Behavioural Data

In line with the previous chapters, percentage ERs, estimate data and RTs were analysed. Consistent with Experiments 1 and 2, accuracy for the above/below and near/far tasks were analysed independently of the distance quantification task. For the above/below and near/far tasks percentage error rates were analysed. For the distance quantification task, absolute difference scores were analysed. For all three performance measures, repeated-measures ANOVAs were conducted. Any unplanned comparisons were Bonferroni corrected.

Accuracy

Above/Below and Near/Far Tasks: Percentage Error Rates

A 2 (Task) x 8 (Distance) ANOVA was conducted on the percentage error rate data. In line with our predictions, there was a main effect of Task, $F(1, 9) = 13.10$, $p < .01$. This showed that participants made fewest errors in the categorical task (M = 1.67%, SD = 1.56), more errors in the near/far task (M = 7.29%, SD = 5.38; see Figure 6.1), suggesting that participants found the above/below task easiest. There was also a main effect of Distance, $F(7, 63) = 7.17$, $p < .01$, however, the data in this respect were not particularly clear and comparisons were not significant when Bonferroni corrected.

The Task x Distance interaction, $F(7, 63) = 5.59$, $p < .01$, showed that there was a difference across distance in the near/far task, $F(7, 63) = 6.72$, $p < .01$, but not in the above/below task, $F(7, 63) = 1.48$, *ns*. As illustrated in Figure 6.1, for the near/far task ER increased the closer the dot was located to the critical distance (4.5 cm). In particular, paired comparisons showed differences between ER at distance 5 and distances 1, 2, 3, 6, 7 and 8 ($ts > 2.85$, $ps < .05$).

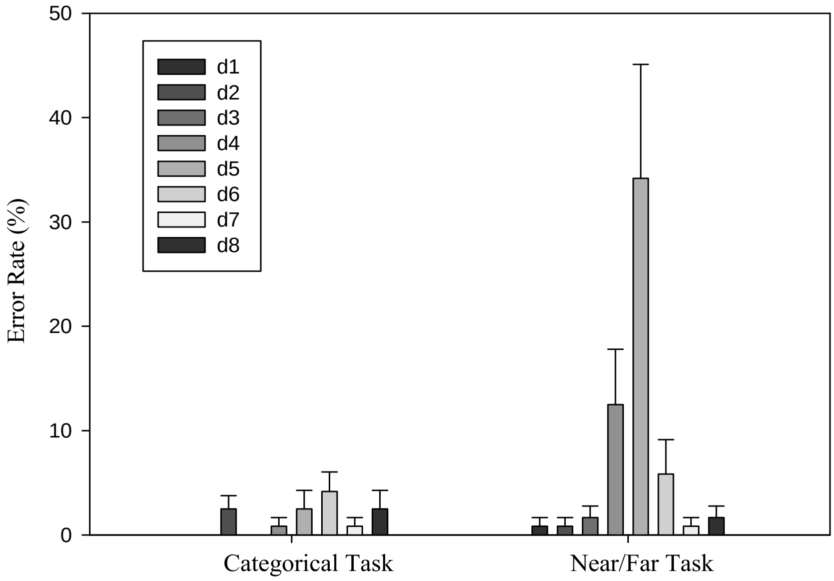


Figure 6.1. Percentage ERs across distance for the categorical and near/far tasks. d1 to d8 refer to the distance of the dot from the bar (in cm).

Distance Quantification Task: Estimate Data

Consistent with Experiments 1 and 2, estimates were examined with respect to the absolute difference scores between the estimates and actual distances. Figure 6.2 demonstrates that distance estimate accuracy decreased as the distance of the dot from the bar increased, $F(1, 9) = 3.99$, $p < .01$. However, although numerically the accuracy in estimations decreased with distance, this effect was not reliable when Bonferroni corrected, *ts* < 3.83. Overall, it seems reasonable to conclude that participants were quite accurate in estimating distance.

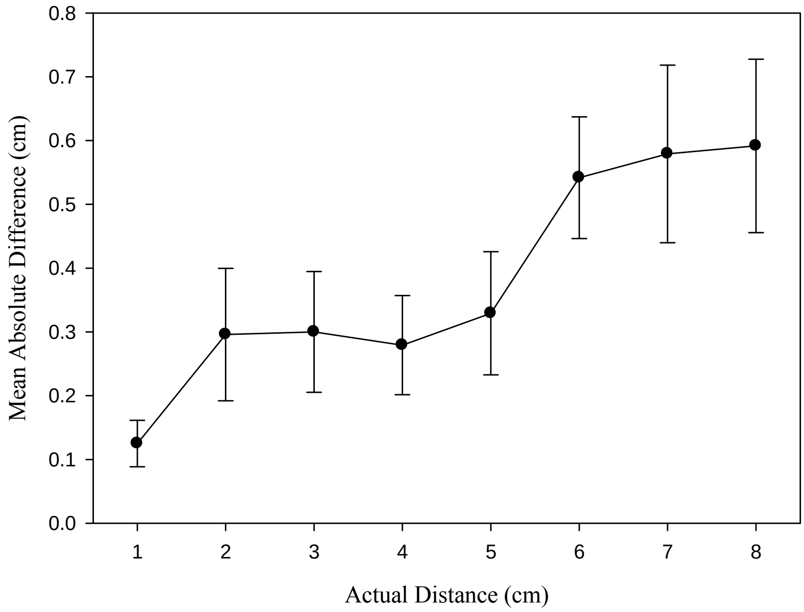


Figure 6.2. Mean absolute difference scores (and standard error bars) between the estimate given and the actual distance being judged.

Response Times

For the categorical and near/far tasks only correct responses were analysed. However, consistent with the analyses for Experiments 1 and 2, all data were included in the analysis of RT and eye movements for the distance quantification task. All RT data were trimmed for outliers (plus or minus 3 *SD*s); by doing this 3% of the data were excluded.

There was a main effect of Task, $F(2, 18) = 11.68$, $p < .01$. Consistent with the predictions, participants took longer to make a response in the distance quantification task (M = 3249.72 ms, SD = 2442.90) compared to the near/far task (M = 906.02 ms, SD = 283.93), and responded fastest in the categorical task (M = 533.29 ms, SD = 108.15). These results showed that participants were relatively fast to make an above/below or near/far judgement but required a much longer time to make a distance estimate. There was also a main effect of Distance, $F(7, 63) = 5.48$, $p < .01$, in which RT increased from distance 1 to distance 4, and then remained relatively constant. However, Bonferroni corrected comparisons showed no differences.

These main effects were qualified by a Task x Distance interaction, $F(14, 126) = 3.97$, $p < .01$. As can be seen from Figure 6.3, there were no differences in RTs for the distances in the categorical task, $F(7, 63) = 1.25$, *ns*. Thus, as predicted, the time taken to make a categorical response was short and comparable across distance. However, distance did affect performance in both the near/far and distance quantification tasks (*Fs* > 4.12, *p*s < .01). Specifically, the inverted U-shaped curve for the near/far task suggests that distances 4 and 5 were the most difficult trials to judge. Indeed, RTs for distances 4 and 5 were significantly different from the RTs for all distances apart from distance 6 (*t*s > 2.57, *p*s < .05). Differences were also found between RTs at distance 1 and distances 3, 6, 7 and 8; distance 2 and distances 3, 6 and 7; and distances 6 and 8 (*t*s > 2.48, *p*s < .05). By contrast, in the distance quantification task, RT increased with distance, suggesting that the time needed to make a distance estimation increased with distance. However, pairwise comparisons only showed differences between RTs for distance 1 and distances 3, 4, 6 and 8; and distance 2 and distances 3, 4, 5, 6 and 8.

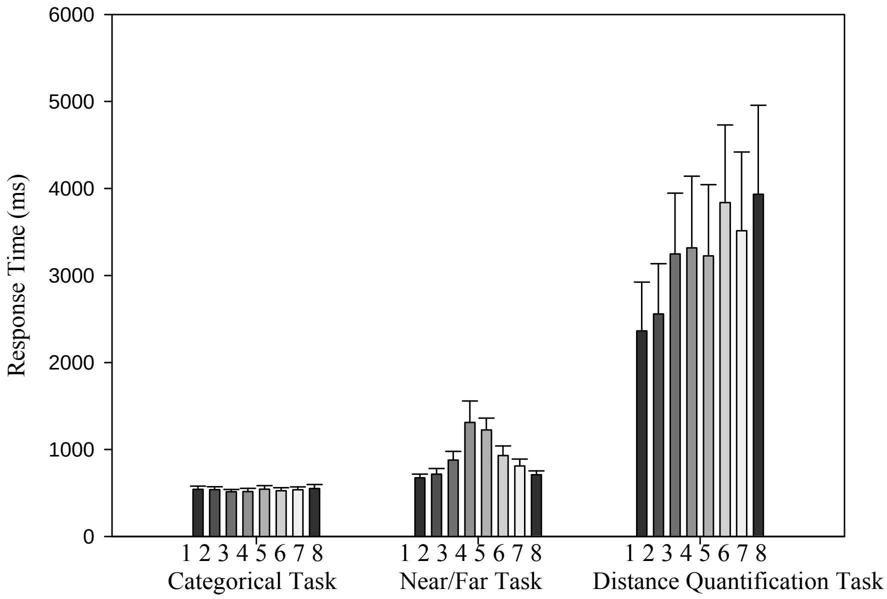


Figure 6.3. Mean RT (and standard error bars) across distance in all three tasks.

6.3.2. Eye Movement Data

Number of Fixations, Number of Saccades and Total Time

As expected, the number of fixations, number of saccades and total time (the total time participants fixated on the stimuli) all reflected the results of the RT analysis. A greater number of eye movements were made during longer RTs. Table 6.1 shows the *F*-values for the main effects of Task and Distance and the Task by Distance interaction. The effect of Distance was found to be significant in both coordinate tasks, *Fs* > 4.54, *p*s < .01, in all performance measures, and took the same patterns as those shown in the

RT data. For the categorical task, the number of saccades made differed across distance, $F(7, 63) = 2.34$, $p < .05$. Differences were found between distance 1 and distances 7 and 8 and between distance 3 and distance 8, *t*s > 2.34, *p*s < .05. Thus, consistent with Experiment 2, a greater number of saccades were made when the dot was located far from the bar. One possible post-hoc explanation for this is that when the dot is located near to the bar, both stimuli can be attended to in a single fixation, however, when the dot is far from the bar, attention may have to be reallocated so that the location of the dot can be verified. Table 6.2 provides the means (and SDs) for each performance measure as a function of task and distance.

Table 6.1

Results from the 3 (Task) x 8 (Distance) ANOVA

Source	*df*	*F*	*p*
		Number of Saccades	
Task	2, 18	27.68	< .01
Distance	7, 63	20.75	< .01
T X D	14, 126	13.79	< .01
		Number of Fixations	
Task	2, 18	27.65	< .01
Distance	7, 63	13.99	< .01
T X D	14, 126	11.40	< .01
		Total Time	
Task	2, 18	13.65	< .01
Distance	7, 63	10.51	<.01
T X D	14, 126	5.00	< .01

Note. T x D = Task x Distance interaction

Table 6.2

Means (and SDs) for Eye Movement Measures across Task and Distance

Task	Distance 1	Distance 2	Distance 3	Distance 4	Distance 5	Distance 6	Distance 7	Distance 8	overall
					Average Number of Fixations				
Categorical	2.21 (.63)	2.20 (.68)	2.17 (.57)	2.32 (.76)	2.29 (.83)	2.32 (.79)	2.41 (.80)	2.39 (.64)	2.29 (.69)
Near/far	2.75 (.46)	2.72 (.60)	3.04 (.82)	3.68 (1.51)	3.72 (1.14)	3.44 (1.09)	3.17 (.87)	3.09 (.77)	3.17 (.84)
Distance	4.55 (1.66)	5.03 (1.92)	6.40 (2.40)	7.00 (3.30)	7.21 (3.31)	8.36 (3.98)	8.80 (4.37)	9.19 (4.86)	7.07 (3.11)
					Average Number of Saccades				
Categorical	1.20 (.59)	1.18 (.62)	1.17 (.63)	1.31 (.72)	1.30 (.82)	1.32 (.81)	1.41 (.73)	1.41 (.69)	1.29 (.68)
Near/far	1.64 (.36)	1.69 (.60)	1.96 (.73)	2.61 (1.52)	2.67 (1.12)	2.38 (1.09)	2.14 (.86)	1.99 (.72)	2.13 (.80)
Distance	3.36 (1.53)	3.91 (1.90)	5.32 (2.36)	5.83 (3.19)	6.09 (3.28)	7.24 (3.96)	7.67 (4.24)	8.14 (4.80)	5.95 (3.04)
					Total Time (ms)				
Categorical	449.91	408.08	436.28	392.62	404.48	389.21	389.83	407.39	409.73
	(239.29)	(229.09)	(254.15)	(207.10)	(260.82)	(225.35)	(223.58)	(212.17)	(226.45)
Near/far	674.88	677.24	844.49	1159.64	1164.33	852.95	734.81	640.33	843.58
	(203.72)	(278.38)	(372.72)	(767.14)	(594.74)	(434.32)	(325.58)	(236.55)	(371.14)
Distance	2326.96	2474.78	3133.42	3208.04	3219.34	3588.84	3585.57	3799.54	3167.06
	(1790.06)	(1750.25)	(2140.60)	(2521.19)	(2625.39)	(2692.41)	(2786.07)	(3149.88)	(2385.84)

Note. Distance = distance quantification task. Distance 1-8 = distance of dot from bar.

Mean Fixation Duration

The main effect of Task, *F*(2, 18) = 23.46, $p < .01$, was driven by the longer fixation durations found in the distance quantification task compared to the categorical and near/far tasks, *ts* > 4.73, *p*s < .01. No differences in fixation duration were found between the near/far and categorical tasks, *t*(9) = -1.70, *ns* (see Figure 6.4). If it is assumed that average fixation duration reflects cognitive processing difficulty, these results indicate that processing for the categorical and near/far task was equivalent and reliably less difficult than processing during the distance quantification task. This probably arises because the distance task explicitly required distance estimation, whereas the categorical and near/far tasks did not.

There was also a main effect of Distance, *F*(7, 63) = 3.14, $p < .01$, and Bonferroni corrected comparisons revealed differences between fixation durations for distances 4 and 8, 5 and 8, and 5 and 7; *t*s > 4.61, *p*s < .002. Interestingly, these main effects were not qualified by a Task x Distance interaction, *F*(14, 126) = .99, *ns*. Thus, the effect of task does not appear to be consistently modulated by distance.

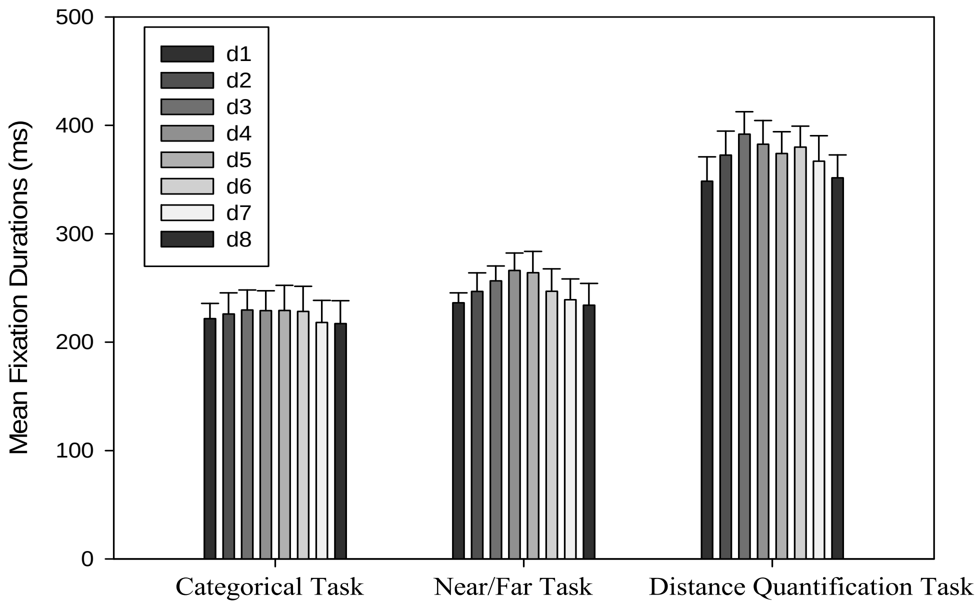


Figure 6.4. Mean fixation duration (and standard error bars) for each distance in all three tasks; d1 – d8 refer to performance distance 1 cm – distance 8 cm.

First Saccade Onset

First saccade onset refers to how long it took participants to move their eyes from the centre of the screen. Saccades less than 2.4 degrees of the visual angle were not taken as an eye movement. There was a main effect of Distance, $F(7, 56) = 11.06$, $p < .01$. Bonferroni corrected comparisons showed significant differences between saccade onsets for distance 1 and distances 4, 5, 6 and 8; distance 2 and distances 7 and 8; and distance 3 and distance 8, $ts > 4.16$, $ps < .002$. This suggests that participants were faster to make a saccade to dots located near to the bar compared to far from the bar.

There was a trend towards a main effect of Task, $F(2, 16) = 3.15$, $p = .07$. Numerically, participants were faster to make the first saccade in the distance quantification task ($M = 168.71$, $SD = 11.90$), than the near/far task ($M = 188.61$, $SD = 48.84$) and were slowest to make a saccade in the categorical task ($M = 185.86$, $SD = 23.76$; see Figure 6.5). The Task x Distance interaction was not significant, $F < 1$.

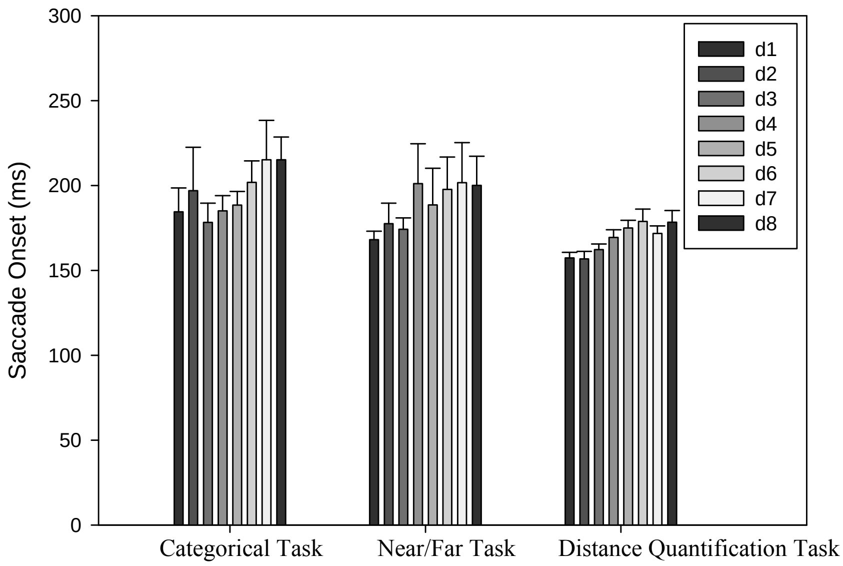


Figure 6.5. Mean first saccade onset (and standard error bars) across distance for each task.

The Location of Fixations

In the introduction, it was hypothesised that patterns of eye movements should reflect underlying cognitive processing (Liversedge & Findlay, 2000; Rayner, 1998). As such, characteristic patterns of where the eyes looked should be found. Thus, the location of the first fixation and the patterns of saccadic movements during trials were analysed.

First Fixation Location

As illustrated in Table 6.3, 69.22% of first fixations landed on the bar, distance 1 or distance 2. In contrast, participants first looked directly at the region in which the dot was located on only 7.02% of trials. This supports the hypothesis that attention is first anchored on a reference point (Kosslyn, 1987) and suggests that participants were most likely to use the bar as a reference point rather than the dot. No differences were found between tasks for the number of times participants looked at the dot, bar, distance 1 or distance 2, *Fs* < 2.61.

Table 6.3

Percentage of First Fixations made in each Task

	M (*SD*)		
Landing position	Categorical Task	Near/far Task	Distance Task
Bar	16.31 (13.78)	13.74 (6.47)	17.62 (11.15)
Distance 1	28.06 (10.02)	37.41 (11.73)	32.83 (7.60)
Distance 2	19.25 (5.43)	20.76 (4.70)	21.68 (4.45)
Distance 3	10.82 (5.90)	11.14 (5.35)	11.97 (6.23)
Distance 4	10.59 (5.00)	8.72 (5.46)	7.57 (6.23)
Distance 5	6.11 (4.65)	4.07 (2.27)	4.97(2.90)
Distance 6	4.30 (2.88)	3.25 (2.66)	2.10 (2.76)
Distance 7	3.52 (3.57)	.68 (1.01)	1.16 (1.36)
Distance 8	1.03 (1.20)	0.22 (.04)	.10 (.31)
Dot	7.75 (6.71)	6.50 (4.00)	6.82 (3.99)

Note. The data refer to trials in which a saccade was made to the stimuli only (excluding those made to the dot).

No Saccade to Stimulus

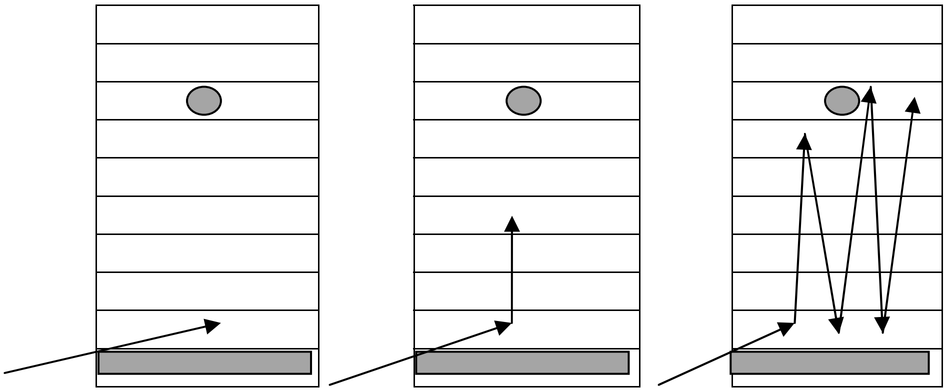
On 26.87% (*SD* = 33.51) of categorical judgements and 6.32% (*SD* =19.17) of near/far judgements participants did not move their eyes to the stimulus, and yet were still able to make a correct response. Thus, it appears that categorical and near/far judgements could (at least on some trials) be made peripherally. This was not the case in the distance quantification task, in which participants always made a saccade from the centre of the screen to the stimulus. This underlines the fact that the distance quantification task appears to be more cognitively demanding than either of the other tasks. Differences were found between the categorical task and both coordinate tasks, *t*s > 2.54, *p*s < .03.

Scan patterns

The patterns of scanning were categorised into seven different types: *No saccade to stimulus* patterns referred to trials in which the participants did not make a saccade to the stimulus and instead remained fixated at the centre of the screen. *Fixations made in a single region* referred to eye movements in which participants stayed fixated in the same distance region (see Figure 6.6A). For example, in these trials one or multiple fixations would be made but critically all fixations were within the same distance region. *Fixations made in two regions with a saccade in between* referred to eye movement patterns in which participants made only one saccade to another distance region (see Figure 6.6B). Again, in these trials one or multiple fixations could be made in the two distance regions, but critically only one saccade was made from one distance region to the other. The first fixation usually fell within the closest regions to the bar, and then the following saccade was made in the direction of the dot (i.e. away from the bar). *Switches* were defined as an eye movement in which the direction of the saccade alternated between towards the bar and towards the dot (like a zigzag pattern; see Figure 6.6C). A *count* was defined as a series of two or more saccades in the same direction that were one or two distance regions apart (see Figure 6.6D). In some trials this pattern was followed by a long saccade back to the start of the count (usually the bar-end), from which the count often started again. *Combinations of switches and counts* were defined as patterns of eye movements which consisted of both switch and count scan patterns (see Figure 6.6E). Finally, *other* referred to any remaining uncategorised trials (see Figure 6.6F).

In all these trials, if multiple fixations were made within the same distance region, for the purpose of classifying patterns, they were included as 'one' fixation. That is, if participants fixated the bar, region 8, region 8, and then the bar, then these trials were included as switches. Similarly, if participants fixated the bar, distance 1, distance 2, distance 2, distance 2, distance 4, distance 5, these were included as counts.

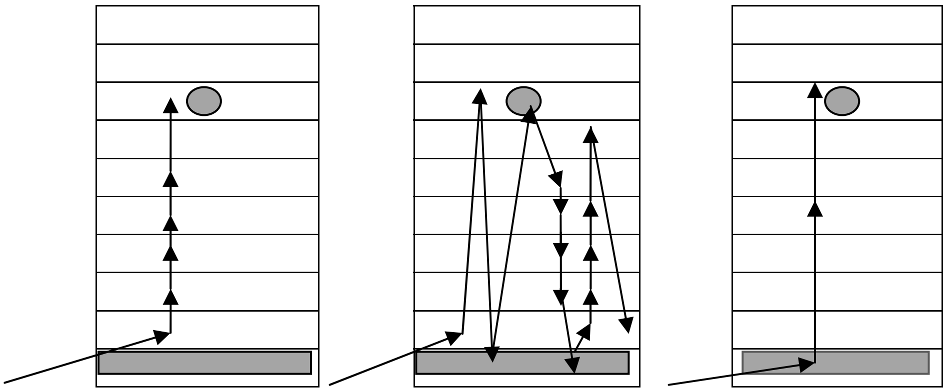
Critically, the patterns of saccades depict saccades made from one interest region to another. It was difficult to discriminate between a switch and a count in distances smaller than 5 cm, hence, saccadic patterns were explored for 5-8 cm only.



A. Fixation in one distance region

B. Fixation in two distance regions

C. Switch



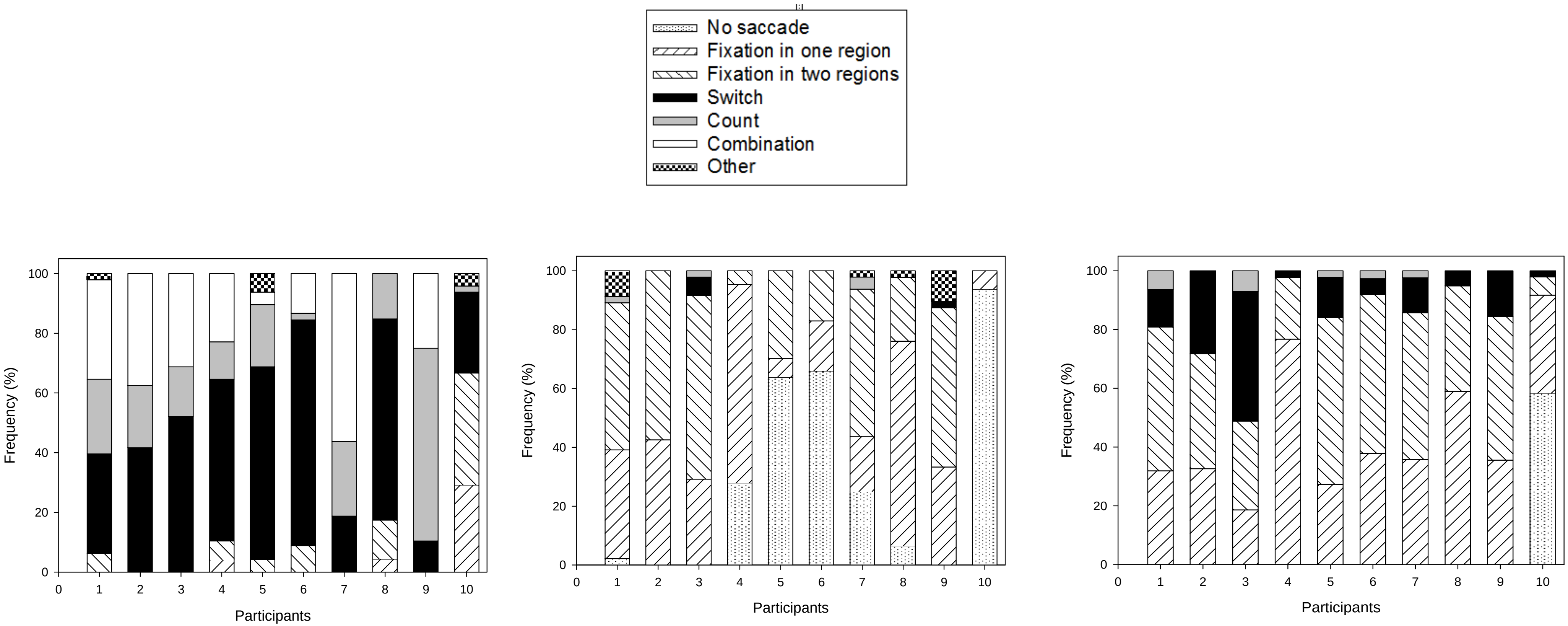
D. Count

E. Combination of switch and count

F. Other

Figure 6.6. Pictorial example of scan patterns. Note that bars and dots were presented in black and the distance regions could not be seen by the participants.

There were two main findings when examining the saccadic patterns. First, there was considerable variability in scan patterns across participants. Second, the saccadic patterns were qualitatively different in the distance quantification task compared to those in the above/below and near/far tasks (see Figure 6.7).



A. Distance Quantification Task

B. Categorical Task

C. Near/Far Task

Figure 6.7. Patterns of saccades on an individual participant basis for each task.

The most striking finding from these analyses was that for the distance quantification task there was a much higher prevalence of switches, counts and combinations than other types of pattern, $t(9) = 5.79$, $p < .01$ (see Figure 6.7A), and this differed from both the categorical and near/far task (ts > 3.51, ps < .01). For the categorical and near/far tasks no saccades to stimulus and fixations in one or two regions were more prevalent than switches, counts and combinations (ts > 7.25, ps < .01; see Figure 6.7B and 6.7C).

On the assumption that different scan patterns reflect qualitatively different cognitive processes (Liversedge & Findlay, 2000; Rayner, 1998), the present data suggest that cognitive processing associated with categorical and near/far judgements is quite similar, and such processing is different from that observed in the distance quantification task. These data also indicate that categorical and near/far judgements do not necessarily entail the computation of precise distance.

6.4 Discussion

The aim of this experiment was to examine the cognitive processes underlying three different VS judgement tasks through recording eye movements. There were two key findings. First, there was a quantitative difference in performance measures when the VS judgement explicitly required distance estimation compared to when a binary above/below or near/far VS judgement was required. The second key finding was that different scan patterns were found during the distance quantification task compared to above/below or near/far VS judgements. Since eye movements reflect cognitive processing (Liversedge & Findlay, 2000; Rayner, 1998), this suggested that qualitatively different cognitive processes underlie distance estimation compared to above/below and near/far VS judgements.

As predicted, categorical above/below VS judgements were made quickly, accurately and with minimal eye movements. Near/far VS judgements were also made relatively quickly and with few eye movements, especially, the trials in which dots were located furthest from the critical distance. Distance estimation was more cognitively demanding, as demonstrated by an increased number of fixations, longer fixation durations and different patterns of oculomotor behaviour. Furthermore, precise distance computation was essential in the distance quantification task, and there was evidence that participants often performed distinct scan patterns when computing distance (e.g.

counts and switches). These patterns were interpreted to reflect that distance was actually being measured in this task.

As hypothesised, for the near/far task, when the dot was located furthest away from the critical distance (i.e. distances 1, 2, 7 and 8), processing resembled that found for categorical VS judgements. That is, responses were fast and with few eye movements. In contrast, and as predicted, in the near/far task, RTs were longer and there were a greater number of eye movements when the dots were located nearest to the critical distance indicating that these trials were more cognitively demanding. Despite this, however, there was little evidence to suggest that participants undertook similar processing to that observed in the distance quantification task. Not only were the RTs, along with number and durations of fixations, greatly reduced in the near/far task compared to the distance quantification task, but also very different patterns of scanning occurred. Specifically, for example, very few distance measuring behaviours (i.e. switches and counts) were observed for this task.

In both the categorical and near/far tasks, the number of fixations made in either one or two regions of the stimuli were much more prevalent. In addition, participants also made above/below and near/far spatial relation judgements peripherally. It, therefore, seems reasonable to conclude that precise distance was not necessarily computed for binary near/far or above/below VS judgements and, as suggested by Laeng and Peters (1995), these judgements can be made following brief visual examination. Critically, both quantitative and qualitative differences have been shown between the distance quantification and near/far tasks, suggesting that the differences in task performance not only reflect differences in task demand, but also differences in the underlying cognitive processes.

Differences in eye movement behaviour were also found between the categorical and near/far tasks. For example, eye movements differed with respect to distance, and, overall, participants made more fixations (and took longer to respond) in the near/far task. However, in line with recent work (e.g., Martin et al., 2008; Van der Lubbe et al., 2006), it would seem that these differences were quantitative and not necessarily qualitative. That is, the increased eye movements and time taken to respond in the near/far trials when the dots were located near to the critical distance may simply reflect increased task demand, rather than different cognitive processes.

In summary, quantitative differences in RTs and eye movements were found between the three VS tasks and these were interpreted to reflect differences in task demand. That is, longer RTs and a greater number of eye movements were found as task demand increased. However, there were also clear differences in the patterns of eye movements found during the distance quantification task compared to both the categorical and near/far tasks. Specifically, above/below and near/far spatial judgements were relatively fast and did not require effortful processing or exact distance information. Conversely, estimating distance was particularly cognitively demanding, and required a precise distance measurement.

In conclusion, the current experiment has provided significant insight into the cognitive processes underlying categorical and coordinate VS processes through the use of eye movement methodology. The key findings indicate that VS cognitive processing that occurs when above/below judgements and near/far judgements are made is often qualitatively different from that which occurs when the task required precise distance estimation. Thus, the results provide evidence to suggest that previously employed near/far tasks may rely on similar cognitive processes as categorical tasks and this may account for some of the inconsistencies of previous research.

Chapter 7
General Discussion

7.0. Outline of Chapter

The structure of this chapter is as follows: Section 7.1 will describe the motivation for the thesis. Section 7.2 will describe the key findings that were considered to be comparatively robust throughout the thesis. Section 7.3 will then describe the results in relation to VF differences. The three research questions set out in Chapter 2 will be revisited in Section 7.4, and conclusions will be drawn. Section 7.5 will then describe the strengths and weaknesses of the thesis before future directions will be discussed in Section 7.6. Finally, closing remarks will be made in Section 7.7.

7.1. Motivation for the Thesis

Kosslyn (1987) suggested that the LH is more efficient at processing categorical VS judgements and that the RH is more efficient at processing coordinate VS judgements. In Chapter 2, it was shown that VS processing declines with age, possibly differentially, and that age also brought about changes in hemispheric processing (see Daselaar & Cabeza, 2002; Dolcos et al., 2002). However, to date, few studies have examined categorical and coordinate VS processing in an ageing population. Thus, the primary research aim set out in this thesis was to investigate categorical and coordinate VS processes in younger and older adults.

Hemispheric dissociation, in terms of a RVF-LH advantage for categorical VS processes and a LVF-RH advantage for coordinate VS processes, has been interpreted to show that categorical and coordinate spatial relation judgements use different VS cognitive processes (Kosslyn et al., 1992). However, the results are not always clear-cut, and there is some debate regarding the importance of task demand in determining these specialisations (see Martin et al., 2008; Parrot et al., 1999; Slotnick et al., 2001). Furthermore, these issues highlighted that the cognitive processes themselves that underlie categorical and coordinate spatial relation judgements have not received a great deal of investigation. Thus, task demand and underlying cognitive processes were also investigated throughout the thesis.

Success in answering the research questions set out in Chapter 2 was mixed. Specifically, the effects of VF lateralisation were not robust and this made it difficult to draw firm conclusions (see Section 7.3). By contrast, other aspects of the results were less ambiguous (see Section 7.2). This chapter will summarise the findings.

7.2. Key Findings

There were four clear findings that have been observed in this thesis. These will now be described.

(i). Younger adults were faster to encode and process information than older adults

The first clear finding was that younger and older adults differed in the time needed to make a response. Specifically, older adults were consistently found to respond more slowly than younger adults. This was regardless of the type of VS judgement being made. Furthermore, in Experiment 3, older adults were not only slower to make a same/different response, but they also spent longer encoding Stimulus 1. This suggests that older adults take longer to encode, process and retrieve information in WM than younger adults. These findings are in line with the generalised slowing hypothesis (Salthouse, 1996).

Interestingly, the SDT analyses did not find any differences between the two age-groups in Experiment 3. This was interpreted to reflect that the underlying processes used for detecting changes in categorical and coordinate spatial relations were the same for younger and older adults. Thus, although older adults were slower to encode and respond than the younger adults, ability to detect changes in spatial relations was similar.

(ii). Categorical spatial relations were processed faster and more accurately than coordinate spatial relations

In each experiment, participants consistently responded more quickly and more accurately when judging a categorical spatial relation than when judging a coordinate spatial relation. This was taken to suggest that processing categorical spatial relations was easier than processing coordinate spatial relations. Specifically, Experiments 1 and 4 showed that participants were faster in the categorical task, less fast in the near/far task and took longest to respond in the distance quantification task. Similarly, in Experiment 2, participants were faster to respond in the categorical task compared to the distance quantification task, and in Experiment 3, participants were faster to respond in the WM task for categorical spatial relations compared to the WM task for coordinate spatial relations.

It is important to note that the longer RTs, higher ERs and increased fixations were suggested to show quantitative differences between categorical and coordinate VS processes that were brought about by differences in task demand. Qualitative differences were also found. These differences will be further discussed in point (iv).

(iii). Distance of the dot from the bar affects performance for coordinate spatial relations

An effect of distance in the near/far and distance quantification tasks has been found consistently throughout the thesis. For the near/far tasks, Experiments 1 and 4 showed that participants were faster and more accurate to judge a distance between a bar and a dot when the dot was located furthest from the critical 4.5 cm distance. More errors were made and RT increased the nearer the dot was located to the critical distance. Indeed, Experiment 4 showed that RT and ER were highest at distances 4 and 5. This was in line with Kosslyn et al. (1992) who suggested that the closer two items are to be related the more difficult it is to discriminate between them. Thus, the closer the dot was located to the critical distance the more difficult it was to discriminate between whether the dot was near to the bar or far from the bar.

For the distance quantification task, Experiments 1, 2 and 4 showed that participants were found to be faster and more accurate when the dot was located near to the bar compared to far from the bar. It was suggested that this was because the scope for error increased with distance. Thus, the larger number of errors and eye movements and the longer RTs found as the distance from the bar increased, were suggested to be quantitative differences that seemed to be brought about by increases in cognitive demand.

(iv). There were aspects of VS cognitive processing that were similar as well as those that were different

To reiterate coordinate VS processes are suggested to require a quantitative expression of distance (Laeng et al., 2003). However, throughout this thesis, it has been argued that it is not clear as to whether participants explicitly compute distance in near/far VS tasks. To be more specific, it has been argued that participants may not necessarily need to compute precise distance before categorising the location of a dot as near or far from a bar. For this reason, it was suggested that above/below and near/far VS judgements may utilise similar cognitive processes. Specifically, in Chapter 3, the possibility that near/far judgements utilised similar cognitive processes as above/below judgements was discussed and a new coordinate task was developed. The distance quantification task was designed to require a precise distance computation on every trial. Thus, it was argued that this task would better capture the precise quantitative and continuous nature of coordinate VS processes than a binary near/far judgement.

For the younger adults, the results of Experiment 1 showed a difference in VF advantage; there was a clear LVF advantage for the distance quantification task, a RVF advantage for the categorical task and no significant advantage in the near/far task. According to Kosslyn (1987), this could be interpreted to be indicative of different cognitive processing systems. However, VF advantages do not necessarily infer functional dissociation (see Section 7.3).

Accordingly, the underlying cognitive processes were directly investigated in Experiment 4, and the experiment conducted was the first to examine patterns of eye movements when making categorical and coordinate VS judgements. Eye movements have been established to reflect moment-to-moment, 'on-line' cognitive processing (Liversedge & Findlay, 2000; Rayner, 1998). Thus, the use of this methodology allowed for greater insight into whether the underlying cognitive processes for different VS judgements were qualitatively distinct, as is suggested, and allowed investigation of the extent to which precise distance computation is required in order to make a near/far spatial relation judgement.

The eye movement data established that the cognitive processes underlying distance estimation were very different than the cognitive processes used for above/below and near/far judgements. Specifically, the results demonstrated that above/below and near/far judgements were fast, reflexive processes, whereas, precise distance computation was comparatively cognitively demanding. Critically, however, the differences in behavioural and eye movement data across tasks were not just quantitative and brought about by differences in task demand. The different scan patterns and locations of fixations showed that there were also qualitative differences. Specifically, as predicted, the scan patterns found in the distance quantification task indicated that distance measuring behaviours occurred within this task. That is, participants were found to either count out the distance in small units, or shifted attention between the bar and the dot, fixating the points at the extreme ends of the distance to be evaluated in order to form a representation of the total distance between these points.

These distinct measuring behaviour patterns were not found to the same extent in the above/below task or the near/far task. To be more specific, very few distance measuring behaviours (i.e. switches and counts) were observed for these two tasks (especially in comparison to the distance quantification task) and instead participants made more fixations in one or two regions and on some trials did not have to make a saccade to the bar-dot stimuli. It, therefore, seems reasonable to conclude that precise distance was not necessarily computed for near/far or above/below VS judgments. Furthermore, in line with Van der Lubbe et al. (2006) and Martin et al. (2008), the results found suggest that the differences between the above/below and near/far tasks in terms of RTs, ERs and number of fixations and saccades seem to be quantitative rather than qualitative. Together these findings were taken to imply that similar cognitive processes may be utilised to make above/below and near/far spatial relation judgements, at least in some situations, and that these processes are qualitatively different from those that underlie distance estimation.

In Experiment 3, the SDT analysis provided insight into whether categorical and coordinate same/different judgements were underpinned by perceptual differences in processing. Specifically, it was argued that if *d'* differed between tasks then this would indicate that there were true differences in the underlying VS processes. The results showed that participants were more sensitive to detecting changes in categorical spatial relations than coordinate spatial relations, suggesting that different processing strategies were employed when encoding coordinate spatial relations compared to categorical spatial relations.

In summary, these results suggest that the cognitive processes underpinning above/below and near/far judgements were similar. By contrast, the results suggest that the cognitive processes underpinning distance estimation were different from those underpinning above/below or near/far VS judgements, and the cognitive processes used for same/different categorical and coordinate VS judgements were also different. Moreover, these results suggest that researchers investigating categorical and coordinate VS processes should be cautious to infer that VF differences are indicative of qualitatively different VS cognitive processes, especially when the coordinate tasks require a near/far judgement. The effects of VF will be further discussed in Section 8.3.

7.3. Visual Field Advantages

When first undertaking this thesis, the motivation for Experiments 1-3 were very much driven by the idea that VF effects would relate to hemispheric specialisations. This assumption is in line with previous work, and this is why the terminologies used in Chapters 1-5 describe VF advantages in terms of LH and RH specialisations. However, it is fair to say that throughout the duration of writing-up these experiments my perspective regarding this topic has changed somewhat. Thus, before the VF results are discussed, it is probably pertinent to be clear about my views on hemispheric specialisation and VS processing.

First, I do not dispute that information presented in one VF initially arrives in the contralateral hemisphere (e.g. see Van der Lubbe et al., 2006). However, quickly this information is transferred to the ipsilateral hemisphere, and it is well established that processing subsequently occurs via activation in both hemispheres. Neuroimaging research provides a reasonable case for suggesting that different patterns in brain activation are due to different types of information being processed. Furthermore, these different patterns of activation may reflect that different types of cognitive process are being undertaken (see Wager & Smith, 2003). However, visual half-field studies do not permit examination of the actual neural networks and areas of the brain activated, and consequently, inferring that differences in relative processing speed or accuracy when stimuli are presented in one VF or another are caused by different neural and functional changes may be questionable. To be more specific, it is a big assumption to make that advantages found in visual half-field studies map on to hemispheric specific neural networks. Furthermore, as mentioned throughout this thesis, even if they did, different hemispheric advantages do not necessarily relate very directly to qualitatively different types of cognitive processes. Therefore, it may be unwise to conclude from the experiments in this thesis that categorical and coordinate VS processes are hemispherically designated.

It is important to note that the effects of VF have been inconsistent both in relation to the different experiments presented in this thesis as well as to the predicted advantages. For this reason it has been difficult to interpret some of the results found. Post-hoc accounts have been considered, however, given that they are complicated and rely on assumptions that have not been directly assessed in the experiments presented, any conclusions drawn on the basis of these results should be treated with caution. Clearly, presenting stimuli on either side of a fixation cross does affect processing. The effects of presentation lateralisation found with younger adults and older adults in the present experiments will now be summarised and considered.

Throughout the thesis younger adults have consistently shown a Task by VF interaction. In Experiments 1 and 3, younger adults showed an overall advantage for the categorical task when the stimuli were presented in the RVF and in Experiment 2 a RVF advantage was found when the dot was located far from the bar. By contrast, an advantage was found for the distance quantification tasks in the simple visuo-perceptual tasks in Experiments 1 and 2 when the stimuli were presented in the LVF, whereas no advantages were found when distance did not necessarily have to be computed (near/far task and same/different coordinate task). Accordingly, for the younger adults, the three visual half-field studies were consistent with Kosslyn's (1987) theory of asymmetry in that they were faster to make categorical VS judgements when the stimuli were presented in the RVF and were faster to make coordinate VS judgements when the stimuli were presented in the LVF.

For the older adults, a Task by VF interaction was only found in Experiment 1, in which there was an advantage for the categorical task when the stimuli were presented in the RVF and an advantage for the distance quantification task when the stimuli were presented in the LVF. When task demand was manipulated in Experiments 2 and 3, no significant advantages were found were found in the categorical tasks. Thus, the older adults' data were in line with Kosslyn's (1987) theory of asymmetry only in Experiment 1. From these age-group summaries, two additional key findings can be stated:

(v). Presentation of stimuli in the LVF and RVF influenced VS cognitive processing

Presenting stimuli on different sides of the fixation point clearly affected cognitive processing and relative advantages were found. What is particularly interesting is that there was an overall LVF advantage in the *d'* analyses. Given that differences in *d'* are suggested to be indicative of different processing strategies it can be argued that participants use different processing strategies when processing information from different VFs. Furthermore, if it is assumed that LVF advantages relate to RH advantages, then this finding is in line with the idea that processing VS information is more predominant in the RH compared to the LH.

(vi). Younger and older adults showed similarities and differences for the effects of VF

In Experiment 1, the same VF advantages were found with the younger and older adults; there was a RVF advantage for the categorical task, a LVF advantage for the distance quantification task, and no VF effect for the near/far task. However, in Experiments 2 and 3, differences emerged. Specifically, in contrast to the younger adults, the older adults did not show a Task x VF interaction in these experiments, and the VF advantages for categorical VS judgements found with the younger adults were not significant with the older adults. This can be taken as evidence to suggest that with age changes occurred in the nature of categorical VS processing. This may be due to compensatory mechanisms utilised to overcome age-related decline.

7.4. Research Questions Revisited

Three research questions were set out in Chapter 2. As mentioned in Section 7.1, the success in answering these questions was mixed. Specifically, it was difficult to interpret some of the differences found between younger and older adults, especially those that involved VF differences. In addition, it was difficult to determine the importance of task demand. A more tangible conclusion was drawn with regards to the underlying cognitive processes for categorical and coordinate VS judgements. Each research question will now be revisited and conclusions drawn.

1. How does Age Affect Categorical and Coordinate VS Processing.

In Chapter 2, two theories of hemispheric ageing were outlined; the HAROLD model and the right hemi-aging hypothesis (see Daselaar & Cabeza, 2004; Dolcos et al., 2002). It was anticipated that the categorical-coordinate paradigm would reveal that the effects of presentation lateralisation found with younger adults would not be found with the older adults, and that age-related decline would be more pronounced in coordinate VS processes.

In Experiments 2 and 3, younger adults showed a Task by VF interaction whereas older adults did not. If it is assumed that VF differences map on to neural processes, the results in Experiments 2 and 3 found some evidence in line with the HAROLD model. This can be interpreted to suggest that hemispheric specialisation for categorical and coordinate spatial relation judgements reduces with age, and arguably, activation is instead spread across the two hemispheres. However, to reiterate, this interpretation should be treated with caution.

With respect to differential decline, in line with Hoyer and Rybash (1992), Experiments 1 and 2 showed no evidence to suggest that coordinate VS processes decline disproportionately with age. Instead, when participants had to estimate distance and judge between four spatial categories, older adults showed disproportionate age-related RT decline for categorical VS processes. In Experiment 3, when RT for encoding Stimulus 1 was taken into consideration, the age-related difference in RT for Stimulus 2 was diminished for the categorical task, but not for the coordinate task. However, this finding probably was due to task demand, as there was no clear LVF-RH advantage for the coordinate task nor was there a Task x Age-Group interaction. Furthermore, the SDT analysis showed no differential age-related differences in processing categorical and coordinate spatial relations. Thus, the series of experiments conducted in this thesis were not in line with the right hemi-aging hypothesis.

2. How does Task Demand Affect Categorical and Coordinate VS Processing?

It has been suggested that categorical and coordinate effects of VF are caused by differences in task demand rather than by differences in the nature of the VS processes per se (see continuous spatial code Martin et al., 2008). The aim of this thesis was to investigate the effects of task demand on VF advantages. Specifically, it was predicted that high demand tasks would produce a LVF advantage.

There was no compelling evidence to suggest that higher task demand induces LVF-RH advantages. However, the patterns of performance across VFs were found to be dependent on two factors. First, VF advantages were found to be dependent on the type of spatial relation judgement being made. Specifically, coordinate VS processes were consistently found to be more challenging than categorical VS processes, and the effects of VF differed between these two tasks. Second, effects of VF were also found to be dependent on the distance of the dot from the bar. However, it is not readily apparent whether these effects of VF were caused by different task demands, and further experimentation is required in order that a more comprehensive evaluation of such effects can be obtained.

3. How do Cognitive Processes that Underlie Categorical and Coordinate Spatial Relations Differ?

The current experiment provided significant insight into the cognitive processes underlying spatial relation judgments. Specifically, the results indicated that SDT and eye movements were informative with respect to cognitive processes underlying VS judgments and provided insight into aspects of VS processing that were similar, as well as those that differed between tasks. There were two key findings from the eye movement experiment. First, a quantitative difference in RT, ER and eye movement measures was found when participants were required to estimate distance compared to a when participants made a near/far judgements. Similarly, there was a quantitative difference in RT, ER and eye movement measures when participants were required to make a near/far judgement compared to when they made an above/below judgement. The second key finding was that different scan patterns were found during the distance quantification task compared to both the above/below and near/far judgment tasks. Since eye movements are suggested to reflect cognitive processing (Liversedge & Findlay, 2000; Rayner, 1998), this suggests that qualitatively different cognitive processes underlie distance estimation compared to above/below and near/far VS judgments. The SDT analyses also suggested that same/different categorical and coordinate judgements were underpinned by different processes. In conclusion, the results showed both quantitative and qualitative differences between cognitive processing of different VS tasks.

7.4. Strengths and Limitations

The research presented in this thesis has several strengths. In Chapter 1, three gaps were identified in the categorical and coordinate literature; namely, ageing, task demand, and the underlying cognitive processes, and the series of experiments conducted in this thesis tried to address these issues. Specifically, the research was motivated by theories of hemispheric ageing and the categorical and coordinate paradigm allowed these specific hypotheses to be investigated. Thus, the current experiments have provided a detailed examination of categorical and coordinate VS processing in younger and older adults.

Novel methodologies, tasks and statistical analyses have also been employed. For example, this research is also one of only a handful of empirical studies that have specifically developed and administered a new coordinate task. Indeed, not only was the distance quantification task developed in Experiment 1 but the box-bar paradigm was also developed in Experiment 2, to investigate the effects of task demand. Additionally, the SDT analyses employed in Experiment 3 has also only been used in one published study regarding categorical and coordinate VS processes to date and Experiment 4 was the first to examine eye movements associated with spatial relation judgements. Importantly, these methodologies were used to provide insight into the cognitive processes underlying categorical and coordinate VS judgements and to assess whether these cognitive processes were qualitatively different. The results found suggest that SDT data and eye movement data may provide a more informative analysis than RT data only, and this is something that should be considered in future work. Thus, this thesis has used innovative task designs and scientific methodologies to try to gain further insight into categorical and coordinate VS processes.

The novel aspects of the tasks developed in this thesis came with design limitations. In particular, the type of response given in the distance quantification task and the different units used by the two age-groups caused problems for the data analysis and subsequent interpretation. Allowing participants a choice of unit also meant that there were discrepancies between the age groups. Younger adults used cm while the older adults chose inches. This then caused problems in comparing and interpreting the results. That is, the use of different units could be considered a confound in the results, however, it is questionable as to whether this confound could have been avoided.

The distance quantification coordinate task was designed to reflect the continuous distance element of coordinate VS processes; however, this increased the chance for error. Furthermore, there was a number of ways in which the estimate data could be marked as correct; if the participants estimated the exact distance, if the estimate was within .5 of a unit, within 1 unit, as a proportion of the estimate, and so forth. Under each margin of error the percentage ER changed, and had knock-on effects for the analysis of the ER and RT data.

It must also be noted that no overall differences in VF effects were found with the ER data. This is in contrast to previous research in which it is usually reported that the same findings are observed with both RT and ER data. The lack of an advantage in the categorical tasks is likely to be caused by the extremely low ERs obtained for this task throughout the thesis. However, the reason for the lack of an advantage in the coordinate tasks is less clear. Thus, in contrast to previous work, the conclusions drawn from the results of the current series of work mainly came from the RT responses.

Finally, the last point is more a caveat rather than a limitation, but it is an important point to be aware of nonetheless. To reiterate, throughout the thesis inferences have been made about the neural networks underlying performance. However, as mentioned in Section 7.3, visual half-field studies do not permit direct examination of the areas of the brain activated, these inferences are to be treated with caution, and would need further experimental examination in order to be validated.

This raises important issues regarding the employment of visual half-field methodologies to assess categorical and coordinate VS processes. Visual half-field studies have been used a great deal in this type of research; however, they only examine the relative performance of each hemisphere, and it is difficult to ascertain why VF advantages are not always significant. With the advance in technology over recent decades, imaging techniques and other methodologies, such as eye movement techniques, are now available that can provide a more, online account of VS processing. Consequently, recent work has begun to utilise these methodologies. This will be further discussed in the following section.

7.6. Future Directions

Throughout this thesis it has become evident that there are two very clear directions for future research with respect to categorical and coordinate VS processing. To date, categorical and coordinate VS processing research has received a great deal of attention with respect to the neural networks employed and hemispheric specialisations displayed. However, the studies in this thesis have highlighted that the precise cognitive processes that are involved in categorical and coordinate spatial judgements are unclear. As such, future research should, perhaps, move away from investigating hemispheric specialisations associated with categorical and coordinate VS processes and, instead, focus on the cognitive processes involved in spatial relation judgements. With this in mind, methodologies should be employed that permit greater discrimination between underlying cognitive processes. For example, eye movements along with measures of brain activity, such as electroencephalograms or ERPs would provide complementary data into the cognitive processes used and would provide insight into the time course of processing by allowing moment-to-moment recordings of online cognition. Additionally, these techniques used in an ageing population would provide further insight into how VS cognitive processes change with age.

Additionally, although investigating categorical and coordinate VS processes under simple laboratory conditions allows manipulation of specific variables and provides a basis from which to derive working hypotheses, the results may not generalise to everyday life situations (as many studies have shown; e.g. Arbuckle, Cooney, Milne, & Melchior, 1991; Channon & Crawford, 2001; Uttl & Graf, 1993). As such, research into categorical and coordinate processes should focus more on ecologically valid tasks, and should be applied to cognitive tasks that occur in daily life.

7.7. Closing Remarks

In summary, the four experiments presented in this thesis provided significant insight into categorical and coordinate VS processing. Specifically, the results of this thesis have shown that there are aspects of categorical and coordinate VS processing that are similar, as well as those that differ. The results found have shown that VF advantages for categorical and coordinate VS processes are not consistent, are difficult to replicate, and unexpected findings are difficult to interpret. This is especially true when investigating younger and older adult populations. The SDT analyses and eye movement data provided further insight into whether there were differences underlying the cognitive processes used to make categorical and coordinate VS judgements. The results demonstrated both quantitative and qualitative differences in cognitive processing for categorical and coordinate VS judgements. Categorical and coordinate VS processing is an interesting paradigm to investigate the effects of ageing, and future research should focus more specifically on investigating the cognitive processes required in spatial relation judgements.

Appendix

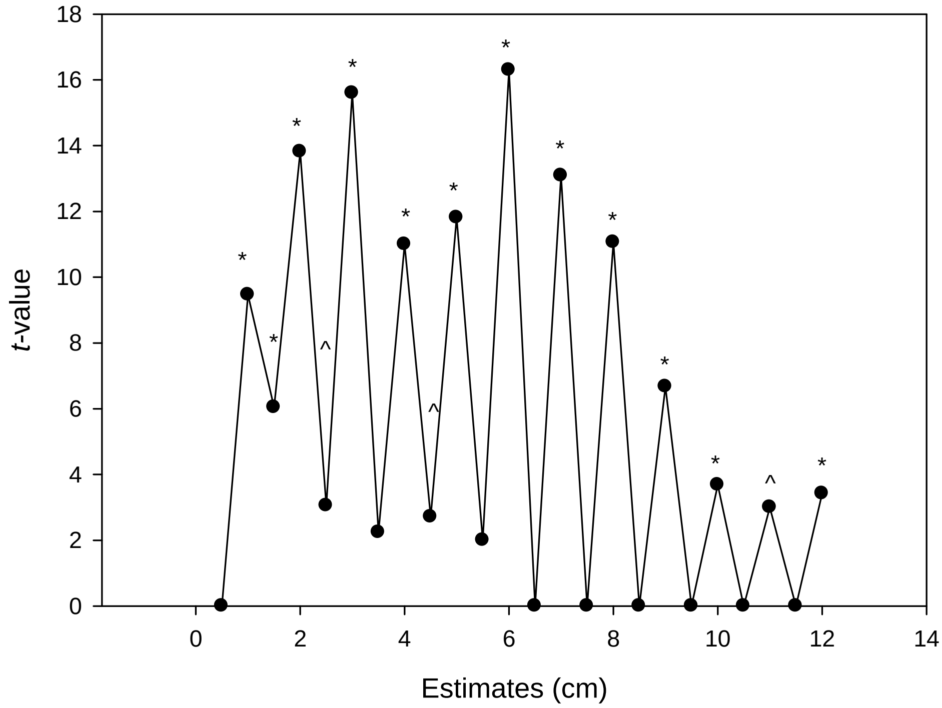


*Figure A1***.** Figure to show comparisons of the frequencies by which participants estimated distance (in cm) in Experiment 1.* = $p < .01$; ^ = $p < .05$; A *t*-value of 0 = insufficient frequencies to make a comparison.

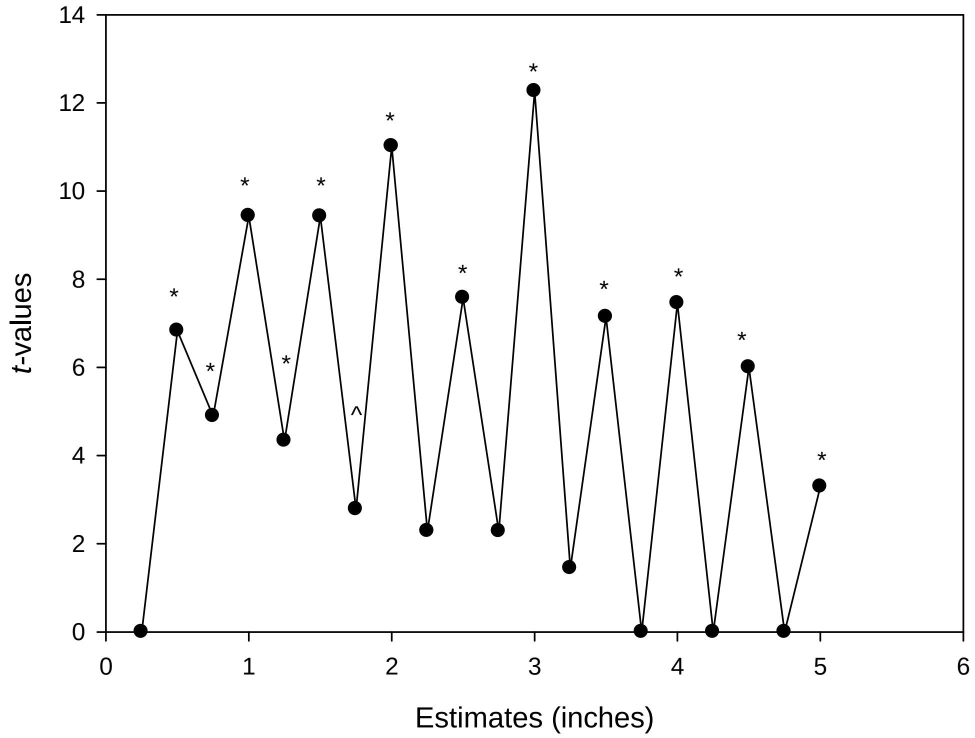


*Figure A2***.** Figure to show comparisons of the frequencies by which participants estimated distance (in inches) in Experiment 1.* = $p < .01$; ^ = $p < .05$; A *t*-value of 0 = insufficient frequencies to make a comparison.

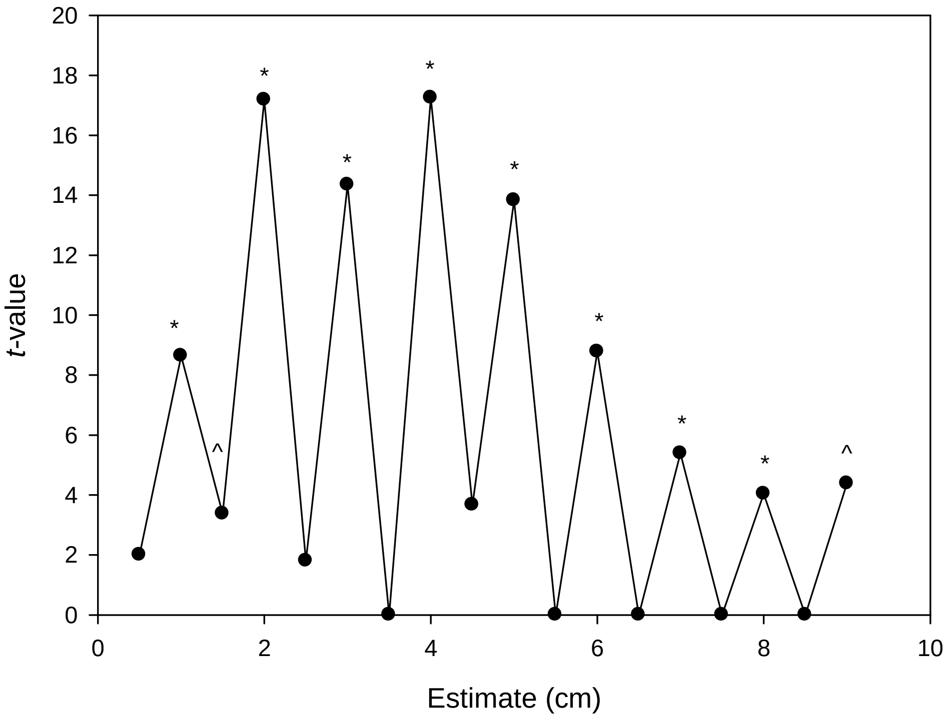


*Figure A3***.** Figure to show comparisons of the frequencies by which participants estimated distance (in cm) in Experiment 2.* = $p < .01$; ^ = $p < .05$; A *t*-value of 0 = insufficient frequencies to make a comparison.

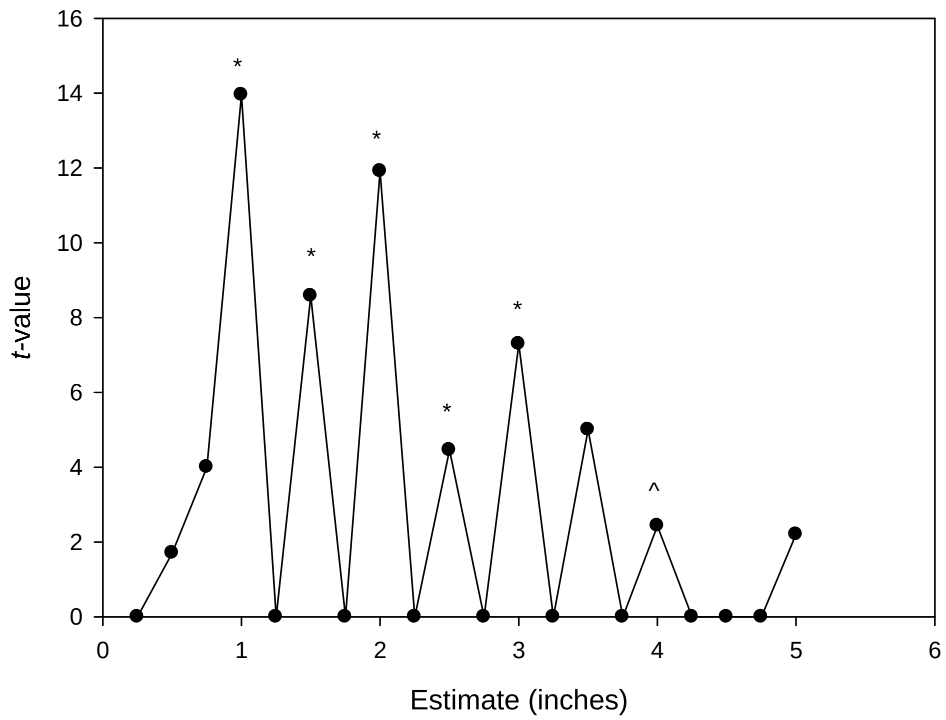


Figure A4. Figure to show comparisons of the frequencies by which participants estimated distance (in inches) in Experiment 1.* = $p < .01$; ^ = $p < .05$; A *t*-value of 0 = insufficient frequencies to make a comparison.

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