# The role of expertise, semantics, and learning in spatial memory

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# Dedications

This body of work is solely dedicated to my mum, my dad, my brother, and my amazing ‘partner’ - thank you

# Acknowledgements

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**Abstract**

This research investigates the mechanisms that underpin object location memory. It approaches this endeavour by examining a recently reported phenomenon of spatial memory, that of exclusivity. Exclusivity states that given the opportunity to encode or retrieve two spatial memories, only one memory is relied upon for object location. This implies that two memories for where an object is located are not better than one. The role of limited capacity has been implicated in the exclusive processing of multiple objects. Accordingly, the aim of this thesis is to explore possible methods that enhance cognitive capacity in a way to overcome exclusivity. These methods include expertise, semantics and learning. It was proposed that expertise would allow for holistic processing of information and it would therefore increase the likelihood of spatial memory integration. Also, the connection between two related spatial memories was manipulated through the employment of semantic categories to aid in paired memory recognition. In addition to this, a learning paradigm was used which allowed for repeated exposure of spatial information over a 5 and 10 day period. The results of these studies indicate a failure to overcome exclusivity. This suggests that exclusive processing is a robust feature of spatial memory. The findings offer a number of important insights for the field. They provide two important accounts for the processing of multiple object locations. One argues memories are encoded and retreival in a strategic manner to avoid interference. The second proposes fragments of memories are encoded and constructively drawn upon at recall. This thesis also puts forward a unique explanation of how multiple object locations are learnt over time.

# Chapter 1

# Introduction

Thinking about space is integral to numerous aspects of psychology. Space defines many features of our world, a good illustration comes from the domain of music, with a musician's ability to interpret musical scores. Anyone who has knowledge of sight-reading would not contest the importance of space intrinsic to music production. Just as notes provide the user with the necessary indicator of tone, space provides the time in which each note should be played. Thus, without the capacity to translate notes into melody, via spatial interpretation, there would be no music. This analogy of space can be generalised to everyday life, and when it is, the importance of space becomes more conspicuous. To treat space purely in terms of physicality is over simplistic and does not reflect the interaction of experience and meaning with space.

We live surrounded by space and as a consequence have developed many biological and cognitive mechanisms that allow us to thrive whilst constrained by physical and spatial boundaries. Representing space allows one to navigate and to locate essential objects. The fluent and easy manner in which we rely on an understanding and knowledge of space conceals the complexity of the processes inherent within it. Regardless of place or time each person has the ability to access with little effort a spacial 'picture' regarding familiar surroundings. For example, we are all able to transverse the route to work, the location of our office, or the relative position of countries and continents on the planet from memory. Thus, the primary focus of this research pivots on a fundamental question of psychology, *how do we build coherent representations of space?*

The structure of this introduction reflects the scientific endeavours that guide the current research. To understand the processes that underlie the construction of a representation of space, one must first interrogate the findings that illustrate what form such representations may take. Thus, the first part of this introduction reviews the literature describing the organisation of spatial representation in memory. Specifically, it focuses on the components that make up such representations and how these result in certain biases. Inevitably the final product of processing spatial information (i.e., a coherent accessible representation of space) will be influenced and determined by the mechanisms that are involved with its construction. Therefore, the second part of the introduction reviews the evidence on factors that influence the way spatial information is encoded, retrieved and interact. Specifically, it centres on questions concerning whether spatial information is encoded automatically, whether it is retrieved in parallel or serially, and finally whether it is integrated or combined. The second part of this introduction is crucial because it offers insights into possible areas of limited capacity when processing spatial information.

## 1.1 Representing space mentally

The first part of this chapter highlights research which has sought to probe spatial memory regarding how information may be organised. It begins with the idea that one constructs a cognitive map of the environment and that such a map-like structure contains within it certain components which can result in memory distortions. This leads onto the next section which focuses on components of cognitive maps such as landmarks and routes and again, highlights how distortions are intrinsic to the representation of such features mentally. The final section reviews the research which has focused on the individual's role in constructing a mental model of space; specifically, that involving viewing perspective and orientation.

### 1.1.1 Cognitive maps and distortions

When thinking of spatial memory one nearly always thinks of maps. There is an intrinsic view derived from the idea that the manner in which humans reconstruct reality externally (e.g., ordinate survey map) in some way must reflect how they would represent it mentally. To a certain extent this is grounded in some evidence (Wilson & Wildbur, 2004) and is certainly always a logical starting point. However, as psychology repeatedly informs us, there is a big difference between reality and how the mind reconstructs reality. One only need refer to visual spatial illusions such as the Ponzo (train tracks) lines to illustrate how distortions are incumbent within the visual system, yet markedly informative. Despite the fact spatial judgement can be an accurate process (Jonides & Baum, 1978; Baird, 1979), estimation of object distance and location has been shown to suffer systematic error. The studying to such errors has led to insights as to the structure and organisation of spatial information.

Considered the forefather of ideas about conceptual cognitive maps, Tolman (1948) theorized that possessing a cognitive map of ones environment is highly adaptive. When referring to cognitive maps Tolman (1948) was not making any aspersions that reality is encoded as a geographical map, rather he was simply stating that certain elements of our spatial environment are represented mentally, and in a way that affords us to achieve many of the daily activities we do not even stop to consider. What Tolman (1948) argued was that rats, and by extension possibly humans, navigated their environment not simply by representing a collection of singular routes (A to B, A to C etc) but rather they held much more global conceptualisations of their environment. Intuitively, this sparked some researchers to contest that spatial information is stored as a holistic representation of metrically retained spatial relations (Kosslyn, Ball, & Reiser, 1978), rather like a mental image. However, to regard such mental representation as the internal drawing of a map has shown to be doubtful.

Some of the first works on how individuals represent geographical locations comes from Stevens and Coupe (1978). They found that geographical locations can be represented either superordinately or subordinately with regards to other geographical locations. For example, Stevens and Coupe (1978) found that individuals tended to misjudge the city of Reno as being farther west than the city of San Diego, when in fact Reno is further east. They attributed this bias to prior knowledge of the state location that each city resides, Reno being situated within the state of Nevada and San Diego in that of California. The relations of these states is contradictory to that of the two cities, in other words, Reno (Nevada) is located further west of San Diego (California) however the majority of the state of Nevada is situated further west than California. Therefore individuals' higher level representation for the positions of the states was interfering (or superordinate) to their judgements as to the locations of the cities.

This kind of research shows that such forms of spatial information as geographical locations are layered and more specifically are represented in a hierarchical manner determined by scale of space. The consequence of this hierarchy leads to the observations of spatial estimation errors on the part of the individual. These errors were regarded by Stevens and Coupe (1978) to stem from a storage computation trade-off where superordinate spatial information dictates location estimates for elements that fall within and below 'higher' categories. This suggests that actual geographical locations of cities may be grouped in mnemonic clusters determined by higher-order spatial information (i.e., the state within which the city is located). The presence of memory bias is a consequence of an ineffectiveness to 'communicate' hierarchically across clusters. Thus, individuals are able to draw on higher or lower order spatial information depending on the query. In some cases the query may draw on higher order information producing an error related to a lower order spatial position. This suggests that cognitive maps are fragmentary and not integrated and people switch between levels of representation in the hierarchy.

The processes of spatial clustering is argued to be an effective memory strategy which generally is useful for spatial judgement (i.e., in the majority of cases cities in California *will* be farther east than comparable cities in San Diego). More importantly, these findings demonstrated that space, rather like verbal information (Jonides & Baum, 1978; Baird, 1979), is represented abstractly rather than literally (i.e., not metrically) and in a fragmentary manner.

Hirtle and Jonides (1985) argued that cognitive maps possess more than simple spatial proximity. They showed that not only can spatial components be organised by geographical clusters but also by subjective clusters imposed upon geographical layout. Additionally, dependent on the kind of cluster imposed (e.g., whether groups of buildings were related or unrelated by function) would dictate the direction of location estimation bias (overestimation and underestimation respectively). The directions of the distortions were such that individuals tended to recall locations closer together if they were from the same spatial cluster than if they were from different clusters. This finding was replicated and extended by McNamara (1986) who additionally showed that directional judgement (i.e., whether an object was to the left or right of another object) was also biased by superordinate spatial relations between clusters.

Chase (1983) shows complexity of hierarchical structures is dependent upon levels of knowledge regarding locations. He found experienced taxi drivers to have far more detailed hierarchical organisation of area within which they worked in comparison to novices. This shows that knowledge and experience are importance factors determining the formation of spatial hierarchies. Hirtle and Mascolo (1986) enforced semantic barriers within a spatial array and found that semantically defining objects within a cluster can in turn produce 'mental clustering'. Furthermore, mental clustering by way of semantics also produced similar distortion effects.

The above evidence is quite compelling and strongly highlights the existence of cognitive structures which have an impact upon the manner in which spatial information is stored and subsequently recalled. One dominant organisation of spatial information is hierarchically. It appears that the spatial components of separate perceptual experiences are not necessarily organised in separate perceptual units[1] but are rather stored in a hierarchical fashion dependent on the geophysical structure intrinsic to the spatial array, subjective interpretation of geophysical structures, and pre-existing spatial or semantic knowledge.

### 1.1.2 Reference points, landmarks and distortions

The location of an object is intrinsically relative. One must quantify the position of an object in relation to that of something else. Stemming from the perception literature researchers showed that individuals rely heavily on landmarks in their environment to find their way and conclude that spatial knowledge is built up through the perception of distinct environmental features (i.e., landmarks) (Allen, Siegel, & Rosinski, 1978; Siegel & White, 1975). Thus, it is not surprising that perceptual structures such as reference points are also present in stored spatial representations, observed during the recalling of spatial information. Consequently, much work has been focused on this area (Bryant & Subbiah, 1994; Lindberg & Garling, 1987; Nelson & Chaiklin, 1980; Schmidt, Werner, & Diedrichsen, 2003; Sheth & Shimojo, 2001; Sadalla, Burroughs, & Staplin, 1980).

Landmarks are a fundamental feature that organises spatial information and it is clearly used to the benefit of spatial location judgements from memory (Allen et al., 1978; Siegel & White, 1975; Blaisdell & Cook, 2005). For example, as the number of landmarks increase so too does the precision of an individual's spatial memory (Blaisdell & Cook, 2005). However, a number of authors have contended that the dominant manner in which landmarks are relied upon can lead to systematic recall distortions (Holyoak & Mah, 1982; Nelson & Chaiklin, 1980; Tversky, 1992). For example, Sadalla et al. (1980) asked individuals to judge the distance between pre-measured salient landmarks and other points of reference. Subjects systematically judged distances between landmarks and non-landmarks to be smaller than between either two non-landmarks or two landmarks. Rosch (1975) also found that distances between locations in a city and salient landmarks result in asymmetry in terms of perceived distance between such objects.

Although, certain biases are evident with the recalling of spatial information in

[1] Although it is recognised that psychological clustering can be the result of perceptual boundaries (McNamara, Hardy, & Hirtle, 1989), the majority of authors have emphasized that such clustering is a consequence of memory structure above all else.

relation to a landmark it has also been shown that such biases can be systematic and predictable. For example, Nelson and Chaiklin (1980) showed that location accuracy increases as the distance from a border or reference point decreases. They argue that Weber's Law can account for this phenomenon in that the size of the just-noticeable difference (jnd) (i.e., the difference between stages of exposure to sensory stimuli) is directly proportional to the absolute magnitude of the judged spatial quantity. In other words, as the difference between one spatial location and another increases so does the level of error embedded within a spatial judgement regarding said location. More importantly, Nelson and Chaiklin (1980) examined the 'type' of distortion that occurred and demonstrated that the direction of distortion was systematically biased towards a given landmark rather than away from it. Based on these findings they propose five postulates that make up a weighted-distortions model of landmark biases: [2]

> Postulate 1: The further away a target is from a landmark the less accurate spatial judgement is
>
> Postulate 2: The direction of distortion is toward the landmark
>
> Postulate 3: The magnitude of the direction-of-distortion effect is dependent upon the distance from the landmark
>
> Postulate 4: In a multiple-landmark situation, the weight (W) for each landmark's spatial-distortion effect decreases with further distance from the landmark
>
> Postulate 5: In a multiple-landmark situation, the weight (W) for each landmark's spatial-distortion effect is directly proportional to viewing time

Just as previous work shows that *subjective hierarchies* can impose a structuring of spatial information (Hirtle & Jonides, 1985), similarly individuals may subjectively impose *subjective landmarks* too. Bryant and Subbiah (1994) demonstrated that individuals segregate regions of space and the categorical boundaries of such segregation are used as points of reference in order to localise and narrow the position of a target object in space. Subjective landmarks also show the same bias patterns (namely attraction bias) as that of physical landmarks.

Schmidt et al. (2003) suggest that object location biases are determined by the nearest landmark and that such bias is 'locally invariant' with the introduction of an additional landmark. They suggest that if two landmarks are present then the direction and magnitude of recall bias is dependent on the nearest landmark.

[2] Several of these postulates have been both supported and developed by subsequent work (Bryant & Subbiah, 1994; Lindberg & Garling, 1987; Lansdale, 1998)

To account for this they propose a *partition principle* for dual-landmark presentations where distortion sources are derived from two separate single-landmark distortions rather than the combining of two distortions into a different distortion pattern. They argue that the combined effect of two-landmark distortions cannot be estimated by each single landmark's distortional field. (Schmidt et al., 2003) also argue that the apparent landmark attraction bias may actually be a 'virtual landmark' repulsion bias. In other words, the creation of a virtual landmark biases object location away from that landmark giving the impression of it's attraction to a nearby actual landmark. Components of this finding have been replicated (i.e., virtual landmark creation), although the majority of evidence is in favour of general landmark attraction (Nelson & Chaiklin, 1980; Bryant & Subbiah, 1994; Hubbard & Ruppel, 2000) as opposed to virtual landmark repulsion.

Lederman and Taylor (1969) extend landmark attraction to boundary attraction. They demonstrated that visual and tactile perception of the location of a point in rectangular field is biased toward the boundary of the field. This suggests that borders or boundaries of visual arrays can act in a similar manner as single reference points. Having said that, Okabayashi and Glynn (1984) shows that complex curved boundaries are less predictable and showed that the shapes of boundaries have varying effects on types and degree of bias.

In summary, the research shows that individuals attribute a landmark-type function to certain elements in their visual field. These elements, known as landmarks, are important to the recalling of an object's location. Overall, landmarks generally improve recall by offering a point of reference from which a relative location judgement can be made, they may also introduce certain biases (namely, an attraction bias where an object is recalled closer to the landmark than it was). Individuals choose what to make a landmark or not (Tversky & Schiano, 1989). This may be determined by it's proximity to a to-be-remembered object (i.e., the closer the landmark the more accurately an object is recalled), comparative size to other landmarks, or subjective importance to a target object.

### 1.1.3 Orientation and perspective specificity

As described above, space must be defined in relation to something else. Such reference can be either relative to another object (allocentric) or relative to the perceiver (egocentric). For example, the whereabouts of a bowl of fruit may be judged in relation to the table it has been placed upon (e.g., it is in the top right-hand corner) *or* relative to the individual who is perceiving the bowl of fruit (e.g., it is diagonally to the left of me). A large body of work has examined the role of the perceiver and specifically the orientation from which a spatial array is positioned in relation to oneself (Shelton & McNamara, 1997; Diwadkar & McNamara, 1997; Mou & McNamara, 2002; Bryant & Tversky, 1999; Franklin & Tversky, 1990; Wang, 1999).

Orientation has been described as the alignment of environmental perception and knowledge (i.e., memory) regarding spatial components in that environment (Peruch & Lapin, 1993). It is well documented that humans (as well as animals) show preference for certain stimuli arrangements and such preferences can impact upon spatial location estimation. For example, the estimation of a stimulus position is much improved when stimuli are arranged vertically or horizontally (as opposed to oblique angles), known as the 'oblique effect' (Appelle, 1972). Much research has examined whether a preferred direction of orientation is apparent in memory representations.

Evans and Pezdek (1980) suggested that when an environment is primarily learned through a map, it allows for relationships between items to be formed as a single perspective. However, when the environment is primarily learned through direct experience such relations are only accessible via the number of perspectives that they have experienced. This notion is supported by a number of findings. Bisiach (1988) showed that individuals with unilateral neglect were only able to imagine perspectives related to the non-neglected side. For example, those with left side neglect when asked to imagine facing north in a familiar environment could only reproduce perspective regarding east oriented stimuli. This suggests that when individuals reconstruct space they do so by accessing a viewer-dependent representation of space rather than a global viewer-independent representation.

Further evidence comes from studies where participants are tested for their recognition of a spatial array either from an experienced perspective or from a novel perspective. For example, Shelton and McNamara (1997) asked participants to memorise a spatial array comprising seven objects in a room from two orthogonal viewpoints. They were then taken to a different room in a different part of the building and were required to recall said object from either a viewpoint that matched the originally learnt perspective, or a viewpoint that was incongruent. They found participants' responses were faster and had greater accuracy from a representational viewpoint that was in line with their initial coding perspective. Shelton and McNamara (1997) argued this was evidence that individuals form egocentric viewpoints that equate to a 'mental image' of a spatial scene. Also, they argued that retrieval of spatial locations from memory is achieved simply by retrieving the encoded visual image. Diwadkar and McNamara (1997) demonstrated the same findings employing a similar paradigm and concluded that interobject spatial relations are also coded and therefore represented in a view-point dependent manner. They proposed that when participants make judgements from novel views (i.e., different than at encoding), they must normalise such a view to ‘fit’ with the encoded view.

Together Shelton and McNamara (1997) and Diwadkar and McNamara (1997) findings suggest that the quality of judgement for an object’s location is highly dependent on access to an initially encoded spatial representation. This implies that representations of space are limited to perceptual experiences; that is, one has greater difficulty making a location judgement from a non-experienced viewpoint of an object. However, this is not to say that individuals are completely precluded to making a judgement from a novel view only that it is less accurate. Just as Diwadkar and McNamara (1997) propose, individuals probably try to manipulate (e.g., mentally rotate) the encoded view to fit the novel view (or vice versa), with some location information being lost among the process of doing so.

Later research challenges the idea of egocentrically dominant spatial representations and shows that recalling an object’s location may not be solely dependent upon it’s relation to the individual (i.e., egocentric). For example, Shelton and McNamara (2001b) manipulated the geometric structure of a room by varying the viewing angle. A square mat was laid out in a square room with to-be-learnt objects placed on it. Subjects were then asked to learn an object array from two stationary view-points. The viewpoints included face-on to the mat (i.e., inline with the mat and the room at 0°) and from the point of the mat’s corners (i.e., misaligned with the geometry of the room and mat at 135°). Thus, if spatial information was coded in an egocentric-dependent manner, then one would expect to observe greater memory accuracy as long as the participants’ encoding and recall viewing angles were consistent, regardless of whether they were aligned or misaligned with the room and mat. Shelton and McNamara (2001b) found that when individuals made relative spatial judgements from a misaligned view-point (i.e., congruent with the initial egocentric representation) they performed just as poorly as judgements made from any other misaligned view, even those they had not learnt the objects from. This striking finding highlights that individuals had only represented one dominant view of the objects’ spatial layout - *inline* with the ‘natural’ structure of the room. In other words, benefits from retrieving spatial information were only evident if the egocentric representation was inline with dominant geometric features that make up the frame of reference within which the objects are bound. This suggests that egocentric (object to person) and allocentric (object to object) frames of reference are both implicated in the recalling of an object’s location.

Subsequent findings support and refine such a notion. Shelton and McNamara (2001a) used a circular room and showed that in the absence of intrinsic allocentric frames of reference (i.e., the frame of a square room) egocentrically learnt views were again preferential. For instance, if an individual learnt the room from 135° they would be better at recalling objects' locations at that viewing angle than any other. It would appear that without the presence of an intrinsic frame of reference, egocentric frames are utilised.

Although it is evident that both allocentric and egocentric frames of reference can be employed, Mou and McNamara (2002) showed that employing an allocentric frame of reference tends to be more accurate. Specifically they showed that performance tended to be better for a novel but allocentrically aligned heading, than a familiar view from direct egocentric experience. Subsequent work examining eye movements shows patterns at encoding and test both reflected movements similar to intrinsic allocentric reference directions. This firstly strengthens the argument that intrinsic geometrically-defined frames of reference are dominant, but also shows that one's eye movements and thus attention focuses on allocentric reference frames at encoding and similar motor-actions are subsequently employed at retrieval (Mou, Liu, & McNamara, 2009).

However, Burgess (2006) posits that whether or not egocentric or allocentric frames of reference are dominant is determined by the nature of the task. Burgess (2006) highlights that the effectiveness of egocentric representations is apparent at small distances and with few locations. However, as such factors increase so does cognitive computation. As one moves through their spatial environment the calculations of object-to-object locations increase dramatically because judgements are represented in relation to one's position egocentrically. Therefore each person-to-object location alters. However, if one is able to hold an allocentrically-defined representation then the only new source of information required for processing is that of one's own position. Thus, a perspective-independent representation is much more efficient and capable of accessing an entire familiar spatial representation from multiple novel view-points, whereas an egocentrically-defined system is strictly limited to *a priori* view-point experience. Burgess (2006) suggests egocentric and allocentric representations must therefore coexist.

Some research is in line with the ideas of Burgess (2006) and argue that whether egocentric or geocentric (i.e., allocentric) dominance is present may itself be dependent on additional factors. Presson, Delange, and Hazelrigg (1989) proposed that spatial information can be represented in functionally different ways. They hypothesized, similar to Shelton and McNamara (1997), that if viewpoints were orientation-specific (i.e., viewpoint-dependent) one would expect more errors to be present when a test view differed from the view in which the spatial content had been encoded. Likewise, if the test view was the same orientation as the learnt view then one would expect fewer errors in location judgements. The experimental set-up for Presson et al. (1989) involved varying the size of a map from 2ft to 12ft and then having subjects learn the map from a specific view-point. They then tested the participants' memory accuracy for routes on the map from either the learnt view-point (aligned) or from a different view-point (contraligned). After controlling for scale transformation effects (i.e., difference in map scales), instructional sets, and referent space size, they found that biases from the contraligned view-point were significantly reduced as the map size increased. This suggests that under certain conditions the representation of spatial information is less constrained to a particular viewing perspective and thus reflective of orientation-free representations.

The evidence indicates that as individuals move through there environment or have to deal with larger and more complex spatial arrays they rely on allocentric and therefore more viewpoint-independent representations Burgess (2006); Presson et al. (1989). However, it remains unclear whether viewpoint-dependent dominance is simply a consequence of the limited number and variety of viewing perspectives employed in previous work. In an attempt to encourage the development of viewpoint-independent representations Shelton and McNamara (2001a) offered subjects additional views of a room layout. They hypothesized that with more learnt viewing perspectives individuals may develop a more coherent representation and thus be able to make accurate judgements from novel perspectives. In fact, they showed this not to be the case. Additional experiences did not overflow to non-learnt perspectives, suggesting individuals had independent representations, one for each learnt view. This suggests that the development of allocentric and thus viewpoint-independent representations of space may not simply be the result of multiple and different egocentric representations of a visual array.

Waller and Hodgson (2006) building on the work of Wang and Spelke (2000) and Burgess, Spiers, and Paleologou (2004) advocate a dual-system representation of space. One system is concerned with tracking relations between the perceiver and objects in the visual field. It is therefore egocentrically orientated, relatively precise, and temporally constrained. They argue that it remains in the mnemonic system for short periods of time after initial visual input. Due to it's precision, if it is available it is a preferred choice for the perceiver. However, in the case of uncertainty individuals may switch to a second less precise but more enduring system anchored in long-term memory. If sensory information is reintroduced then reliance can again switch back to an egocentric view. This idea has been echoed in other work which attempts to consolidate viewpoint-specific and viewpoint-free representations (Waller, 2006). Presson et al. (1989) theorise that integrated viewpoint-free spatial information and orientation-specific information may be available flexibly. They also argue that integrated conceptualisations are likely to stem from long-term memory representation compared to viewpoint-dependent ones that are related to perceptual processes. The corollary of this would mean allocentric systems are continuously mediated by egocentric input from perceptual and short term memory processes (Burgess, 2006).

The overall evidence seems to suggest a difference in reference frame dominance dependent upon whether the task involves on-line or off-line processing. On-line processing of spatial information is subject to transient 'snapshots' of spatial relations determined by self-to-object encoding (egocentric). In comparison, off-line processing relies on a more enduring representation defined by object-to-object relations (allocentric) and is viewpoint-free. Although the evidence is building for orientation-free representations of space it is evident that certain egocentric and allocentric perspectives are employed to a great deal in everyday processing of spatial information. However, the majority of research on this area has tended to focus on relatively short-term spatial constructs (Wang & Spelke, 2000; Shelton & McNamara, 1997; Mou, McNamara, Valiquette, & Rump, 2004; Shelton & McNamara, 1997). It is yet to be established the consequences of long-term learning on one's reliance on viewpoint-free representations. Research suggests that dealing with large scale spatial arrays where movement is involved would be the most likely environment to encourage the development of enduring and coherent mental representations of spatial (i.e., where separate representations have been integrated). Arguably, such situations where repeated exposure is involved (i.e., a familiar environment) are the ones where multiple long-term viewpoint-independent representations are developed as opposed to short-term perceptual experiences (e.g., Shelton & McNamara, 2001a).

## 1.2 Models of spatial memory

There have been a number of important model and research developments within the field of spatial memory. All have attempted to describe observable findings drawn from individuals' reports of object location, each with subtle nuances in method and accountability. There is a clear dual-component approach to spatial coding according to the majority of proposed models. One component is concerned with fine-grain, coordinate, metric-type properties of an object's location and refers to the precise location of an object. The second is concerned with the category, frame, and 'rough' location of an object and refers to the proximal location of an object (Huttenlocher, Hedges, & Duncan, 1991; Lansdale, 1998; Kosslyn, 1980; Bryant & Tversky, 1999).

### 1.2.1 Categorical-coordinate model

Kosslyn (1987) proposed a categorical-coordinate model in which he theorized there to be two distinct subsystems involved in the computation of categorical and coordinate spatial information received from the senses. Coordinate representations specify the location of an object in terms of a precise metric (e.g., the magazine is 5cm from the edge of the coffee table), whereas categorical representations are more global quantifications and place an object within a framework (e.g., the magazine is on the coffee table). Under this theory, it was hypothesized that separate neural networks should be responsible for each form of processing.

Some empirical work has supported this notion, mainly showing that the left hemisphere shows advantage for categorical spatial relations whereas the right hemisphere for coordinate estimation (Kosslyn, 1987; Kosslyn et al., 1989; Kosslyn, Thompson, Gitelman, & Alpert, 1998; Hellige, 1989). It is argued because such subsystems are discreetly different in terms of computation (i.e., categorical and coordinate information processing), each subsystems dominance will be dependent upon the task. For example, initially one may need to recognise roughly where an object is (i.e., on the coffee table [categorical processing]), then when action is required (i.e., grasping [coordinate processing]) one will need more local and metric-driven information. Thus, a functional difference exists between the two systems. The coordinate system guides action and the categorical system recognises shapes (Borst & Kosslyn, 2010). Sergent (1991) logically states that coordinate information must contain within it some relative information such as a frame of reference, implying that coordinate and categorical information may not be entirely independent as first thought by (Kosslyn, 1987). Some evidence has emerged to support such a notion of interconnectedness (Bruyer, Scailquin, & Coibion, 1997; Niebauer, 2001). This evidence seems to reflect established ideas of hierarchical storing of spatial information (Stevens & Coupe, 1978). Thus, fine-grain coordinate information is stored at a lower level of a hierarchy to that of categorical information.

### 1.2.2 Categorical adjustment model (CAM)

Huttenlocher et al. (1991) proposed the categorical adjustment model (CAM). This model can be likened to that of Kosslyn's (1980), but in addition it is able to account for numerous biases observed in the spatial memory system which imposes its own cognitive structure on the information received from the visual system. Huttenlocher et al. (1991) also propose a dual-systems account of human spatial processing. They argue there are two levels of encoding an object's location. First, an object is encoded in terms of fine-grain information. This relates to a representation in memory regarding the absolute unbiased location of an object, that is not to say the exact location of the object, but rather an unbiased encoded representation. Second, an object is coded with regards to a bounded region termed by Huttenlocher et al. (1991) as a 'category'.

According to Huttenlocher, a general example of fine-grain and categorical information can be likened to that of a piece of orange cloth. The orange cloth itself considered as a category, which consists of a range of specific shades considered to be fine-grain information. This can be generalised to the spatial domain where a spatial display may be coded in terms of bounded sections (category) at particular coordinates (fine-grain). The model also assumes each category possesses some kind of preferred (in the sense of memory structure) typical location where an object is most precisely remembered (i.e., unbiased). The prototypical location in the Huttenlocher et al. (1991) examples is considered to be a central location (i.e., the centre point of a categories boundaries). Shifts toward typicality can be seen elsewhere in the literature such as Belli (1988), who demonstrated memory for an artificially coloured object will shift towards the usual colour of the object. Likewise, Neuberg and Fiske (1987) found that when attention is compromised, judgements of people are bias towards stereotypical categories.

According to the CAM, a distribution of estimated biases is observed when an object is located outside of its typical position. Hence, as long as categorical and fine-grain representations are encoded exactly and aligned, no bias is present in an individual's response (although the estimation may still be inexact in terms of the object's absolute location, just exact in terms of where they remember it to be). However, when categorical and fine-grain representations are misaligned there is a level uncertainty ingrained within the representation and therefore individuals make an estimate as to an object's location and consequently bias is observably introduced.

According to the model, bias stems from two possibilities. First, because recall is made up of the fine-grain information *and* the typical or preferred location according to the category, a weight-average estimate is calculated which resides somewhere between the two representations. The degree to which it is weighted towards either is dictated by the level of precision within each source of information. If the source of information relating to an object's coordinate location (fine-grain information) is less precise than that relating to the typical location (given the categorical boundaries) then recall estimation will be biased towards the more precise source (i.e., towards the typical location of the category). The opposite bias is assumed if it is weighted (more precise) for fine-grain information. The second basis of estimation comes from the fact space is represented in terms of divided categories and as such boundaries are imposed upon the representation. This means overlap with other categories' boundaries is possible when the object is located close to a category boundary. Thus, when fine-grain information is inexact and near to a boundary the distribution of possible values will be truncated causing a shift in reporting towards the centre of the category. Huttenlocher et al. (1991) refer to these two sources of bias as *prototype effects* (see above) and *boundary effects* respectively.

There is much empirical evidence to support such a model of spatial memory bias (Huttenlocher, Newcombe, & Sandberg, 1994; Huttenlocher, Hedges, & Vevea, 2000; Huttenlocher, Hedges, Corrigan, & Crawford, 2004; Huttenlocher, 2008), illustrated most cogently in a series of experiments where participants were asked to remember the location of a dot in a circle (Huttenlocher et al., 1991). Response patterns provided strong evidence that participants were actually dividing the circle into quadrants (categories) and the centre point of these quadrants acted as a prototype or preferred response location. Additionally, the weighting of uncertainty between fine-grain and categorical information led to predictable patterns of bias that were extremely well accounted for by their proposed quantitative model.

### 1.2.3 Hybrid encoding of location memory model (HELM)

Lansdale (1998) proposed the hybrid encoding of location memory (HELM) model. Amongst other things, this model introduces an elegant method of quantifying spatial memory and allows for the independent specification of response bias. The model utilises confusion matrices as the basis of analysing the recall of spatial information. Lansdale (1998) argued that this form of quantifying spatial memory is far more powerful and informative than previous abstracted statistical analyses (see Chapter 2 for a more detailed account). The HELM model assumes two forms of encoding necessary to account for location recall performance - exact and inexact. The model offers certain advantages over previous models. Primarily it allows for the analysis of exact and inexact recall under one model. It also enables the modelling of responses biases that may be unique to a set of stimuli. Lansdale (1998) shows clear evidence that the encoding of location specifies varying representations which contain degrees of inexactness. Just as in Huttenlocher et al. (1991), each encoding of location generates a mostly symmetrical distribution of inexactness around the exact location.

HELM proposes three processes in the recalling of location information. One component of a spatial representation is exact memory, without error and commensurate precision. An example of this might be to estimate an objects location in terms of a broad direction or location (e.g., 'over to the left' or ' in the living room'). The second component is inexact recall which assumes that memory for an object is represented inexactly. This inexactness is manifest as a response in and around the target location. HELM assumes equal strength in memory of inexact traces and as a consequence the distribution of possible responses is uniform around the exact location. HELM then models the probability of encoding such a response and the clustering of responses around the correct location. The third component deals with the possible biases that may be present in responding to a spatial array on a continuum (i.e., left-right linear spatial array - which is typically employed when fitting the HELM model), where some responses are more likely than others.

Essentially HELM states that memory is encoded with a level of precision and that level of precision will determine the distribution of possible responses drawn from memory. Lansdale (1998) distinguishes between exact and inexact in terms of bias and contends (similar to Huttenlocher et al., 1991), only inexact memory is subject to response bias. This is a central theoretical tenet of the model and separates exact and inexact as unique psychological processes, whereby exact recall is an all-or-nothing process and inexact recall is a spectral process. [3]

### 1.2.4 Intrinsic-reference and spatial-framework model

Two models have been developed with similar objectives in mind. The intrinsic-reference model (Mou & McNamara, 2002; Mou et al., 2004) and the spatial-frame-work model (Bryant & Tversky, 1999; Franklin & Tversky, 1990) both sought to establish the representation of space with the perceiver in mind, compared to other models which focus on the interaction of encoding specifications related to singular or inter-object representations.

[3] The experimental design employed for the testing of HELM is heavily utilised in the current research and it is therefore further discussed detail in Chapter 2

The intrinsic-reference model has been developed by Mou, McNamara and colleagues (Mou & McNamara, 2002; Mou et al., 2004; Shelton & McNamara, 2001b; Mou, Fan, McNamara, & Owen, 2008; Mou et al., 2009) and aims to explain discrepancies in memory performance where recalling objects' location from some matched egocentrically established representation perform is no better than novel viewpoints. The work is borne from early findings which showed a clear preference for egocentric-dominant reference frames (Diwadkar & McNamara, 1997; Shelton & McNamara, 1997, see section on Oriention specificity). Later findings were incompatible with simple egocentric-viewing preference and instead Mou et al. (2008) extended the idea of frames of reference to focus on inter-object representations. The basic premise of the model is that the alignment of one's memory representation with either an initial egocentric viewing perspective or geometric frames of reference intrinsic to a room layout (e.g., borders or object arrangements etc.) will determine the quality of spatial judgements from memory. The model is quite clear that egocentric viewing perspective is subordinate to geometric frames of reference. The model has also been generalised whereby object locations are coded in relation to 'intrinsic reference directions'. According to the model, preferred reference choice can be determined by many intrinsic factors including the geometry of the spatial array, perceptual organisation of interobject relations, instructions, and alignment of egocentric viewing perspective and spatial layout (Mou et al., 2009; Mou & McNamara, 2002) .

The spatial-framework model (Bryant & Tversky, 1999; Franklin & Tversky, 1990) shares multiple similarities with the intrinsic-reference model and arguably is attempting to explain the same findings. The model proposes that space is encoded in terms of the relation of the body to a spatial array and retrieval of encoded information is dependent on the congruency of such relations. Evidence where participants would construct spatial representations from verbal descriptions, showed there to be a preference to encode things in a 'front/back' fashion in relation to one's body and an 'up/down' fashion when in relation to the environment. Additionally, memory retrieval times reflected that when other axes in the spatial array where confounded with either body-dominant or environment-dominant axes, advantages were observed for either axes over any other. However, when body-dominant axes and environment-dominant axes were confounded body axes were typically relied upon. As a consequence of these findings, Franklin and Tversky (1990) have proposed that body axes are employed as frames of reference for the encoding of objects in space. According to this model, the availability and salience of egocentric axes is dependent on perceptual and functional components of the body and environment. This is in contrast to the intrinsic-reference model that proposes environmental structures to be dominant.

However, there have been some recent findings which weaken the theoretical assumptions of the spatial-framework model. Quite interestingly when Mou et al. (2004) (see also Avraamides & Carlson, 2003) used arrows to indicate a directional location of objects instead of verbal instructions (e.g., 'left of...', 'right of..') the spatial-framework model did not hold. They subsequently concluded that spatial-frameworks are not a result of spatial memory organisation and representation but rather originate from discrepancies in interpretation and therefore processing of directional language. Further support for this comes from Avraamdes and Sofroniou (2006) and Avraamides and Carlson (2003).

Each model attempts to account for specific aspects of spatial memory. Each has sought to tackle some very different yet necessary questions with regards to how representations of space are developed, function and relied upon. One singular model that explains how the relations between objects and landmarks, between objects and local frames of reference, local frames of reference and global frames of reference, and all of such relations with regards to the observer's perspective, locomotion, and prior knowledge is still a distal accomplishment. When considered in such sobering terms the realisation that no single model can account for all scientific directions of endeavour is not entirely surprising. However, some general consensus and enduring aspects are emerging from dual-components accounts which focus on the interaction of fine-grain and more global location processing. In comparison other models have placed the perceiver at the centre of the debate and argued for the importance of geometric frameworks which are ingrained in one's environment. The lacuna between these perspectives is an understanding of how the two relate to one another. In other words, how individuals integrate fine-grain and categorical information into frames of reference and in turn, how frames of reference are integrated into coherent models of space.

## 1.3 The neurological foundations of location memory

### 1.3.1 What & Where (How) systems

Neurological findings add some support to the evidence derived from behavioural insights. Postma, Kessels, and van Asselen (2004) posit there to be three functional steps to remembering where something is located. First, the object of interest must be recognised. Second, its location in space must be specified, and third, the object's identity and its location must be combined. Initial evidence for the first two propositions comes from Milner and Goodale (1995) who found the presence of two distinct neuronal 'streams' within the brain, both of which originate from the visual cortex and can be generalised as consisting of a 'what' and 'where' functionality.

One stream partitions out through the occipitotemporal cortex to the anterior of the inferior temporal cortex, with an extension to the ventrolateral prefrontal cortex and is known as the *ventral stream*. Damage to this area typically results in an inability to visually recognise objects. The processing of object identity in the ventral stream is reasonably well established in the literature (Kravitz, Saleem, Baker, Ungerleider, & Mishkin, 2013). However, the second stream which stretches to the parietal lobe, known as the *dorsal stream*, has been challenged as simply dealing with 'where' information. In fact, the intricacies of both streams are more complicated than originally conceptualised by Milner and Goodale (1995).

Evidence now suggests that the ventral stream deals with object identity and object quality information. It has been implicated in processes such as habit formation, long and short-term memory, reward, and value (Kravitz et al., 2013). Reflective of these processes the ventral system involves the representations of stable and enduring features of visual information, rather than relations that are specific to a particular array of objects.

More contradictory to the original 'what'/'where' system (Milner & Goodale, 1995) is a reconceptualisation of the dorsal (i.e., 'where') stream into a 'how' system. Research now shows that the dorsal stream stretches from the early visual cortex to posterior regions of the parietal cortex. This is known as the *occipitoparietal circuit* and consists of the parietal-prefrontal pathway (which deals with eye movement and spatial working memory), parietopremotor pathway (which deals with representation of visual coordinates relative to body position [necessary for visually guided action in space]), and the parieto-medial temporal pathway (which is specialised for processing distant space and space in a object-centred reference frame - arguably an element of navigation).

Although these two areas were originally thought to mostly be independent of one another it is now thought both are capable of spatial processing (Milner & Goodale, 2008) and in fact communication along the entirety of the streams is more likely (Webster, Bachevalier, & Ungerleider, 1994). For example, the ventral stream provides information needed to represent landmarks where as components of the dorsal stream provide spatial information for their relative position (useful for navigation) (Kravitz, Saleem, Baker, & Mishkin, 2011; Kravitz et al., 2013). These types of information are thought to be integrated around the hippocampal regions. Additionally, both pathways receive information from the front eye fields, suggesting eye movements initiated by one stream may activate the other (Kravitz et al., 2013).

In terms of egocentric and allocentric processing it is possible that each occur in both streams, although categorical (view-point dependent) specifications of space may be confined to the left hemisphere and coordinate (viewpoint-free) to the right (Kosslyn, 1987). Recent findings by Niebauer (2001) go further and suggest that categorical encoding may represent a preliminary step in specifying space with more precise coordinate processing following.

In summary, the ventral system seems to deal with object identity and quality informaiton on a more conscious level and the dorsal system is involved with visually guided action, navigation and spatial working memory on a more unconscious level.

### 1.3.2 Neuronal maps

The above neurological findings are predominately related to perceptual processing of spatial information but there is also much evidence with regards to the mnemonic processes that occur with spatial information. O'Keefe and Nadel (1979) introduced the idea of *the hippocampus as a cognitive map.* In doing so they theorised that via patterns of neuronal firings the hippocampus constructs a map-like structure of the spatial environment. There is now building evidence that supports this concept (O'Keefe & Dostrovsky, 1971; Hafting, Fyhn, Molden, Moser, & Moser, 2005; Burgess, Jackson, Hartley, & O'Keefe, 2000; Solstad, Boccara, Kropff, Moser, & Moser, 2008; Taube, 2007).

The first piece of evidence comes from O'Keefe and Dostrovsky (1971) who discovered the existence of a neuron that would only fire when the organism was in a particular location and that location alone. When in another location the neuron would fall silent. These neurons are known as place cells (O'Keefe & Dostrovsky, 1971). A series of additional cells have since been discovered including grid cells (Hafting et al., 2005), border cells (Burgess et al., 2000; Solstad et al., 2008), and head-direction cells (Taube, 2007). The functions of these cells can be seen to mimic what has been observed in various behavioural experiments.

For instance, place cells are involved with coordinate or fine-grain information regarding spatial locations. Border cells are closely related to informing a place cell when or when not to fire and represent frames of reference intrinsic to the place cell's firing field (Burgess et al., 2000; Solstad et al., 2008). Grid cells form equilateral triangular shapes of firing patterns and the combination of many different grid cells form a nexus of firing patterns allowing for navigation via metric representations of space (Hafting et al., 2005). Head-direction cells have shown to be sensitive to the head-direction of the perceiver, namely, that a particular head-direction cell will only fire when the individual is facing a specific orientation. The anatomical locations of these cells are mainly limited to the hippocampal regions including the entorhinal cortex (Burgess et al., 2000). The striking predictability of how these unique cells' behaviour has led to a group of researchers being able to predict the precise location of an individual within a virtual environment purely on the basis of their brain's neuronal firing patterns (Hassabis et al., 2009).

In agreement with behavioural work regarding preferred lines of axes (Franklin & Tversky, 1990; Bryant & Tversky, 1999; Sholl & Nolin, 1997), evidence from neuroscience shows that axial perceptual preference may well be attributable to neuronal structuring in the brain. Appelle (1972) demonstrated a perceptual preference for horizontal and vertical organised visual arrays. This has been supported with evidence from neuroscience with the recording of fewer neuronal units located in the oblique angles than in vertical or horizontal axes (Li, Peterson, & Freeman, 2003).

## 1.4 Automaticity of coding spatial information

Owing to the clearly abundant nature to which humans process and rely on spatial information for a large majority of tasks, it begs the question as to whether spatial information is coded automatically or requires some degree of effort. This is very important to examine because a large body of research shows a direct relationship between the amount of effort required to process information and the level that one attends a stimulus, and one's subsequent memory performance (Craik & Lockhart, 1972; Lozito & Mulligan, 2006). Relating this back to the question of how we build representations of space, the ease with which we are able to process spacial information is an important component of the building process.

Hasher and Zacks (1979) laid forth a number of cardinal conditions that must be met in order to determine whether an input source is processed automatically. The five criteria they set out are as follows: i) Whether one attends a stimulus or not (intentional vs incidental exposure) will only affect a process if it is not automatically encoded; ii) instruction of how one should carry out an automatic task should not result in any performance change; iii) interference of tasks with other operations will have little impact upon automatic processes; iv) anything that impacts attentional capacity (affective or otherwise) should not reduce task performance if the process is automatic; v) one would not expect to observe developmental changes (once they have been established from early childhood) in performance for automatic processes.

Some research provides evidence that the coding of spatial information is in line with Hasher and Zacks (1979) criteria (see Mandler, Seegmiller, & Day, 1977; Ellis, 1990, 1991). However, in response to the methodological weaknesses apparent in previous work (e.g., Mandler et al., 1977), Naveh-Benjamin (1987) conducted one of the first experiments that considered quantification of spatial memory itself; working under the premise that only once spatial memory performance could be measured appropriately could its automaticity be tested. The approach taken regarded spatial memory ability to be on a continuum, where a representation could be anywhere from completely accurate to including degrees of inexactness (see Chapter 2 of this thesis for a more detailed overview). Naveh-Benjamin (1987) set up five experiments each to address one aspect of Hasher and Zack's (1979) criteria. The results are contradictory to earlier work and suggest spatial coding does not fit with criteria set out by Hasher and Zacks (1979) to substantiate automaticity.

Taken together research provides evidence that the processing of spatial information either involves little effort (Ellis, 1990, 1991) or alternatively involves some degree of effort Naveh-Benjamin (1987, 1988). A point that is illustrated very nicely by these types of contradictory findings is that each approach are attempting to make generalisations to the processing of *all* spatial information. However, it is clear that such generalisations are not congruent with either both examinations of the evidence, or the sheer complexity and variety of the tasks spatial information is used for. It is logically inevitable that some tasks will require the employment of spatial information in a very precise and necessary fashion in order to carry out certain tasks successfully. In contrast, some tasks will require little or no information regarding the spatial element. For example, if one were presented with one object in a room it is likely that one will recall the location of that object regardless of instructions or attention. However, if one were to be presented with three objects in the same room one would arguably have to employ more attention in order to recall the three objects as precisely as one had previously with a single object. This is not to say that one form of spatial processing is more automatic than the other, only that varying levels of effort (i.e., attention) are required which will be reflected in subsequent spatial memory performance.

Lansdale (1998) furthers this point and argues that the level of measurement previously employed may not have been fine enough to capture the maximal level of precision that reflects the true performance of each experimental paradigm (intentional vs. incidental) and therefore an overestimation of incidental recall may have prevailed (resulting in no differences in performance between intentional and incidental conditions). This idea is also inline with suggestions that different levels of automaticity correspond to different levels of spatial encoding precision. For example, if one were to test for three locations within a house and each subject was asked which room of the house are the objects located in, participants in the incidental and intentional condition may well both answer with the corresponding rooms correctly. However, the participant in the intentional condition may well be able to judge precisely where in each room the object was located whereas the participant exposed to incidental learning may not. Consequently, Lansdale (1998) found significant performance differences between intentional and incidental learning of spatial information. Thus,

It is argued by Postma et al. (2004) that owing to the intrinsic nature of not only establishing where an object is located but also what object it is that is located there, spatial memory must involve both automatic and effortful mechanisms. They speculate that object position per se may well be encoded automatically however the binding process of object position and object identity is a rather more effortful process. Additionally, the integration of precepts into a coherent singular memory must involve some conscious effort. More support for this comes from Creem-Regehr (2004) who demonstrates that the location of an object in terms of coordinate details is encoded automatically, whereas the coding of the object's identity involves effort. This highlights that one cannot attend to the identity of an object without encoding at least some location information.

Other evidence also supports a dual-processing account (i.e., effortful vs. non-effortful components) of coding spatial information. Caldwell and Masson (2001) provide compelling evidence that object location memory comprises two components, automatic (unconscious) and effortful (conscious). Caldwell and Masson (2001) employed a paradigm[4] which enabled the comparison between conscious and unconscious processes within the same task. Through varying instructional commands two comparable conditions produce the same outcome for unconscious and conscious processes or divergent outcomes. Thus, by examining the pattern of results the level of interdependence between conscious and uncon-

[4]the *process-dissociation procedure* by Jacoby (1991)

scious processing could be inferred. Results showed that two different levels of conscious processing were involved in object location memory. This provided a very neat explanation for some of the contradictory findings regarding the effortful nature of spatial encoding (e.g., Mandler et al., 1977). Age invariance as proposed by Hasher and Zacks (1979) was assumed to indicate the presence of an enduring automatic and thus unconscious process. Caldwell and Masson (2001) showed that the conscious and thus effortful component of location memory did not vary across age, rather only the unconscious (described as automatic) component varied, demonstrating advantage for younger participants over older ones. Additionally, they showed that habit strength influenced unconscious elements of memory but not conscious elements which suggests practice effects are a consequence of qualitative changes to the more unconscious processes involved in object location memory.

### 1.4.1 How do we 'build' coherent representations space?

This final section aims to highlight findings which support or oppose the idea of spatial information integration. Much research has examined how and when representations of space which are viewpoint-free (Shelton & McNamara, 1997) are developed and relied upon. For example, Peruch and Lapin (1993) posit whether spatial location involves connecting successive egocentric viewpoints with intrinsic frames of reference. Although it has been well established that people do not hold map-like representations (see the first part of this introduction on distortions), it is also quite evident that coherent representations of space are apparent through experience. For example, if one were to consider their place of work, no doubt a fluid manipulation from multiple non-experienced perspectives is achievable from memory.

Awareness of abilities such as these led Evans and Pezdek (1980) to pose an interesting question. Specifically, they enquired as to the effects of asking individuals to learn a spatial environment from a map (i.e., a pre-formed holistic interpretation of space). This way an interconnected (albeit a metrically scaled one) representation could be created with one viewing. They found that individuals were in fact much better at recalling interrelationships between buildings from differently-viewed directions when learning them from a map compared to individuals who learnt one or two views of the corresponding spatial environment. This suggests that holding a viewer-independent map-like representation does appear to offer the possibility and benefits of viewpoint-free spatial judgements. However, these may be difficult to develop from limited experiential views.

### 1.4.2 Integration of spatial information

Integrating multiple pieces of information are argued to have numerous advantages via a probabilistically additive effect (Jones, 1987), the elimination of systematic bias (Bryant & Subbiah, 1994), or by increasing precision over singular pieces of information(Lindberg & Garling, 1987). Thus, investigating whether spatial information can exploit such benefits is important.

An example of multiple information advantage is highlighted cogently in the verbal domain. Rubin and Wallace (1989) showed that two related routes (i.e.,cues) to retrieving a memory were greater than the arithmetic sum of each memory separately. In their study the subject would be prompted for a learnt word ('RED') with 'either/or' cues such as 'It's a Colour' or 'It rhymes with dead'. Participants would receive both cues 'It's a colour' and 'It rhymes with dead'. They found that recall was much better for the 'either' condition over the 'or' condition. In other words, the multiple cues for the same memory were more efficient in extracting the memory for the target object over and above the sum of its individual memories. Rubin and Wallace (1989) argued that some form of aggregation or integration of the related information had taken place producing a qualitatively different and more powerful memory cue. This phenomenon is often described as 'superadditivity', where not only do the multiple cues enhance recall but improve it beyond the aggregated recall efficiency of each cue separately.

Findings like this are the basis for assuming integration is reflective of some form of additive effect where the aggregation of two pieces of information has greater effect on memory performance over the sum of its constituent parts. This has also been observed in the visual domain where combining separate fixations form a more detailed visual representation (Hollingworth & Henderson, 2002). Shimamura and Wickens (2009) put forward a biological account of superadditive memory strength suggesting the medial temporal lobe acts to bind contextual features through a process of hierarchical relational binding.

Within the field of spatial memory research is divided as to whether such processes can and do occur. This next section highlights the research which predominantly supports processes conductive to integration of spatial information.

Sawa, Leising, and Blaisdell (2005) using a touch screen procedure and Blaisdell and Cook (2005) using an open-field search task both demonstrate evidence for the possibility of spatial information integration in pigeons. The experimental design was such that pigeons would learn a stimulus pairing where the spatial distance was kept constant (e.g., A-B). They would then train the subjects as to the location of a target stimulus in relation to only one of the original stimulus (e.g., A-C). Therefore participants would have no a priori knowledge of the spatial relation between C and B (e.g., B-C). Thus, it is argued that if they are able to estimate C's location given B as a reference cue then they have integrated the representations (A-B + A-C). The measure of integration was whether there was an observable increase in correct estimates of C's location over successive learning trials. Interestingly, Blaisdell and Cook (2005) showed that integration was not apparent until some 7 months after separate paired association had been learnt with the target stimuli.

Sturz, Bodily, and Katz (2006) used human participants and applied the same integration paradigm as Blaisdell and Cook (2005) did with pigeons. Their findings showed the same outcome, that is, individuals were able to infer a novel relationship between previously learnt routes. However, Sturz et al. (2006) argue for a different conclusion than integration. They found that humans initially used a generalisation strategy, which means they would make judgements as to the target's location from the novel cue as if it were the learnt cue. In other words, they would simply repeat the learnt spatial relation for the novel spatial relation judgement task. They would then shift this estimation until it became progressively close to the target location from the view-point of the new novel landmark. Thus, given the appearance that they had inferred its location based on previous knowledge of other stimuli relations. Additionally unlike Blaisdell and Cook (2005) who showed reminder trials seemed to help pigeons locate the novel spatial relation, Sturz et al. (2006) showed absolutely no effect of this nature in humans. These findings are reiterated in a real-life replication study by Sturz, Bodily, Katz, and Kelly (2009). Again, Sturz et al. (2009) argue that no integration has taken place on the basis that individuals showed initial preference to generalise a novel location based on a learnt spatial relation rather than infer its position based on knowledge of related spatial relations.

Molet, Jozefowiez, and Miller (2010) provide contradictory evidence to that of Sturz et al. (2006, 2009). They found evidence for integration in the absence of search-task availability. Essentially they made search a non-option because they only allowed for a single choice on each trial to be made and moved the target object at test. This meant any search strategies would not carry over to the outcome trial. This left a strong possibility that search strategy could not explain the finding and therefore integration was a more plausible occurrence.

Molet, Bugallo, and Gambet (2011) support such findings of integration and generalise them to virtual reality settings. They also posit a spatial coding hypothesis based on the temporal coding hypothesis by Savastano and Miller (1998) which states that, i) an association between two spatially related events occurs in the presence of contiguity (close proximity) and, ii) the spatial element of the association is incorporated as part of the associative process (i.e., a spatial representation is formed that the stimuli share), iii) the spatial information contained within the associations plays a role in the topography of the response when only one associate is presented, iv) individuals are able to superimpose spatial relations that share a common target that was never presented together (Molet et al., 2011).

Molet, Gambet, Bugallo, and Miller (2012) sought to study the conditions under which disparate information may cause conflicting associations to be blocked. Based on ideas by Escobar, Matute, and Miller (2001) they focused on the test context as a factor that may determine whether two associations will be retrieved when they have been learnt separately with a common element to each. Escobar et al. (2001) argue that the condition under which information is retrieved may not only increase recall of stimulus initially learnt under those conditions but that it may also decrease the recall of any conflicting information (see also Anderson, Bjork, & Bjork, 1994, for a similar concept). Molet et al. (2012) tested this idea by requiring learning of the same cues with different spatial relations across two different virtual environments. Essentially, individuals would learn the positions of A-B and also the location of a target object in relation to A-B. Then a second association would be learnt using the same stimulus (A-B) but this time they were located in a different position within a different environment and with a different outcome object. This meant that there was landmark overlap between stimuli and Molet et al. (2012) showed that retrieval context can be used to differentiate learnt association and prevent interference. In essence, subjects used the retrieval context to help disambiguate any conflict between stimulus interference.

However, another and equally likely possibility that could be applied to such an experimental paradigm (Molet et al., 2012; Sturz et al., 2006; Blaisdell & Cook, 2005; Sawa et al., 2005) is that the subjects hold two separate but related representations and they are simply accessing such presentations in a step-wise manner. For example, when cued with reference point A this triggers the A-B relation which in turn triggers the B-S relation. Thus, the subject may not represent all three relations in one coherent unit but he/she is rather cuing associated corresponding spatial information for each relationships. The idea that an inference is made between A-S would therefore not hold if a step-wise strategy was employed.

There is also another methodological problem with some of the applied designs owing to individuals always making judgements (the ones considered evidence for integration) by using *only* one cue, then inferring a targets location based on knowledge of its spatial relation to another related cue. However, integration as has previously been argued, would necessarily assume that each component has been integrated into a qualitatively different representation. Therefore, each representation consists of *all* common spatial relations. One could equally argue that more reliable evidence of integration (rather than a step-wise serial retrieval of spatial information) would arise when subjects are afforded the opportunity to make a spatial judgement when presented with both learnt cues. If individuals' judgements given two learnt cues are greater than one this would more convincingly argue for the presence of spatial integration.

### 1.4.3 Non-integration of spatial information

There is also quite substantial evidence for the lack of spatial integration in humans. The next section highlights the difficulties that are evident with integration of spatial information. It provides an opposing argument to spatial integration as highlighted previously in this chapter and suggests that related spatial representations are held very distinct from one another.

Foo, Warren, Duchon, and Tarr (2005) investigated the possibility of route integration in humans and examined whether novel short-cuts could be inferred after learning a number of related map-like routes (i.e., vectors). They found inference of a third novel route was generally inaccurate in terms of both estimation of distance and angular direction of the novel route. The patterns of errors were such that individuals tended to underestimate both the angle and distance of the short cut from a finishing position back to the start, suggestive that subjects were unable to draw on two separate but related route memories to make an inference regarding a third unlearn route.

Additionally, Foo et al. (2005) showed that when landmarks were uncertain error dramatically increased suggestive of learning effort for both the acquired route and the novel short-cut. However, whenever landmarks were consistent performance gains were observed. The overall inaccuracies of short-cut estimation provides evidence for representations of routes that are not metrically quantified. If they were, then estimation of distances and angular direction should also be inferred based on such metric information. However, Foo et al. (2005) also note that such errors were typically somewhere in the vicinity or roughly in the right direction of where the short-cut should metrically be. This imprecision is perhaps expected given the evidence on biases and distortions present in spatial representations (see section 1.1 of Chapter 1). They argue the findings demonstrate that path integration systems in humans are coarse and inaccurate but that this does not preclude the presence of such integration. Interestingly, error decreased (accuracy increased) when landmarks were present. Foo et al. (2005) argue this is reflective of short-cut estimation that is based nearly completely on landmark configuration rather than actual path-like representations (i.e., lines between paths).

Further research comes from Foo, Duchon, Jr., and Tarr (2007) who provide evidence that humans dominantly rely on local landmarks to calculate the distance and angle of a short-cut. This is in comparison to employing path-integrated type knowledge (i.e., global survey-like representations). This suggests that spatial judgements may be dependent upon the division of spatial distance information. This could be explained by the fact landmarks appear to allow individuals to break up space into more accurate sections. This would be inline with research that suggests spatial accuracy to be a function of distance from a landmark (Nelson & Chaiklin, 1980). Thus as one moves along a route if more landmarks are present aggregation of each spatial segment could potentially be more accurate than estimation of the whole distance.

Wang and Brockmole (2003) and Brockmole and Wang (2002) examined whether integration was present across nested environments. For example, one small-scale environment (a laboratory) located within a large-scale environment (a campus). They found that subjects did not integrate their newly acquired knowledge about spatial relations of the small-scale array within their existing knowledge of the large-scale environment. When asked to point towards landmarks located within the campus representation and/or the laboratory representation, participants showed larger pointing errors for campus landmarks over laboratory landmarks. This, Wang and Brockmole (2003) argue, reflects the hierarchical nature of spatial representations (Hirtle & Jonides, 1985) and suggests nested spatial representations are kept separate within the mnemonic system. They argue that such retrieval independence suggests both representations cannot be maintained in working memory. Also, either they are not retrieved simultaneously or they are not retrieved as a single unit, meaning they have not been integrated (Brockmole & Wang, 2002).

Similarly, Avraamides, Adamou, Galati, and Kelly (2012) and Greenauer and Waller (2008) investigated the integration of spatial relations across different perceptual experiences. Specifically, they tested the idea that if an individual learnt a spatial array from two separate view points were they then better at judging the relations between those spatial arrays. Their findings suggest that individuals kept each representation separate in distinct spatial units.

The idea that representations of space are held in unique units is contradictory of the evidence that suggests it is possible to integrate spatial information.

Recently there have been findings to suggest that not only are spatial representations held in distinct units but more strictly that these units are not freely able to be drawn on even independently. This phenomenon is known as 'spatial memory exclusivity' (Baguley, Lansdale, Lines, & Parkin, 2006) and is the focus of the final section.

## 1.5 Spatial memory exclusivity

*"the assumption usually made [concerning the effect of combining two probabilistic processes] is that the stochastic relation among the processes is one of independence. However, it would often appear in principle no less plausible to entertain an assumption of exclusivity instead."* - (Jones, 1987, p.230)

Exclusive processes can generally be defined as those that occur mutually exclusive to one another. In the case of an event where both processes have the possibility of being engaged, the outcome will result in only one being so (Jones, 1987). Memory exclusivity, more specifically, refers to instances where two memory searches or retrievals are found to be exclusive of one another. There is evidenced of exclusive memory retrieval in semantic and autobiographical memory (Maylor, Chater, & Jones, 2001). Maylor et al. (2001) argued that search rates of disjunctive categories (e.g., fish and cars) should exceed search rates of a single category (e.g., fish or cars) if non-exclusive processing was occurring. They found that subjects drawing from two distinct categories performed no better than those searching from a single category either for semantic or autobiographical memory. They argue that if access to long-term memory is exclusive then such exclusive processing as witnessed in semantic and autobiographical memory should be apparent in other areas of memory retrieval.

However. there are some arguments as why mulitple cues might nearly always result in performance gains. Fragmentation hypothesis (Jones, 1976), for example, proposes multiple cue advantage that is in contrast to findings of spatial exclusivity. The fragmentation hypothesis states that a memory trace is made up of fragments that represent components of a learnt visual stimulus. The memory trace is activated on presentation of any single element as a cue. Jones (1976) highlights that on average one would expect to see some advantage for multiple cuing simply because it is more likely that at least one of the elements is stored in the memory trace. For example, if a stimulus contained 4 elements and providing all elements are stored within a memory then only one of those elements is needed to cue recall of the stimulus. However, if only 2 element were stored within a memory then one would expect multiple cueing to have a higher chance of activating either of the 2 stored elements, thus, on average resulting in some recall advantage.

Tulving and Pearlstone (1966) and Tulving (1974) argue that the function of semantic categories in the recalling of verbal information have been shown to be similar to that of reference points in recalling spatial information (Lindberg & Garling, 1987). That is, prompting the recall of a word by its belonging to a specific category may aid significantly in the recall of that word. This suggests that if reference points act in a similar manner to semantic categories for words then just as two reference points for the same target (i.e., two reference points drawn from the same spatial category) should aid in recalling the location of that object just as words drawn from the same semantic category aid in the recalling of a word. This suggests that cueing with the spatial category (i.e., both anchor points common to a target) should help to access the target location.

In contrary to such ideas, a special case of memory exclusivity has emerged recently in the literature known as 'spatial memory exclusivity' (Baguley et al., 2006). This type of exclusivity describes an event where given the opportunity for retrieval of two related pieces of spatial information only one of these is retrieved. This suggests that not only in some circumstances is spatial integration not possible but, in the case of multiple competing spatial memories, two spatial representations for the same target object are no better than one. In a series of experiments Baguley et al. (2006) manipulated the type, ordering, and pairing of multiple reference points with a common target object. The premise was to establish the benefit of holding two representations for a target object over one. The experimental design involved presenting a target object (T) in relation to a single reference point (A)(known as an 'anchor point') or alternatively in relation to two anchor points separately (A-T, B-T) (see Figure 1.1). Thus, a subject would either have one representation for a target object (A-T) or would have two (A-T, B-T). This meant at test a single memory can be prompted with its corresponding cue (A or B), or dual memories can be prompted simultaneously with their corresponding cues (A and B). In addition to the basic design format, they attempted to ensure separate representations were being held and also to encourage integration through manipulating the pattern of A-T, B-T presentations. For example, A-T and B-T were presented in close succession so identification of a common target element was salient.

The results across nearly all of their experimental manipulations showed that no benefits were obtained from having two representations over one. This led Baguley et al. (2006) to conclude that no integration between representations (A-T, B-T) had occurred. After a comparison of various statistical models they

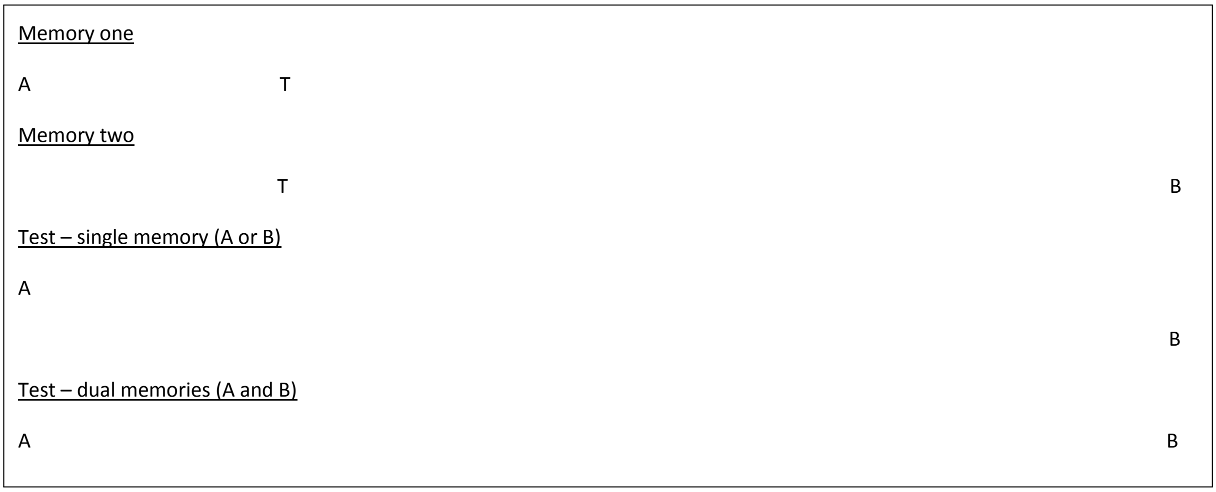


Figure 1.1: An example previous experimental paradigm

argued that the most likely explanation of such non-integration was accountable by 'exclusive' processing of the two representations. That is, not only was there no integration but the participants do not attempt to access a second representation if they fail to access the first. Baguley et al. (2006) argue that failure of retrieval from one representations does not lead to any attempt to access a second. Thus, having learnt the location of an object in relation to two reference points on different occasions subjects could only retrieve one of such occasions. This is unique compared to previous research where representations were held in unique spatial units but were equally accessible. Thus, exclusivity provides a condition where either retrieval of two representations is not required or not possible.

It is clear that exclusive processing is contrary to some notions of multiple cuing and the beneficial role reference points should play in spatial location judgements. However, the findings from (Baguley et al., 2006) are convincing and stretch over a number of experiments all demonstrating consistent findings.

## 1.6 Research rationale

The area of spatial memory integration is of great importance to uncovering the mechanisms behind a phenomenon that is relied upon daily with untold ease, that is, the process of building a cognitive representation of one's spatial environment. The finding of spatial exclusivity provides the field with a phenomenon that has the potential to lead to great insights into how multiple representations of space interact or fail to interact. There is very little research into exclusive processes generally but particularly regarding spatial memory exclusivity. Yet, an attempt to overcome exclusivity will undoubtedly lead to an understanding as to why it occurs and under what conditions it may be present.

How spatial information is processed may go some way to explain under what conditions integration is possible or not. It is a plausible starting point to make an assumption as to why exclusivity (and thus, non-integration) may occur under some circumstances. That starting point is to assume that is it a capacity issue. This is logical considering the various research which is contradictory with regards to the possibility of integration. Thus, this thesis tackles exclusivity by aiming to manipulate processing capacity (e.g., the encoding and retreival of spatial information) in a favourable manner with the aim of encouraging non-exclusivity and thus integration.

The literature highlighted in the introduction provide background research for investigating this. It is apparent that integration of spatial information is possible and in addition it has the potential to enhance memory. Three mechanisms that may increase the potential for non-exclusive processing are examined in this thesis. The first focuses of the way stimuli is perceived and subsequently processed. It attempts to enhance the way related memories are stored holistically. The second investigates limited capacity for retrieval of multiple pieces of spatial information and also assesses the effects of distinction between like memories. The third mechanism adopts an approach that introduced repeated exposure as a means of freeing up any processing associated with learning new spatial information. Although these mechanisms are expanded at the beginning of each empirical chapter the three approaches are briefly summarised below.

### 1.6.1 Expertise

The role of expertise have not so far been investigated as a potential means of overcoming spatial memory exclusivity. Only one study has attempted to tackle this, an unpublished study carried out at the University of Loughborough by Harding (2006). The results tentatively showed expert individuals (musicians) performed marginally better at recalling the location of a letter when positioned above two corresponding musical phrases in comparison to when the letter was positioned above one. This was in contrast to the non-experts who performed better when presented with just one musical score rather than with two. The overall findings point to an expertise benefit of receiving additional spatial information. In light of these findings along with the commonly cited benefits of experts within both the spatial and other domains two main questions are considered in the current research: How might common expertise advantages (i.e., automaticity, familiarity, holistic processing) impact spatial memory exclusivity?

### 1.6.2 Semantics

The second approach exploits the role of semantics in memory exclusivity. Semantics clearly play an important part in spatial memory (Hirtle & Jonides, 1985; Pezdek & Evans, 1979), just as they do in the majority of memory processes (Rohrer & Pashler, 1998; Logan & Schulkind, 2000). It is clear both subjective and objective semantic influences help to organise spatial information whether it be by category or hierarchy. Semantic information has been shown to influence one's ability to processing multiple pieces of information. In turn, multiple information processing strategies may be key factors in memory exclusivity, either circumventing or promoting it. This aspect of the thesis asks the question of how is capacity for spatial information influenced by semantic information processing?

### 1.6.3 Learning

The idea that repeated exposure and long-term experience are important factors in spatial integration is supported from early work involving animals (Ellen, Parko, Wages, Doherty, & Herrmann, 1982; Ellen, Soteres, & Wages, 1984). After all, one cannot mentally transverse a friend's route home or locate a stranger's office. These mental achievements are only available from experience and are arguably the conditions under which they should be tested. Thus it is more realistic in some ways to study exclusivity and the possibility of overcoming it when individuals are repeatedly exposed to spatial information over time. The spatial memory research area research area suffers from a dearth of human-orientated work. Additionally, learning arguably brings together both semantics and expertise under one approach. Baguley et al. (2006) also propose that one possibility that may account for their findings is the novelty and abstractness of the stimuli and task. They highlight that combination of spatial information may require consolidation and practice with each separate component. What is the role of learning in exclusive processing of spatial information?

## 1.7 Summary

The question really arises as to whether capacity limitations can be circumvented to encourage integration of spatial information. If this is found to be or not to be the case, either way, it will provide an insight into when and how such aggregation takes place. Mental representations of space are undoubtedly the end result of extremely complex processes. However, the mechanisms that underlie such seemingly spontaneous phenomena are far from being fully understood.

The aim of this thesis is to provide a better understanding of conditions that may allow for and encourage integration by circumvention of a phenomenon opposed to such development (spatial memory exclusivity). It seeks to add unique insights into the existing knowledge base by adopting appropriate measures of spatial memory, employing empirically grounded findings on expertise and semantics, and finally, to allow for longer term, and therefore more temporally realistic learning settings than have been applied previous.

# Chapter 2

# Research Methodology

This chapter will set out the methodology employed throughout this research project. It will firstly summarize previous designs employed by researchers in the field of spatial memory and highlight the benefits and appropriateness of the specific methodological stance taken here.

## 2.1 Research approach

Research tasks that aim to investigate spatial memory are extremely varied and specialized. Their apparatus range from single dots, water-mazes, map configurations, to virtual reality scenarios. All aim to investigate spatial memory through the evidence contained within participants responses, whatever form they may take. There appear to be nearly as many experimental tasks as there are avenues of research into spatial memory. Such variation means concrete comparisons across aspects of spatial memory are relatively difficult which unavoidably impacts the ability to draw overarching conclusions. The approach taken in the current research is to establish consistency not only between the current research and previous research regarding exclusivity, but also coherence between the experiments contained within this thesis.

Although it is acknowledged than components of one form of spatial memory (e.g., object location) are naturally involved in that of others (i.e., spatial navigation), distinct areas of spatial memory can rarely efficiently be examined in isolation. This is mainly due to the discrepancy between low-level and high-level processing features of spatial memory. Thus, although many aspects of spatial information encoding and retrieval fall under the term of spatial memory, each aspect can encompass quite distinct processes. The requirements of the methodological approaches that investigate features of high-level spatial processing components can conceal those mechanisms of low-level processing.

This epitomises the beauty and difficulty of studying such a field as spatial memory. That is, the breadth of processes available to study are complexly interesting, however, at the same time make for a challenging topic to investigate with absolute certainty. The range of tasks spatial memory is involved in stems from the fact that nearly every action individuals perform contain some elements of space. To understand how spatial memory works is essential to understand how a large proportion of the memory system functions. Unquestionably, spatial elements are ingrained in a huge proportion of information we process visually. Therefore, it is not surprising that this variability in information sources has a massive impact upon the idiosyncratic way in which spatial information is encoded, represented, and recalled.

This thesis aligns itself with the view that it is necessary for spatial memory research to be explicit regarding the aspect of spatial memory it is investigating and also employs a methodological approach that is in-line with the research objectives. The distinctions between spatially-related goals can be very subtle but can have massive implications for the way spatial information is encoded, structured, and retrieved. Thus, this research reduces ideas of mental spatial representations to the minutiae of cognitive processes that may underlie it.

## 2.2 Measuring memory imprecision

Observing response errors from any mnemonic task is a crucial part in understanding memory processes (Naveh-Benjamin, 1987; Lansdale, 1998). The adoption of this notion in the past has provided sagacious design approaches and valuable mnemonic insight. Research frequently demonstrates that inbuilt psychological processes have a tendency to contaminate information from the senses and the result of such contamination is only understood when the patterns of errors are examined. For example, errors evidenced in eye witness testimony have informed research into episodic and autobiographical memory (Loftus & Palmer, 1974), errors apparent in acoustic coding have led to insights into the phonological representation of information in short-term memory (Baddeley, 1971, 1990). It is clear that within patterns of error lie important information regarding the phenomena under scrutiny. Spatial memory is no exception to this (e.g., Naveh-Benjamin, 1987; Huttenlocher et al., 1991; Lansdale, 1998).

Naveh-Benjamin (1987) heavily criticised previous research into location memory and claimed that it had missed the recording of vital location information present in memory, mainly due to constraints in analytical conventions. The specific criticism was of researchers only paying attention to the percentage of objects whose location was recalled exactly. Anything other than this was considered an error. However, Naveh-Benjamin (1987) demonstrates that one participant's error could be very different from another. This is summed up succinctly in his description of the following scenario:

*"Subject A places all the objects in the test phase in close proximity of their original location in the matrix, but none in the exact position. Subject B, on the other hand, does not remember the spatial location of any of the objects presented except one. So Subject B randomly places all the objects in relation to the spatial arrangement in which they had appeared, except the one which is placed in its exact position. Use of a measure of percentage of objects memorized in their exact location, as is customarily done, will result in attributing better memory for spatial location to Subject B, which, of course, can be quite misleading."* - (Naveh-Benjamin, 1987, p.597).

Naveh-Benjamin (1987) highlighted this discrepancy in the case where subjects only recalled 35% of objects correctly but on examination of their deviations from correct (i.e., error) it showed that on average subjects had a good knowledge of the relative location of the objects.

What can be learnt from past research is that one's research design and methodology should not only be capable of capturing 'correct' responses but also errors made with incorrect responses (i.e., degrees of correctness). Thus, the current research employs the same assumptions that underpin Naveh-Benjamin's (1987) approach to spatial memory quantification (see below, e.g., Lansdale, 1998). In addition to this it adapts the experimental design used by Baguley et al. (2006) which is rooted in these ideas.

Specifically, the cued-recall design of Baguley et al. (2006) allowed for the testing and comparison of multiple-cue (multiple memory) performance. In terms of quntifying location memory performance a mixed approach is adopted which is dictated by the research objectives. However, broadly speaking it either takes on the form of a single-value metric compiled by Baguley et al. (2006) which quantifies degrees of location accuracy (via the 'Dscore', see below), or alternatively extends this metric to an approach which allows for a visual description of location error distributions through the use of matrices (Lansdale, 1998). Both, experimental design and unit of location-memory measurement are set out below.

The measurement of spatial memory derived from Lansdale's (1998) paper on exact and inexact recall allows one to assess degrees of spatial memory accuracy reflective of the levels of spatial information available to the participant (rooted in Naveh-Benjamin's idea of 'near-miss' errors), which argues individuals will often have a good idea where an item is located but just not to the levels of perfect recall. The advantage of this is that it can measure those instances when people use inexact memory to estimate where an object is and recall its exact location In other words, this approach makes good use of instances where recall is inexact but close to exact. Additionally, inherent in the statistical modelling associated with this measurement method, it enables one to examine any biases present in the recall process (e.g., any tendencies to estimate closer or further away from a particular landmark or target).

## 2.3 Experimental Paradigm

Space can only be quantified through the comparison of relational points. One cannot substantiate space unless it has been defined by some boundary condition. Inevitably the memory for a target object must be quantified by the perceiver in relation to something else, a reference or anchor point. This is a basic understanding of spatial memory processing and leads to the ideas of relational points and in particular allocentric frames of reference (see Shelton & McNamara, 2001b; Burgess, 2006). It is this relational aspect of spatial memory that allows one to test hypotheses as to the effectiveness of multiple memories. The incorporation of references point into the stimuli presentations allows for the establishment of separate spatial memories which contain location information regarding a common target object. The design specifically exploits fixed reference axes (know as 'anchor points') combined with paired-associative learning/cued-recall to establish multiple memories for a common target object (see diagram section below for more details). A composite stimulus is employed that participants see part or all of depending on conditions. Each presentation is created by maintaining a constant position for a specific target location whilst presenting the target a number of times in relation to unique anchor points. A target object's position can later be cued simultaneously with multiple anchors or sequentially with a single anchor. Purely for point of understanding, this process can be likened to viewing an object from two different perspectives. It may be best illustrated with a simple example:

John places his house keys in one of nine draws organised horizontally in the kitchen. At the far left hand side of the nine drawers is an anchor point in the form of a kettle. At the far right hand side of the nine drawers is another anchor point in the form of a toaster. John firstly looks to the kettle on the right and tries to remember the distance from the kettle to the drawer containing his keys. He then looks to the left and again tries to estimate the distance from the toaster to the drawer containing his key. After leaving the kitchen for a period of time John returns and tries to remember within which drawer his keys are located. Having been presented with both the kettle and the toaster at the point of learning, John has the opportunity to rely on both of these appliances as reference points to help him estimate within which drawer his keys are located.

Thus, just as that employed previously (Lansdale, 1998; Baguley et al., 2006) a spatial array is configured into nine distinct units. The nine units are displayed horizontally, regarded as a linear plane. Nine units are used because this has shown to be sufficient to approximate the information in a continuous location task without making analysis intractable. showed than the use of nine divisions preserves most of the information of continuous data.

Targets are randomly assigned to each space until all spatial segments are filled with a corresponding and unique target object, whatever form that may take. At fixed positions to the left and right of the nine spatial segments are where anchor points are placed to enable the cuing for specific memories for a target object. Thus, for each memory the subject holds a unique association between the anchor and the target, referred to as an 'anchor-target relation'. At test, a participant will be presented with a cue in the form of the anchor they were presented with at learning, referred to an 'anchor-cue presentation'. Manipulations as to the number of anchor-target relations and the number and combinations of anchor-cue presentations allows one to test the effects of holding single or multiple memories for an object's location. The exact nuances of the experimental layout are illustrated below.

### 2.3.1 Diagrams of experimental conditions

Throughout this thesis a number of acronyms are used to describe variations in target-anchor and cued recall presentations of stimuli. Although these are described throughout the thesis they are illustrated below in diagrammatic form to offer the reader a central point of reference with which to visually remind themselves of the discrete differences between stimuli presentations. There are three types of stimulus presentation.

The first is paired-single anchor presentation (PSA). This consists of presenting a target object in a specified location twice. Once in relation to an anchor point to the right of the target and once in relation to an anchor point to the left of

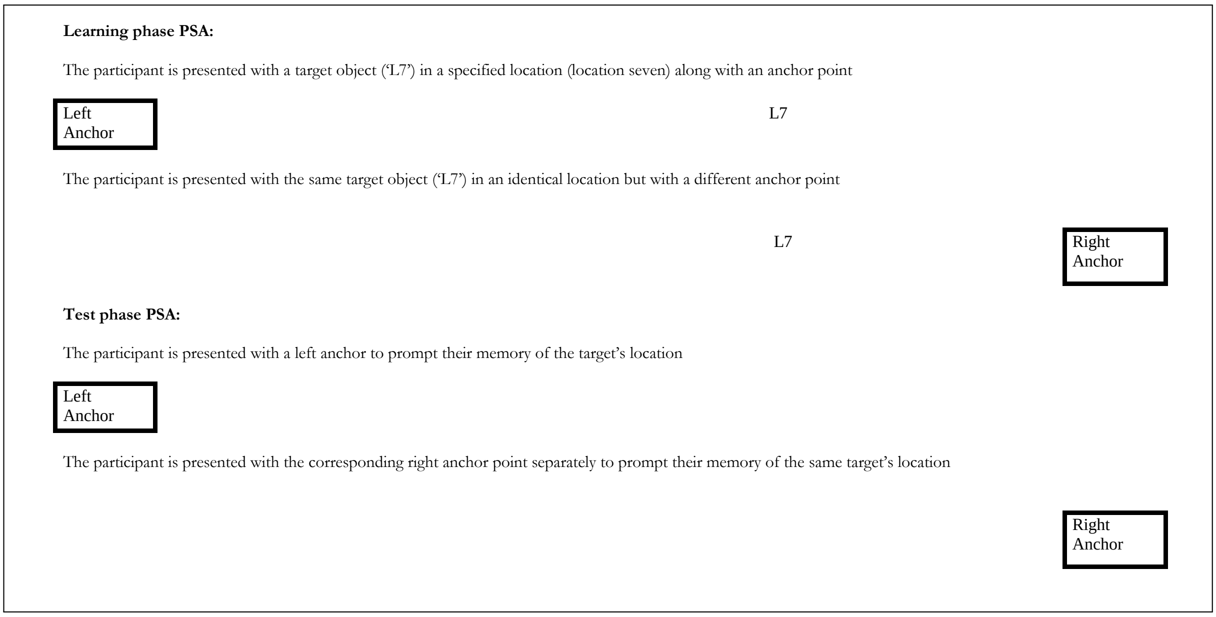


Figure 2.1: Design for PSA learning and PSA test

the target (see Figure 2.1). The PSA presentation type can also be employed at test (provided a contingency at learning has presented the target in relation to two anchor points in some form). For example, a PSA test condition involves presenting two cues for the same target object on separate occasions (see Figure 2.1).

The second type of presentation is dual-anchor (DA). This involves presenting two anchor points simultaneously (see Figure 2.2). If DA is employed in the learning phase then the participant would see two anchor points, one to the left one to the right, along with a target object presented at some specified location in between the anchor points. If DA was used as a test contingency then the participant would see both anchor points , one to the left and one to the right. They would then make a judgement to the targets location based on seeing this.

The final type of a stimulus presentation is in a single-anchor (SA) format (see Figure 2.3). This presents a target object in relation to only one anchor point. If employed at test the participant would just see one anchor point from which to recall a target object's location. The SA presentation can take two forms, single-anchor left (SA-L) and single-anchor right (SA-R). In the majority of cases both SA-L and SA-R are employed for control purposes, so that any directional bias can be counterbalanced for the SA condition as a whole. However, they are treated as an overall single anchor presentation type.

Each type of presentation can be applied at encoding or test or both. They

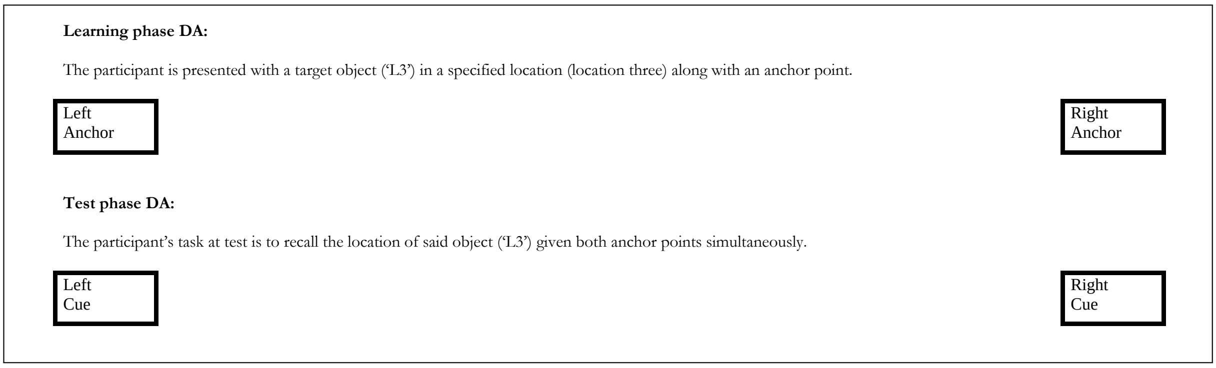


Figure 2.2: Design for DA learning and DA test

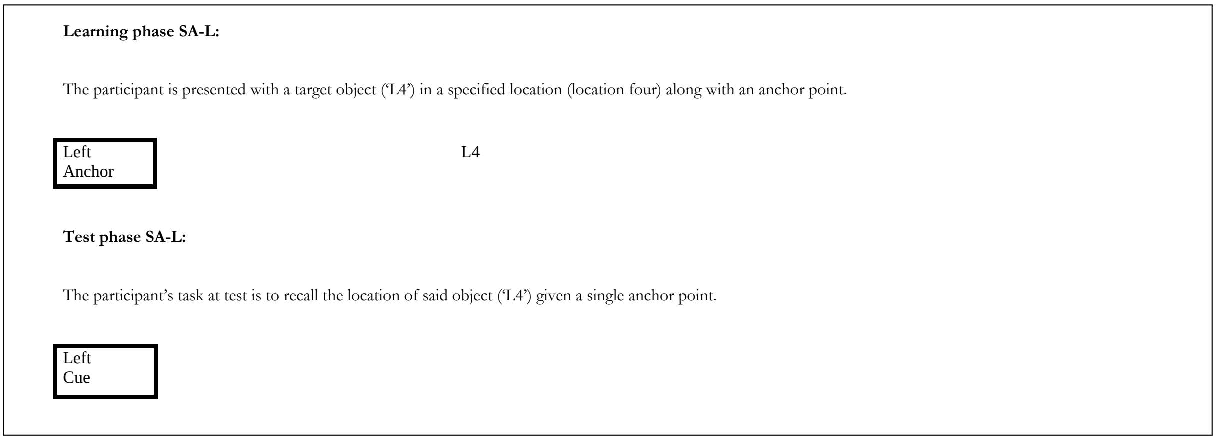


Figure 2.3: Design for SA-L learning and SA-L test

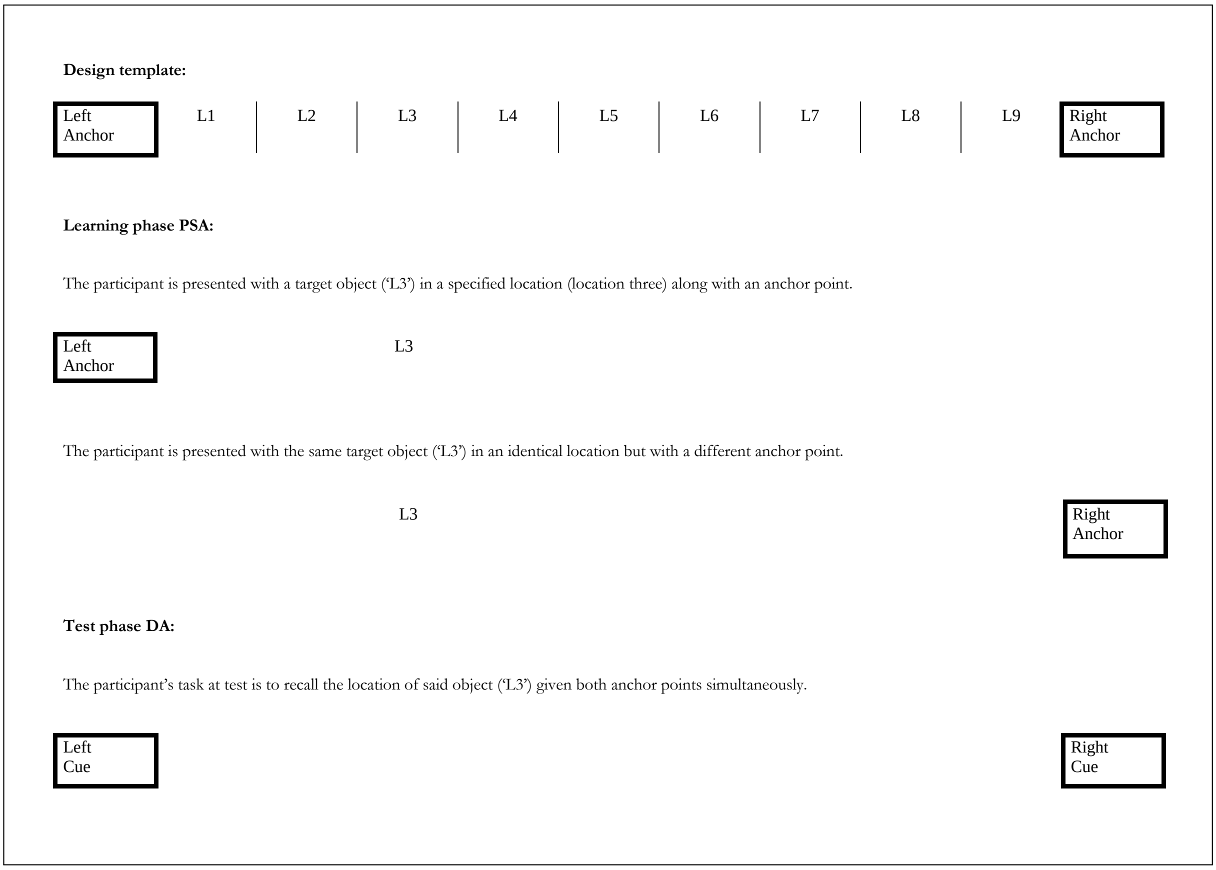


Figure 2.4: Design for PSA learning and DA test

can also be employed in many kinds of combinations, for example, PSA may be employed at learning with DA at test (see Figure 2.4). If this is the case the condition will be abbreviated to PSA-DA to signify the learning and test contingencies that make up an overall experimental condition.

### 2.3.2 Design template

A diagram is presented at the beginning of each experiment to aid it illustrating the different manipulations made to common elements of the design, some of which can be subtle. Each diagram takes the same basic structure (see Figure 2.5). The stimuli can vary according to a number of components of the stimuli and dependent on these components the links and relationship they share with one another can vary. For example, the anchor points can contain elements that are common to each other or the target or both. Within the digram the boxes represent actual stimuli types and the ellipses represent theoretical links

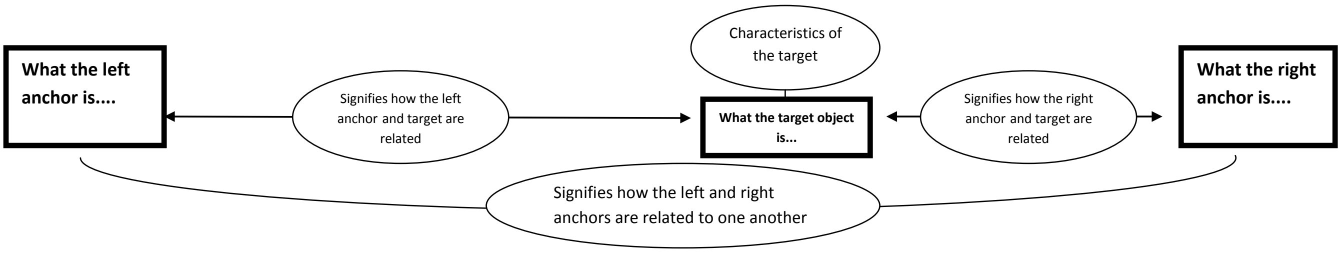


Figure 2.5: Generic design template illustrating manipulations in each experiment

between the boxes.

It is argued that the simplicity of this design is an important feature of investigation. The use of complex configurations and/or pictures can sometimes blur the underlying processes of object-location. It is hoped by manipulating components within a simple design these processes will be more overtly observed and consequently discussed.

## 2.4 Unit of analysis

Accuracy of location memory can be measured in terms of distance or deviations from perfect accuracy. This is essentially the number of quantifiable units a response is observed to be from its actual location. In this sense the accuracy of location memory is conceived of in terms of location error. As the magnitude of error increases accuracy necessarily decreases. Owing to the inverse relationship between location error and accuracy these terms are used interchangeably throughout the thesis and no distinction is required between the two unless highlighted otherwise.

Two values stem from the measurement of location accuracy under the current paradigm. The first is a raw score which relates to the number of deviations a response is from an expected location. The second is a chance-corrected score. The raw score represents an actual quantification of absolute distance of a response in relation to a target location. The unit of measurement for distance is relative to the size of the total spatial plane. This means that a unit is the total size of the plane divided by nine. The raw score value represents the number of such units a response is away from its expected location. Owing to the symmetrical nature of the stimulus array the absolute deviation is calculated (Baguley et al., 2006). This is necessary to omit any arithmetic signs and allowing for the summing of all raw scores per individual. The corrected-chance value is necessary due to the variation in potential deviations across locations. This variation arises from the horizontal nature of the array which is described in more detail below.

### 2.4.1 Estimating and correcting for chance responses

When calculating deviations for a target's given location there are probabilistic discrepancies which are a consequence of the horizontal array. The maximum deviation from the correct target location in a horizontal stimulus array depends on the location of the item. In particular it is smaller for items at or close to the centre of the array than at the extremes. For example, if one were to be presented a target object in location 5 (i.e., central location), then the maximum chance deviation a response could be from that location is four (i.e., if the response was in location nine). If the target was instead presented in location nine a chance response could have a maximum of eight deviations. This discrepancy can be corrected by scaling the observed score by its expectation under an equiprobability model (i.e., one in which the location of the response is determined by chance alone - as would happen if a participant guessed at random).

The formula for calculating each location's chance deviation value is the sum of the possible absolute deviations either side of a given target divided by the number of possible locations in the linear plane. Each response an individual gives is divided according to the average deviation value by chance at which the target was presented. The output value is labelled as a *Dscore*[1]. This is best illustrated in confusion matrix form where the deviation structure for each target location is clearly described (see Table 2.1).

In order to illustrate the information contained within a Dscore a few examples will be calculated. For example, if a participant were presented with an object in location three the chance number of deviations their response will be from that target location is 2.6667 (see Table 2.1). That is, if the probability of responding in all available locations was equal then the average number deviations away from the given target location would be 2.6667. If that participant were to respond in location one they would be two deviations away for the target and would obtain a raw score of minus two. This would give an absolute deviation

[1]Although the Dscore represents location error it can quite easily be reformulated to a form which signifies accuracy directly, simply by applying the formula 1 - *Dscore*. This is know as an information transmitted score (Tscore)

| Location | | | | | | | | | | Chance value |
|---|---|---|---|---|---|---|---|---|---|---|
| L1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | = 4 |
| L2 | 1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | = 3.2222 |
| L3 | 2 | 1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | = 2.6667 |
| L4 | 3 | 2 | 1 | 0 | 1 | 2 | 3 | 4 | 5 | = 2.3333 |
| L5 | 4 | 3 | 2 | 1 | 0 | 1 | 2 | 3 | 4 | = 2.2222 |
| L6 | 5 | 4 | 3 | 2 | 1 | 0 | 1 | 2 | 3 | = 2.3333 |
| L7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 1 | 2 | = 2.6667 |
| L8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 1 | = 3.2222 |
| L9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | = 4 |

Table 2.1: Confusion matrix illustrating the calculation of expected deviation values for each location

score of :

$$absolute(1-3) = 2$$

The absolute score is then divided by the chance score for the location in question which results in a corresponding Dscore of:

$$\frac{2}{2.6667} = 0.75$$

## 2.5 The use of confusion matrices

Although the Dscore provides location information on a continuous scale and is a more appropriate metric of memory than proportion of correct responses, an additional form of analysis is employed which is intrinsically linked with Dscore but allows for the bias in responding to be assessed. The use of confusion matrices stems from the development and testing of the Hybrid Encoding of Location Memory (HELM) model by Lansdale (1998). The employment of such matrices, as of the type seen in Figure 2.1, allows one to not only measure degrees of location accuracy as advocated by Naveh-Benjamin (1987) but to observe any biases. Essentially the confusion matrix allows one to actually see patterns in responses and offers an extremely rich source of information, which is arguably required when examining a complex and fickle phenomenon such as location memory. This thesis also employs confusion matrices to examine learning (see Chapter 5) as it allows one to observe explicitly the pattern of changes to such a matrix over time.

Although confusion matrices will not need to be interpreted by the reader in the main body of the text, the process of seeing how confusion matrices reflect an individual's location estimation is important to illustrate the nature of the form

| Location | L1 | L2 | L3 | L4 | L5 | L6 | L7 | L8 | L9 |
|---|---|---|---|---|---|---|---|---|---|
| Target L1 | 0 | 0 | 0 | **X** | 0 | 0 | 0 | 0 | 0 |
| Target L2 | 0 | **X** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Target L3 | 0 | 0 | 0 | 0 | 0 | **X** | 0 | 0 | 0 |
| Target L4 | 0 | **X** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Target L5 | 0 | 0 | 0 | 0 | **X** | 0 | 0 | 0 | 0 |
| Target L6 | 0 | **X** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Target L7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **X** |
| Target L8 | **X** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Target L9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **X** |

Table 2.2: Confusion matrix illustrating a hypothetical response pattern for one participant. Targets (i.e., presented location) are given vertically in the first column and the participant's responses are presented in the first row.

they take. A series of example responses for each target location are presented in Table 2.2. As can be seen this participant got three locations perfectly correct (L2, L5, and L9) with the rest quantified in terms of number of units away from exact location (i.e., grey boxes). Confusion matrices will be directly relied upon in Chapter 5 of this thesis where it is used to illustrate the change in precision distribution of spatial information temporally.

## 2.6 Testing spatial memory models

Directly taken from Baguley et al. (2006) and based on ideas from Jones (1987) three statistical models are used to account for performance outcomes. Three models are specified, each of which attempts to account for a variety of possible scenarios.

### 2.6.1 Exclusivity model

Results from analysis of the experimental data that fit the exclusivity model are reflective of occasions where an individual accesses one spatial memory and no attempt is made to access the second. Based on single memory performance, the exclusivity model can be calculated which would equal the performance of a single memory.

$$(A_j + A_k)/2$$

'*A*' in the formula represents availability of spatial information for one memory (i.e., from one anchor) with subscripts representing separate memories.[2] Availability is estimated using the inverse of the Dscore. This is argued to represent the amount of information contained within a memory (as opposed to error) and is calculated simply by subtracting the Dscore from one (i.e., Tscore = 1 - Dscore). Hence the exclusivity formula can alternatively be expressed as:

$$1 - ((Tscore_j + Tscore_k)/2)$$

Performance one would expect for exclusivity can be obtained by inputting observed performance from having a single memory (obtained using performance in the SA-SA condition) into the exclusivity formula. From this it is easy to see that if two spatial memories are acting exclusively then performance should equal that of one spatial memory. This means a simple test of exclusivity is to compare SA-SA condition performance (i.e., that observed from having one spatial memory) with that of the PSA-DA condition performance (i.e., that observed from having two spatial memories). If the difference between these conditions is not statistically significant then one can argue that exclusive processing of two spatial memories has occurred. If however there are significant differences between these two conditions then it is likely exclusivity is not occurring. In such circumstances it is important to then test alternative models to help explain how two spatial memories are being processed in an advantageous manner. The simplest model where some kind of performance gain for two memories is expected is the independence model which is set out below.

### 2.6.2 Independence model

Data that fits the independence model suggests that retrieval of one memory is unaffected by retrieval of another memory. This will result in higher levels of recall from two cues than from one because a second attempt is made if retrieval fails. Thus, exclusive processing assumes no attempt is made after failure of one memory retrieval, however independence states that in such a scenario the individual can switch to retrieve a second memory. The independence model can be calculated based on single memory performance using a probability model for independent events.

$$(A_j + A_k) - (A_j * A_k)$$

[2]availability refers to the probability of recall multiplied by memory precision. A simplifying assumption of the model is to assume precision is on average cancelled out and therefore a constant.

The independence model is again calculated from SA-SA data that has already been transformed into a Dscore but not a Tscore:

$$1 - ((1 - Dscore) * 2 - (1 - Dscore)^2)$$

or using the Tscore directly the independence model can be expressed as:

$$1 - (Tscore * 2 - Tscore^2)$$

### 2.6.3 Superadditivity model

Superadditivity is simply assumed to have taken place when memory performance for two cues not only exceeds one cue but also exceeds that predicted by the independence model. Under this model both memories are retrieved and used to improve response. This suggests that performance increases are due to some kind of calculation between the two memories (e.g., averaging them, integrating them). Superadditivity implies that some form of aggregation or integration of spatial information has occurred forming a different and more precise representation than each separate memory singularly. Thus, the use of integration in the context of this thesis implies data which takes the form of the superadditivity model. Superadditivity can be implied if performance exceeds that predicted by the independence model.

$$A_{j \cup k} > (A_j + A_k) - (A_j * A_k)$$

## 2.7 Summary of research methodology

An approach to the study of location memory is presented here based in previous work that:

1. has evolved from the same underlying objectives as previous research (to test object-location memory and exclusivity)

2. employs a methodology that is specifically designed for capturing the complex nature of object-location memory

3. allows for much easier and more robust comparisons to other research within the object-location memory field

4. maintains a level of consistency between conditions where exclusivity has previously been found and where it will now be manipulated further

# Chapter 3

# Expertise and Exclusivity

## 3.1 Introduction

Task ability is often determined by the attentional demands of the task in relation to availability of cognitive capacity (Newell & Simon, 1972). One domain which consistently demonstrates the extension of typical attentional capacities is that of expertise. There is considerable evidence that particular styles of perceptual processing displayed by experts can lead to significant improvements in memory performance (Simon & Chase, 1973; Ericsson, Chase, & Faloon, 1980; Ericsson & Chase, 1982; Ericsson & Kintsch, 1995; Kiesel, Kunde, Pohl, Berner, & Hoffmann, 2009).

The reduction of load on cognitive capacities can be attained via three main aspects of expertise processing, chunking of information, holistic processing, and automaticity of encoding. There is currently only one study which has used expert subjects (musicians) to overcome spatial memory exclusivity (Harding, 2006). This, however, was an unpublished project and it had some severe limitations (e.g., small sample size, small effect size). Confirmation or disconfirmation of such findings will help to understand the processes that underpin exclusive spatial memory processing.

The remainder of this introduction is split into two parts. The first part deals with the primary rationale for the chapter as a whole. The second part deals with an additional aim that it is hoped will aid in understanding what information is being encoded with each spatial memory.

### 3.1.1 Primary aim

### 3.1.2 Expertise and chunking

Experts have been shown to perceptually organize spatial arrays in a way to reduce demand on short-term storage of visuo-spatial material (Chase & Simon, 1973). Such storage is limited to about 3-4 objects (Cowan, 2001; Cowan, Johnson, & Saults, 2005; Broadbent, 1971; Vogel, Woodman, & Luck, 2001) which in turn are restricted by complexity (Alvarez & Cavanagh, 2004). Short-term storage of visuo-spatial material is also greater for objects presented in a uniformed manner than for those presented in isolation (Luck & Vogel, 1997). Experts can avoid limitations of STM by 'chunking' information into larger LTM units, which can be later accessed using markers in STM (Chase & Simon, 1973). Jolicoeur, Tombu, Oriet, and Stevanovski (2002) showed more specifcially that chunking at encoding or retrieval significantly reduces the requirements of the central processor and consequently any blocking of information.

The efficiency of chunking is illustrated cogently in digit span tasks, where participants can typically only recall seven pieces of information (Miller, 1956). However, if they chunk the information (i.e., instead of 4 and 2, they remember 42), this limit can be expanded by some margins. For example, through chunking strategies it is possible to extend one's digit span from 7 numbers up to 100 (Gobet & Simon, 1996). More recent works suggest that the capacity to recall even just seven items also involves some form of chunking and a more realistic estimate of short-term visuo-spatial memory is around 2-3 items (Cowan, 2001; Cowan et al., 2005). In terms of the current research, the chunking of related spatial information (i.e., two cues pointing to the location of a common target) in LTM may increase the likelihood of accessing at least one of those memories.

### 3.1.3 Expertise and configural processing

Configural processing is the ability to recognise the relations between multiple features of a visual stimulus (Navon, 1977). Experts have shown to possess such a skill and they typically process expert-specific information in a more configural and feature based manner than novices (Busey & Vanderkolk, 2005). This type of processing has been associated with a number of expert domains including chess, face processing, and sentence processing.

Much evidence has shown that the way individuals process faces is dependent upon their ability to recognise the relations between features of the face (i.e., its feature configuration)(Kimchi & Amishav, 2010; Rhodes, Hayward, & Winkler, 2006). Maurer, Grand, and Mondloch (2002) highlight that face processing crucially involves holistically 'gluing' together first-order relations into a Gestalt representation.

In line with the idea of integrating the relations contained in a visual array, Chase and Simon (1973) argued integration is typically achieved when a meaningful relationship is required between remembered items. For example, Chase and Simon (1973) showed chess players to have superior memory over novices for the layout of a chessboard when it resembled a likely composition. They argued that it is the meaningful links between chess pieces that enables such rapid and reliable recall of complicated structures. This was further reiterated when *non-experts* were shown to outperform experts in reconstructing a chess board when the layout was non-normal and therefore in a configuration which is not meaningful to experts. Inherent within a configuration of chess pieces are inter-object spatial relations. This suggests that spatial components of a stimulus array are encoded in a similarly beneficial configural manner as the objects (chess pieces) themselves.

Another form of expertise where configural processing is apparent is that of sentence processing. When an individual processes (i.e., reads) a sentence they extract a representation of that sentence which is stored in long-term memory (Anderson, 1974). This is an integrated representation of its constituent ideas. Foss and Harwood (1975) argued cuing with two related pieces of text information may exceed the sum of corresponding single-cued probabilities (i.e., superadditivity) because text is encoded in a Gestalt manner, where a configural path is established between two parts of a single sentence. Therefore, recognition of related sections of text based upon common semantic themes and elements may allow for recombination of related sections of text at a later time (Sasson, 1971).

The fact that experts have the ability to extract higher-order relations from multiple stimuli, whether this be a human face, configuration of chess pieces or meaning from a series of words, enables them to develop 'templates' (Gobet & Simon, 1996, 2000). These are described as schematic-like structures which contain multiple individual perceptual components that together produce an integrated representation qualitatively different from each constituent part (Gobet & Simon, 2000). In the current research (which uses text expertise) it is clear how this element of expertise processing may help to overcome exclusivity or at least encourage some form of integration between separately presented pieces of expert-specific stimuli.

### 3.1.4 Expertise and automaticity

One other aspect of expertise processing is that certain stimuli are encoded automatically (i.e., with little attentional effort). Automaticity has been shown to play a vital role in expertise processing (Feltovich, Prietula, & Ericsson, 2006) and typically is the result of repeated exposure and practice with specific stimuli (Posner & Snyder, 1975). It is argued that as stimuli become more familiar and attended to there is a shift in processing strategy from algorithmic computation to direct memory retrieval (Logan, 1988; Crutcher & Ericsson, 2000). A good example of this comes from the Stroop effect (Stroop, 1992), where the semantic meaning of a word is extracted with minimal processing effort.

Some research shows that chess experts are able to organise complex chess configurations unconsciously, suggesting that little attention is required (Kiesel et al., 2009). Other benefits of reduced processing effort include dual-task capabilities. Shaffer (1975) showed that expert typists could both carry out typing while reciting nursery rhymes. Hatano, Miyake, and Binks (1977) showed that experts using an abacus to make arithmetic calculations could just as quickly and accurately do so whilst answering non-related questions such as 'what is the highest mountain in Japan?'. Spelke, Hirst, and Neisser (1976) exemplified the advantages of low-demand text processing. They showed with little practice students could read unfamiliar texts (at normal speed) whilst writing down and comprehending relations among dictated words. More recently, Reingold, Charness, Pomplun, and Stampe (2001) found chess experts were able to encode chess positions automatically and in parallel.

In line with the idea of dual-task processing, Feltovich et al. (2006) point out that automatic processes have the ability to make additional cognitive resources available (i.e., attention) by way of minimising disturbance to central processing. They go on to propose that this freeing up of resources allows for higher-order functions to occur. Thus, only when lower-order processes become more automatic can higher-order action such as inference and integration be achieved (Feltovich et al., 2006). With regards to exclusivity, the employment of expertise may well allow individuals to take advantage of automatic processing benefits. For example, stimuli may be processed in a manner which allows for attention to be focused on important information (e.g., the location of an object), as well as other elements of the visual array (e.g., the anchor points).

### Secondary aim

If one is to investigate the interaction of two pieces of spatial information, it would be prudent to also examine interactions with non-spatial elements at both encoding and retrieval. It is important to understand what information is and is not being encoded and consequently retrieved. Interactions at learning will certainly involve STM whereas interactions at retrieval will be more influenced by LTM processes. Specifically, the focus of the secondary aim of this chapter is to examine how object identity information and location information interact and influence performance of each other.

Luck and Vogel (1997) found evidence that visual short-term memory capacity is determined by the number of objects, not the number of object features. Luck and Vogel (1997) presented participants with a stimulus array for 100ms, then after a 900ms pause they were shown either the same or a different array for 2000ms. They were asked to respond to whether it was the same or different to what they had seen in the first presentation. Objects were defined by a varying number of constituent features (e.g., orientation, colour). Luck and Vogel (1997) found that if they increased the number of features this did not affect recall performance. However, if they varied the number of objects they found that performance significantly deteriorated after around three items. These findings suggest that object features are integrated to form a single unit of information with each component retaining the capacity to be retrieved individually otherwise recognition change of features would not have been possible (Luck & Vogel, 1997). Follow up research extended the range of object features to include spatial location (Lee & Chun, 2001). Lee and Chun (2001) found that individuals' performance (up to approximately 3-4 objects)[1] was invariant to spatial location information. Thus, object features including orientation, colour and spatial location appeared to be integrated into a single unit made up of object information in working memory.

Similarly, interactions between elements in LTM are of interest. Evidence suggests that object fragments or components are integrated in LTM and thus the cuing of any one fragment (i.e., object identity) will naturally cue all other elements (i.e., its spatial location) (Jones, 1976). Jones (1976) showed that cuing for location, colour, or object type (identity) by either one of the cued-properties, all other properties or 'fragments' were instantly available, known

[1] This is not to say more objects cannot be stored in STM, only that they cannot be stored to such a high-fidelity as to be recalled accurately. For example, a large stimuli array may allow for the representation of more objects than 3-4, but at a cost of lower-fidelity than a smaller array (Vogel et al., 2001). This may well lead to more chunking and the capitalisation on guessing (Cowan, 2001; Cowan et al., 2005).

as 'all-or-nothing' retrieval. Consequently he put forward the 'fragmentation hypothesis' of cued recall.

The fragmentation hypothesis proposes that a memory trace is made up of fragments that represent components of a learnt visual stimulus. The memory trace is activated on presentation of any single element as a cue. This has implications for the retrieval processes of a memory trace composed of more than one element. Interestingly, this suggests that cueing with multiple elements of a memory trace is no more effective than cueing by any single element on its own, assuming that all elements had been encoded. However, Jones (1976) also highlights that on average one would expect to see some advantage for multiple cuing simply because it is more likely that at least one of the elements is stored in the memory trace. For example, if a stimulus contained four elements and all elements are stored within a memory, then only one of those elements is needed to cue recall of the stimulus. However, if only two elements were stored within a memory then one would expect multiple cueing to have a higher chance of activating either of the two stored elements. Thus, on average this would result in some recall advantage.

In summary, the secondary aim of Experiment 1 is to assess whether object identity and object location aid on another. In other words, does knowing what an is help to know where it is and vice versa.

### 3.1.5 Research rationale

It is clear that expertise processing has a number of advantages over novices when it comes to perceptually organising and retrieving information related to domain-specific stimulus arrays. The expert domain used in the current research is that of text processing. The choice to use text was both empirically grounded as well as pragmatic. Text was chosen specifically instead of traditional geometric shape-type objects, because text is semantically rich, processed automatically (Rawson, 2004), in a higher-order and Gestalt manner (Foss & Harwood, 1975; Anderson, 1974), and has the ability to be processed along side concurrent tasks (Spelke et al., 1976). Additionally, previous research where non-exclusivity (i.e., superadditivity) has been observed tended to employ text stimuli (words/sentences) in one form or another (Anderson & Bower, 1972; Rubin & Wallace, 1989), or other expert domain-specific stimuli (Harding, 2006). Additionally, it is also argued that similar to a musical score (see Harding, 2006) text also possesses a temporal component. For example, as an individual reads along the text to the point of the target object they will have encoded temporal information along with any spatial information. This, it is argued may aid in integration of compatible temporal information encoded from a related source (i.e., a second anchor-target relation) (Arcediano, Escobar, & Miller, 2003; ?, ?, ?).

From a pragmatic point of view, text processing has a number of benefits as a form of expertise. Text processing is a widely acquired expert skill that approximately 99% of the population are capable of (CIA World Book, 2012). This means sample sizes can be large enough for robust statistical modeling. Also, a series of experiments could be sustained for the period of research employing and manipulating a common stimulus type. This allows for a change in experimental outcomes to be measured in a more coherent and valuable manner, giving a clear and comparable picture of research direction.

Additionally, in order to gain further insight into how exclusivity occurs, the current research also examines the interaction between spatial and non-spatial information at retrieval (i.e., secondary aim), specifically how object identity and object location interact to produce memory .

## 3.2 Experiment 1

In Experiment 1 it was aimed to encourage integration between paired spatial memories and thus discourage exclusivity. It sought to achieve this by employing stimuli that are processed holistically and as meaningful units. It is argued that individuals may not be wholly consciously aware of creating connections between spatial information and it is proposed that having an underlying connection between memories will increase the likelihood of integration.

### 3.2.1 Design

A 2 (SA vs. PSA [between]) by 2 (Semantic anchor link vs. Non-semantic anchor link [within]) mixed design was employed. Experiment 1 aimed to test whether a common link between two spatial memories for the same target helped overcome exclusivity. Given that each paired anchor point (left and right) represented separate spatial memories, a common link between memories was achieved by establishing a connection in the form of sentence coherence, theme, and writing style, between anchor points (see Figure 3.1).

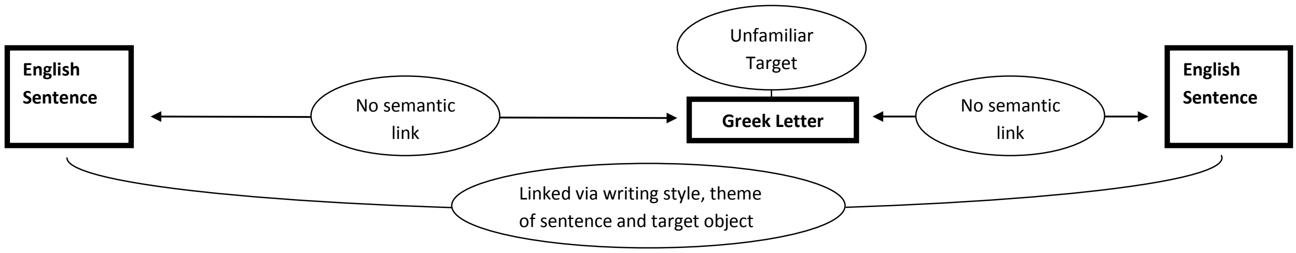


Figure 3.1: Example of design for experiment one

### 3.2.2 Stimuli

Sentences were selected that possessed a theme and were representative of a particular author's style of writing but were not familiar to the individual. A pool of fifteen sentences was created and tested on a pilot sample ($N = 5$) for ease of combination. The nine most easily combined sentences, as measured by correct combination by the pilot sample, were selected. Two example sentences are: "A Thaum is the basic unit of magical strength. It has been universally established as the amount of magic needed to create one small white pigeon or three normal sized billiard balls." (Terry Pratchett - The Colour of Magic), or "About twelve o'clock we turned out and went along up the bank. The river was coming up pretty fast, and lots of driftwood going by on the rise." (Mark Twain - The adventures of Huckleberry Finn).

The target object consisted of one of nine Greek symbols and was presented at a specified location above the sentence. The sentence was split at the point of the target object, leaving a left hand section of sentence and a corresponding right hand section (see Figure 3.2). Anchor points were created by underlining the first 2.5cm's of the sentence (at the far left) and the last 2.5cm's of the sentence (at the far right). During PSA presentation participants would see a target object (e.g., the Greek symbol $\pi$) positioned above a sentence twice, once in relation to a left-hand section of the sentence and once in relation to the corresponding right-hand section of the sentence. At test, participants were cued for a target object's location with the underlined sections of text that acted as relational anchor points from which spatial judgements could be made.

The stimuli, comprising nine non-famous yet stylistically distinct quotes taken from well-known texts (e.g., Homer's Odyssey; Emily Bronte's Wuthering Heights) were translated into Turkish for a non-expertise control. Turkish was selected on the basis that it uses a Latin alphabet very similar to English. Thus, it would

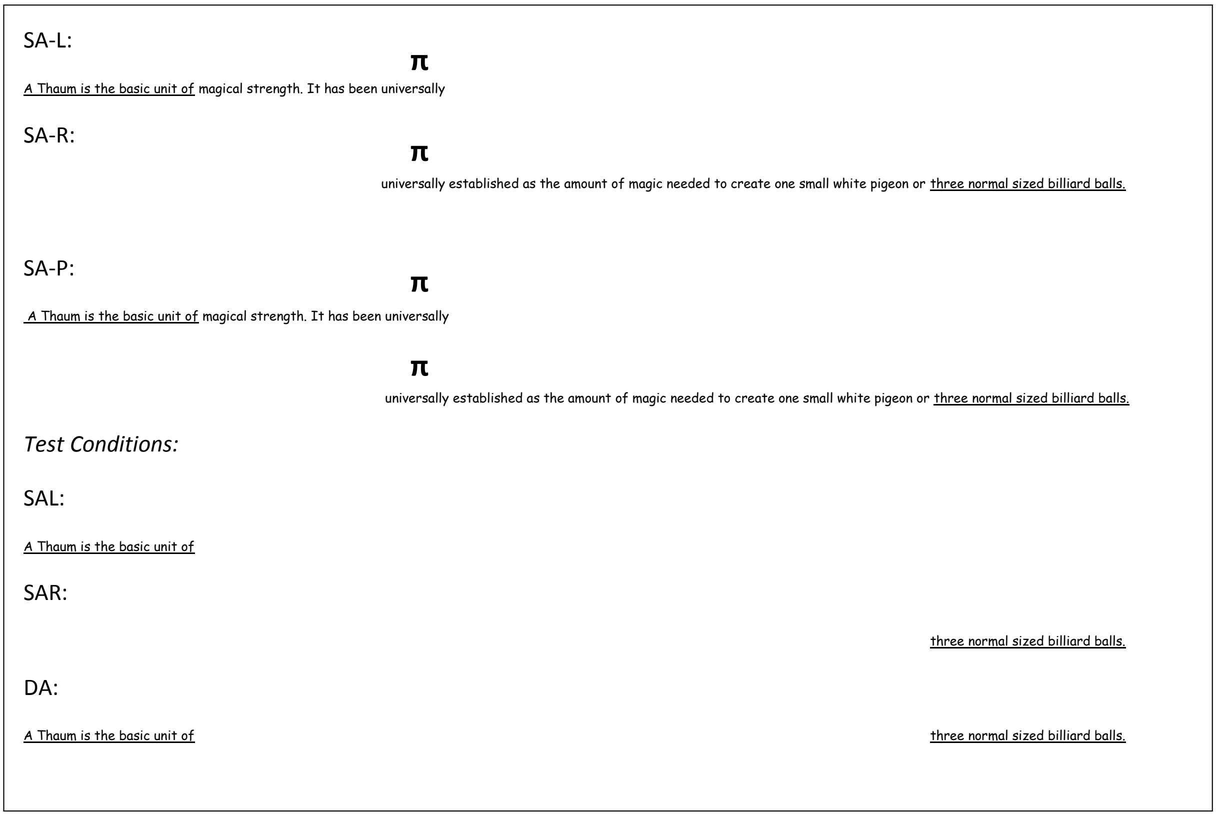


Figure 3.2: An example of learning and test conditions using whole sentences as stimuli - experiment one

appear visually similar to English but without being processed in a manner illustrative of expertise.

### 3.2.3 Participants & Procedure

A total of 43 participants (19 female; mean age = 27.3 years; $SD$ = 7.7; Range = 20-51) were recruited from the University of Leicester and paid £3.00 for their time. All participants were English speakers and had normal or correct-to-normal vision. Participants were blocked by anchor type (either SA-SA or PSA-DA) and given four booklets (one learning and one test in English and Turkish) with corresponding standardised instructions. The task was also explained to them verbally, including the number of sentences to be presented and the type of target object. It was emphasized that their task was to remember the location of the Greek symbol in relation to the underlined section of text presented on the left or right of the target object. Individuals were instructed to spend no longer than 4-5 minutes on both the learning and test booklets. In between learning and test a short distracter task was employed (counting backwards in 3s) to prevent short-term memory rehearsal. To assess memory for an object's content participants were given all anchor words again after estimating all target locations, and were asked to identify which target object (i.e., Greek symbol) was associated with (a) given anchor point(s) (i.e., underlined section of text). This information was used to calculate a target recognition score (TRscore).

### 3.2.4 Results & Discussion

Performance across all conditions was better than chance (i.e., Dscore $< 1$). Fig 3.3 shows location error was lower in the English condition (SA-SA & PSA-DA), however, participants in the PSA-DA condition (i.e, two-memory condition) did not outperform participants in the SA-SA condition (i.e., one-memory) in either language condition. The mean Dscore for the English PSA-DA condition was 0.53 ($SD$=0.22) and for the English SA-SA condition it was 0.69 ($SD$=0.32). The mean Dscore for the Turkish PSA-DA condition was 0.86 ($SD = 0.19$) and for the Turkish SA-SA condition it was 0.82 ($SD = 0.24$).

Multi-level modelling was performed as it allowed for the modeling of an non-orthogonal predictor (TRscore) of Dscore (Baguley, 2012b). Three models were estimated. Model one included TRscore (correct vs. incorrect), Anchor condition (PSA-DA vs SA-SA), and Language condition (English vs. Turkish) as predictors of Dscore. Model two was the same as model one but it included two-way interactions. Model three included three-way interactions. Comparisons of models one, two, and three predicting location error (Dscore) showed model two to be a better fit of the data (see Table 3.2). This model showed both Target Recognition (TRscore) and Language (Turkish as the reference category) were significant predictors of Dscore (see Table 3.3).

| Mean Dscore comparisons | $t$ | $df$ | $p$ |
|---|---|---|---|
| English PSA vs. English SA | 1.70 | 36 | 0.09 |
| Turkish PSA vs. Turkish SA | 0.30 | 36 | 0.76 |
| Overall English vs. Overall Turkish | 4.23 | 76 | $< 0.001$ |

Table 3.1: Summary of mean Dscore comparisons for PSA-DA vs. SA-SA across both language conditions and anchor type, including an overall comparison between English and Turkish performance for Experiment 1

When presented with semantically coherent stimuli (English sentences) participants' location error was significantly reduced over non-semantic stimuli. Analysis of interaction effects showed that in the SA-SA condition, recalling a tar-

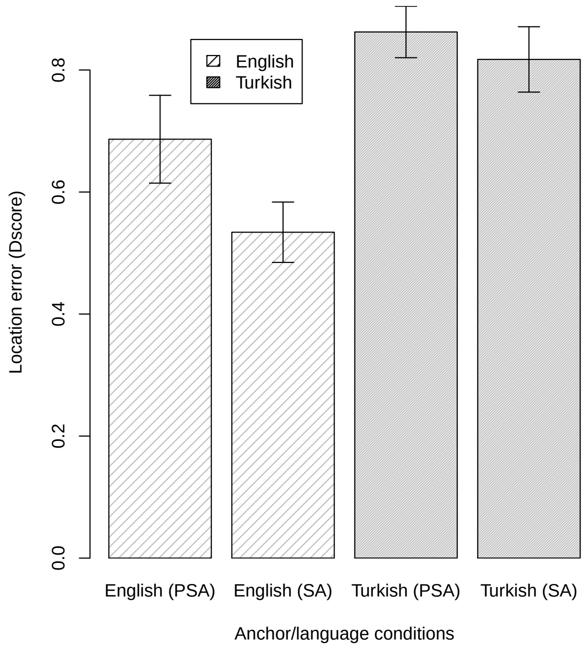


Figure 3.3: Mean location error (Dscore) including 95% CI for each anchor type (PSA-DA and SA-SA) and for both expertise conditions (English and Turkish) for Experiment 3

get's content (TRscore) aided in one's location memory accuracy (see TRscore x Turkish Table 3.3). However, if an individual was presented with two anchors (PSA-DA), correctly identifying the target led to a significant decrease in memory accuracy (see Table 3.3 and Figure 3.4).

The results suggest that having semantically rich information (i.e., English sentences) available at encoding and retrieval enhances overall location memory accuracy. This is in-line with literature that states that level of processing generally enhances memory ability (Craik & Lockhart, 1972; McDaniel, Friedman, & Bourne, 1978). However, semantic coherence between two anchor points for a common target object did not improve location memory over a single anchor point. This suggests a common link between two memories, as manipulated using stylistically distinct sentences, is not enough to encourage integration and overcome exclusivity. Additionally, holistic processing of sentences did not appear to offer any observable benefits for the PSA-DA condition over SA-SA. This suggests text expertise was not able to circumvent any load deficits that may have been contributing to exclusivity.

| Model | *df* | AIC | BIC | logLik | Test | L.Ratio | *p* |
|---|---|---|---|---|---|---|---|
| 1 | 6.00 | 1246.48 | 1273.95 | -617.24 | | | |
| 2 | 9.00 | 1232.57 | 1273.78 | -607.28 | 1 vs 2 | 19.91 | <0.01 |
| 3 | 10.00 | 1233.81 | 1279.60 | -606.90 | 2 vs 3 | 0.76 | 0.38 |

Table 3.2: Summary of model comparison statistics for model one, two and three in Experiment 3

| | Estimate | *SE* | *df* | *t*-value | *p*-value |
|---|---|---|---|---|---|
| (Intercept) | 0.66 | 0.06 | 675 | 10.91 | <0.01 |
| TRscore | -0.26 | 0.08 | 675 | -3.44 | <0.01 |
| Turkish | 0.33 | 0.07 | 675 | 4.79 | <0.01 |
| PSA-DA | 0.00 | 0.08 | 38 | 0.03 | 0.98 |
| TRscore x Turkish | -0.18 | 0.09 | 675 | -2.05 | 0.04 |
| TRscore x PSA-DA | 0.33 | 0.09 | 675 | 3.63 | <0.01 |
| Turkish x PSA-DA | -0.09 | 0.08 | 675 | -1.03 | 0.31 |

Table 3.3: Parameter estimates for model two in Experiment 3 with anchor type (PSA-DA vs. SA-SA), language (English vs. Turkish) and TR score predicting location error (Dscore) for Experiment 1

The analyses suggest that the complex nature of the stimuli may have overloaded cognitive capacity. The fact participants' performance in the PSA-DA condition was significantly worse than SA-SA across both language conditions indicates a unique disadvantage of the stimuli for the PSA-DA condition. It is possible that individuals were not able to match the correct two segments of the same sentence at encoding. If this were the case then this type of mismatching has been shown to be very counter productive for expertise processing. For example, when faces are a mixture of incongruent halves (i.e., celebrity's top halve and unfamiliar bottom halve) people find it very difficult to recognise them (Young, Hellawell, & Hay, 1987). That is, it is difficult to separate out the two halves of the whole. In terms of the current research it is possible that if incorrect connections were made during learning then presentation at test of the correct halves would have disrupted the subjects' ability to match learnt stimuli with respective retrieval cues.

The current research is also in conflict with a previous finding using expertise and clearly shows that expertise processing of domain-specific stimuli does not offer any advantage for holding two spatial memories over one. Harding (2006) used well-known musical scores and showed that they were a benefit to recalling the location of a letter positioned above two segments of related pieces of music. This suggests that perhaps it is not necessarily an expert's ability to process the

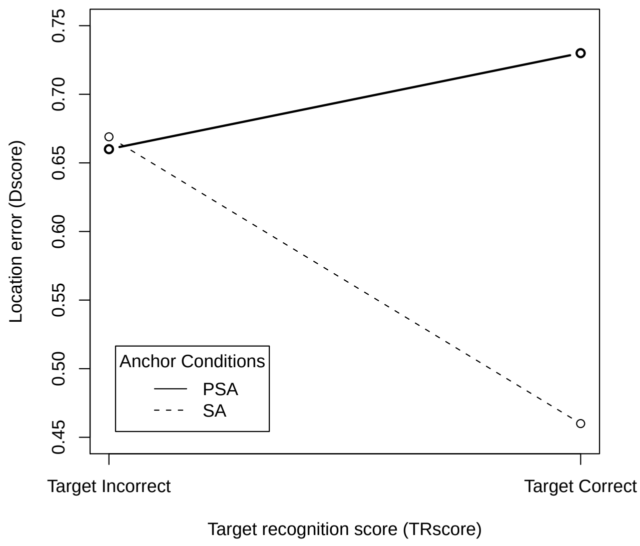


Figure 3.4: A plot showing the interaction between location error (Dscore) and object identification (TRscore) across anchor conditions (PSA-DA vs. SA-SA) for Experiment 1

information holistically or in a Gestalt manner which led to PSA-DA advantages but rather the familiarity between related memories.

It could be argued that any advantage from employing stimuli that are encoded with minimal effort and in a Gestalt manner may be cancelled out by either the load of processing full sentence stimuli or the lack of a more explicit connection between two related segments of a sentence. Therefore, experiment two seeks to lighten cognitive load and increase probability of recognising the relation between components of two related sentence segments.

## 3.3 Experiment 2

Experiment 1 showed overall performance gains for the English sentence stimuli. Experiment 2 builds on Experiment 1 by employing stimuli which offer individuals an even stronger connection between paired memories. Experiment 2 retains text as stimulus to observe comparable changes across the two experiments. In order to enhance integration potentiality further by lightening cognitive load, familiar sentences are employed.

Familiarity in this instance will provide an explicit (rather than implicit, as seen in Experiment 1) connection between paired anchor points (i.e., between memories for the same target object). It is argued that familiarity will offer a number of additional benefits to the processing of spatial information. First, it will reduce overall processing load because the sentences will be processed more automatically and this will also enable more attention to be directed towards the task of encoding the location of the target. Attention can be focused towards recalling the object and its location rather than trying to learn the content of the sentence. Participants will not need to try and remember the content of the sentence. Second, familiarity will enable individuals to position the target object based on their knowledge of the sentence structure (i.e., the point along the 'plot' of the sentence at which the target object appears). Third, the sentence sections form a coherently distinct unit which allows for the potential of holistic processing and differentiation between other sentences.

### 3.3.1 Design

A 2 (SA vs. PSA [between]) by 2 (Familiar vs. Non-familiar [within]) mixed design was employed. Exclusivity was assessed in the same manner for Experiment 1 (i.e., comparing SA-SA with PSA-DA, see Experiment one - 'Methods'). Experiment 2 aimed to increase the link between two spatial memories for the same target as well as reducing overall task load. Given that each paired anchor point (left & right) represents separate spatial memories, a connection between memories was achieved by establishing a common link between anchor points, in the form of *a priori* knowledge of a sentence's content, theme, and syntactical structure (see Figure 3.5). To achieve this the current experiment uses *nursery rhymes* as sentences which offer familiar and distinct content.

Unlike Experiment 1, Experiment 2 was programmed using E-Prime© which enabled more consistent presentation of stimuli and recording of responses. Familiarity was ensured by asking participants to tick next to each sentence whether they knew the sentence well enough to reproduce it verbally with little rehearsal or assistance. Nearly one hundred percent of participants ticked yes to all nursery rhymes. The current design ensures no additional cues such as the edge of the computer screen were employed by dimming the light, thus, obscuring the display's borders.

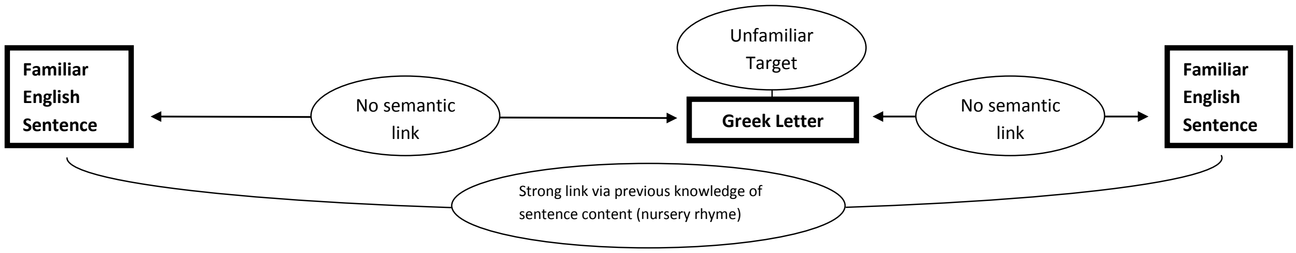


Figure 3.5: Example of design for experiment two

### 3.3.2 Stimuli

Nine nursery rhymes were selected based on popularity according to a survey for National Bookstart Day of 2,500 people (Booktrust, 2009). Two example sentences are: "Jack and Jill went up the hill to fetch a pail of water, Jack fell down and broke his crown and Jill came tumbling after." and "Humpty Dumpty sat on a wall. Humpty Dumpty had a great fall. All the kings horses and all the king's men Couldn't put Humpty together again." The target object remained the same as Experiment 1 (Greek symbol) and was presented at a specified location above the sentence. As in Experiment 1, the nursery rhyme sentences were split at the point of the target object, leaving a left hand section of sentence and a corresponding right hand section (see Figure 3.2 for an equivalent example using non-familiar sentences). Anchor points were created by underlining the first 2.5 cms of the sentence (at the far left) and the last 2.5 cms of the sentence (at the far right).

During PSA presentation participants would see a target object (e.g., Greek symbol $\pi$) positioned above a sentence twice, once in relation to a left-hand section of the sentence and once in relation to the corresponding right-hand section of the corresponding sentence. At test, participants were cued for a target object's location with the underlined sections of text that acted as relational anchor points from which spatial judgements could be made. The non-familiar English sentences from Experiment 1 were used as control stimuli. This offered a comparison between familiar and non-familiar semantically rich stimuli.

### 3.3.3 Participants & Procedure

Participants were recruited from the University of Leicester and Nottingham Trent University ($N$=60) and had normal or corrected-to-normal vision. Participants were paid £3 for their time. The learning phase involved the participants being presented with all sections of the nursery rhymes with corresponding target objects on a screen. Each presentation was timed to last for 14 seconds. A short distracter task (30 seconds) was used to prevent rehearsal. The test phase involved presenting participants with either left or right (SA) or both anchors (DA) to cue the target object's location (i.e., one half of a nursery rhyme or both corresponding halves). Participants would click with a mouse directly on the screen where they remembered the target object to be in relation to the given anchor(s). The test phase was not timed.

### 3.3.4 Results & Discussion

Results show that Dscore was better than chance (i.e., Dscore<1) across all conditions. Figure 3.6 shows a slight advantage for PSA-DA over SA-SA in the nursery rhymes condition. The mean Dscore for the nursery rhymes PSA-DA condition was 0.61 ($SD$ = 0.26) and for the SA-SA condition it was 0.63 ($SD$ 0.28). The mean Dscore for the English PSA-DA condition was 0.83 ($SD$= 0.26) and for the English SA-SA condition it was 0.69 ($SD$ = 0.16).

The findings show the same detriment of employing non-familiar yet semantically rich stimuli in the form of English sentences. Specifically, the results show that there was a significant decrease in location accuracy for PSA-DA over SA-SA in the English condition as was observed in Experiment 1 (see Table 3.4). However, there was no significant difference between PSA-DA and SA-SA for the Nursery Rhyme condition. Overall location error in both PSA-DA and SA-SA was lower in the Nursery rhyme condition over the English (non-familiar) condition. This suggests that holding existing knowledge of stimuli content enhances object location memory performance. Although not statistically significant, the initial experimental findings are promising because they show PSA-DA performance to be greater than SA when anchor points are familiar (see Figure 3.6).

| Dscore comparisons | $t$-value | $df$ | $p$ |
|---|---|---|---|
| English PSA-DA vs. English SA-SA | 3.18 | 57 | $< 0.001$ |
| Nursery PSA-DA vs. Nursery SA-SA | 0.02 | 57 | 0.98 |
| Overall Nursery vs. Overall English | 3.17 | 118 | $< 0.01$ |

Table 3.4: Summary of mean Dscore comparisons for PSA-DA vs. SA-SA across both familiarity conditions including an overall comparison between non-familiar and familiar performance for Experiment 2

Linear modelling was used to investigate whether anchor condition or stimulus

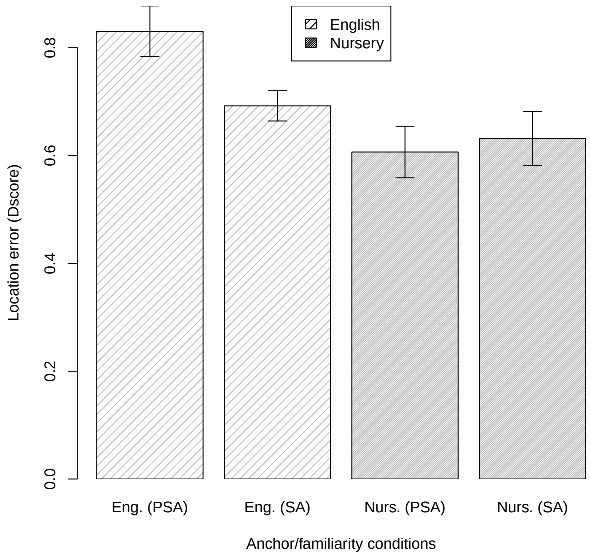


Figure 3.6: Graph showing mean location error (Dscore) across all familiarity (English vs Nursery) and anchor conditions (SA vs PSA) including 95 % CI for Experiment 2

type were having an effect on location memory accuracy. Two models were estimated. Model one included Anchor type (PSA-DA vs. SA-SA) and Familiarity (English vs. Nursery) as predictors of Dscore. Model two additionally included an interaction between Anchor type and Familiarity type (Anchor x Familiarity). Model comparisons showed marginal differences between the two models. On inspection of the interaction term model two was chosen as it was more informative (see Table 3.5). A summary of model two can be seen in Figure 3.6. This shows anchor condition (PSA-DA vs SA-SA) to be a significant predictor of location accuracy. If an individual is in the PSA-DA condition they typically perform worse than in the SA-SA condition. However, as can be seen from Figure 3.6, this is substantially attributable to non-familiar sentence performance. The interaction effect (Figure 3.7) is perhaps more informative and shows that if an individual was presented with nursery rhymes in the two memory condition (i.e., PSA-DA) their location accuracy increased significantly, whereas if they were presented with non-familiar sentences the performance gains were marginal.

| Model | *df* | AIC | BIC | logLik | Test | L.Ratio | *p* |
|---|---|---|---|---|---|---|---|
| 1 | 5.00 | 2128.12 | 2153.12 | -1059.06 | | | |
| 2 | 6.00 | 2126.29 | 2156.30 | -1057.15 | 1 vs 2 | 3.83 | 0.05 |

Table 3.5: Summary of model comparison statistics for model one and two in Experiment 3

| | Estimates | *SE* | *df* | *t* | *p* |
|---|---|---|---|---|---|
| (Intercept) | 0.69 | 0.04 | 1035 | 15.98 | $< 0.01$ |
| Anchor | 0.13 | 0.06 | 1035 | 2.13 | 0.03 |
| Familiarity | -0.06 | 0.05 | 1035 | -1.14 | 0.25 |
| Anchor x Familiarity | -0.15 | 0.08 | 1035 | -1.95 | 0.05 |

Table 3.6: Parameter estimates for model one with Familiarity (English vs. Nursery rhymes) and Anchor type (PSA-DA vs. SA-SA) predicting location memory accuracy (Dscore) for Experiment 2

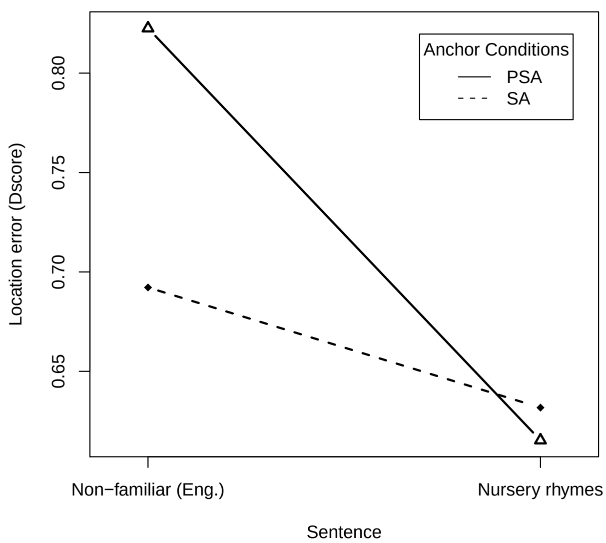


Figure 3.7: An interaction plot between anchor conditions (PSA-DA vs. SA-SA) and familiarity (English vs. Nursery rhymes) for Experiment 2

## 3.4 General Discussion

### 3.4.1 What the findings mean for exclusivity

The overall findings show semantically rich stimuli will generally enhance location memory performance. This suggests recalling the location of an object in relation to a semantically rich source will be more accurate than a non-semantically rich source. The results suggest expertise processing does not play a role in overcoming spatial memory exclusivity. Through the use of expertise it was shown that an ability to recognise two related memories and the use of information which is holistically processed does not circumvent exclusive processing.

Results also show that implicit semantic links between two sources of spatial information (non-familiar yet semantically rich) do not encourage aggregation of said memory sources. This suggests that if memory interference is occurring and preventing integration then exclusive processing is not attributable to the semantic incoherence of related memory units. In Experiment 2 the use of nursery rhymes ensured that each memory could be explicitly recognised as being part of a whole. This had no significant effect on performance for two memories in comparison to one.

These results indicate that having familiar stimuli significantly improves spatial memory performance over simply semantically rich content. This is most saliently observed by examining the extent of improvement from having familiar sentences for the PSA-DA compared with SA-SA condition (see Figure 3.7). This illustrates sharply the importance of individuals being able to recognise that two halves of the sentence belong to a complete unit of information. This would hold no benefit for the SA-SA condition as individuals receive only one part of the sentence (i.e., there is nothing to match it up to).

There is evidence of some performance gain from having familiar sentences. Experiment 2 showed significant differences in location memory performance between familiar and non-familiar sentences. Presumably, this indicates the contribution of reduced load (i.e., not having to remember the sentence as well as the target) when encoding location information. The benefits observed across the PSA-DA condition from having familiar stimuli indicate the importance of explicitly recognising the connection between information that is processed alongside spatial information (i.e., information within which spatial information is contained).

### 3.4.2 What the findings mean for expertise

These findings are incongruent with those of previous research (Harding, 2006). Harding (2006) manipulated semantic processing of spatial objects through the use of musical expertise. Results from Harding (2006) showed that when a letter was placed above two segments of a musical score, experts showed advantage for having two memories over having one. The current findings support the idea that familiarity of stimuli does show improvement when holding two related memories in comparison to non-familiar stimuli. They are, however, in conflict with the idea that general expertise processing offers any advantage for holding two spatial memories over one. Thus, the ease at which domain-specific stimuli are processed, the ability to chunk information into more manageable processing units, and the capacity to extract higher-order connections between related pieces of information is not sufficient to observe any benefits from holding two spatial memories.

Quite why musical expertise demonstrates an advantage over reading expertise is difficult to explain. However, it may be accounted for by the fact that music-related stimuli are processed with more ease than that of whole sentences. With each word of a sentence comes semantic content and the development of a propositional representation, whereas musical scores evoke a representation of patterns of auditory information. This difference in stimuli can be argued to stem from a difference of visual and perceptual processing demands between the two stimulus-types. Take for instance one word which consists of multiple letters and contains semantic *and* acoustic content. In comparison, one note will consist of one tone and has the advantage of only being stored acoustically. This again reiterates the idea that a further reduction in stimuli processing might produce levels of performance in line with Harding (2006). Additionally, the semantic content that provides a connection between two memories, through familiarity, is helpful up until a point. After that, it may burden memory capacity at a cost to either location information or object identity information.

It could be argued that the familiarity of the sentences in Experiment 2 freed up resources by not requiring participants to encode the sections of sentence that acted as test cues. In the familiar sentence condition individuals could extract the meaning of the sentence with little effort. Individuals could instead rely on long-term existing knowledge in order to retrieve verbatim information. Therefore, at encoding subjects could attend features of the stimulus other than syntax, such as spatial content. In contrast, non-familiar sentences would involve the encoding of verbatim information because this information was required at test as a cue.

The effortless manner in which we process text may have been counteracted by the overloading of semantic content. This is evident in Experiment 1 where the participants in the PSA-DA condition performed significantly worse than participants in the SA-SA condition. The processing of unfamiliar text for the purpose of recall was simply too much for an individual. This suggests the effortless nature of text encoding does not necessarily equate to effortless retrieval and can hamper location memory, unless the stimulus is familiar. Arguably another important factor, as observed in Experiment 2, is the semantic connection between paired anchor points which came from employing familiar text (i.e., nursery rhymes).

The improvement witnessed from Experiment 1 to Experiment 2 suggests that the advantages of stimulus familiarity are particularly beneficial for the PSA-DA condition. This means that some element of familiarity must help the interaction of multiple memories either at encoding or recall. It is argued that this advantage could take the form of two possible benefits. First, familiarity allows the two segments of sentence to be recognised as being two parts of a whole. Second, it allows attentional resources to be focused elsewhere (e.g., object identity and object location). However, seeing as familiar stimuli would improve recall in both SA-SA and PSA-DA condition it might be more plausible that familiarity allows for easier identification of related anchor points, which is not required when only having one memory for an object (i.e., in the SA-SA condition).

### 3.4.3 Interaction of memory information

The results from the interaction analysis support the notion that the PSA-DA condition placed more demand on cognitive load than the SA-SA condition, at least in Experiment 1. Heavy task demands meant that competition between fragments of the learnt memory was arguably preventing spatial information retrieval in some instances, in favour of non-spatial information. This would need to be tested in further experiments to establish whether under a reduction of load two memory fragments interact in a more harmonious manner. In other words, are participants able to employ object identity and object location information collaboratively when they have the resources to process to both? This examination would highlight whether task-overload induced the 'what'/'where' trade-off as observed in Experiment 1 of this chapter.

What can also be deduced from these findings is that 'what' and 'where' information are processed separately. This is evidenced by the existence of a trade-off in Experiment 1. Neurological findings add support to this idea. Postma et al.

(2004) posited there to be three functional steps to remembering where something is located. First, the object of interest must be recognised. Second, its location in space must be specified, and third, the object's identity and its location must be combined. Lucke (2005) provides evidence that the binding of object features occurs in spatial working memory (probably in the dorsal stream Kravitz et al., 2013). This suggests that in the case of the current findings effort is required at the point of encoding to combine spatial and object identity information. When effort is diverted, under conditions of heavy cognitive load, working memory capacity is stretched leaving what and where information unable to be combined. Under such circumstances this seems to result in recalling probably the most salient feature at time of encoding (i.e., *either* where the object was *or* what the object was).

### 3.4.4 Explaining disparity between English sentence performance from Experiment 1 to Experiment 2

The results show there to be a discrepancy between the English sentence performance in Experiment 1 and Experiment 2, even though the same stimuli was employed. As can be seen in Figure 3.3 the English PSA-DA and SA-SA Dscore was much lower than that in Experiment 2 (see Figure 3.6). This change can be explained by changes in procedural approach. Experiment 2, for purposes of increasing consistency in trial presentation, transposed the stimuli from Experiment 1 to a computer-based format. This, it is argued, provides better consistency of trial presentations and higher level of record accuracy of an individual's response. This meant that presentation time for each trial was less variable than that of Experiment 1 but was also overall reduced. Nelson and Chaiklin (1980) show that the levels of distortion of location accuracy are directly proportional to stimuli presentation time. Thus, the overall performance decline seen in Experiment 2 can be attributed to less exposure time to each anchor-target presentation. Given that the pattern of the relationship remained consistent between PSA-DA and SA-SA performance across both experiments strongly suggests the differences in absolute performance were likely a consequence of procedural change (i.e., a reduction in viewing time). This is supported when comparing the differences between mean Dscores for PSA-DA and SA-SA conditions across both experiments (Exp. 1 = 0.15, Exp. 2 = 0.14), which reflect near identical mean differences.

## 3.5 Conclusions

At the beginning of this chapter it was hypothesised that the processing of information in an expert manner would help to overcome exclusivity of spatial memories. The evidence shows that for text expertise this was not the case. This contradicts Harding's (2006) findings where musical experts showed some advantage for holding two memories for a target object in comparison to one memory. The incongruence between the current findings and that of previous work questions the generalisability of domain-specific expertise skills to the same task.

However, the findings do provide foundations on which to develop alternative strategies that may overcome exclusivity. The findings show that recognising related pieces of information contained within two memories is important for memory performance. When a link between memories is not apparent performance in the PSA-DA condition is disproportionately impacted compared to the SA-SA condition.

These results also indicate that the use of entire sentences (at least unfamiliar ones) may require too much attention and result in an overloading of working memory. If sentences are familiar this appears to attenuate the amount of effort required to process the sentences. The consequences of extensive processing load can be seen to result in an apparent trade-off between binding of an object's features at encoding. Thus, freeing up capacity to attend to an object is of utmost importance to allow memory fragments to work together at retreival (at least in the PSA-DA condition).

The results highlight that a heavy processing load significantly affects the two memory condition (PSA-DA) more than the single memory condition (SA-SA). This is evident by the fact the PSA-DA condition reached chance in Experiment 1 but the SA-SA condition did not. If processing effort was equal for both conditions then one would expect equal detriment across both conditions. The unequal detriment might be attributable solely to the nature of the stimuli, but it might also be attributable to underlying effort required in the processing of two pieces of spatial information. In other words, the load differential may be accounted for by the stimuli or it might be a mixture of the stimuli that is exacerbated by the effort required for encoding two spatial memories.

# Chapter 4

# Semantics and Exclusivity

## 4.1 Introduction

Experiments 1 and 2 demonstrated that familiarity had a positive impact on retrieving information from two related memories. This finding suggests that expertise processing per se is not enough to overcome exclusivity. The finding did show however that ability to recognise the connection between two sentences had a positive effect on location memory performance. Furthermore it appeared that sentence stimuli required excessive attentional effort. This led to a trade-off between retrieving fragments of a memory trace (i.e., an object's identity *or* its location).

The experiments in this chapter therefore seek to reduce load at learning, increase the semantic connection between related anchor points, and make related memories more distinct from one another (Experiment 3). Experiment 4 also adapts the presentation at learning and test of the stimuli to ascertain a better understanding of whether two memories are actually held and accessible.

### 4.1.1 Semantics and parallel processing

From Experiments 1 and 2 it was clear that semantic content (if unfamiliar) burdened memory processes. Moreover, it was also clear that the connection of semantic content between two spatially-related memories improved accuracy at recall. Thus, it appears it is rather the *amount* of stimulus content that was the culprit for overloading memory capacity not semantic content per se. This means if semantics can be employed in a way that has minimal impact on processing load but at the same time exploits ability to recognise the connection between two related memories, it might be possible to overcome exclusivity.

Additional benefits may be observed from employing semantics in this more efficient manner (i.e., no overload cost whilst retaining the benefits of semantic coherence between memories). Grouping of stimuli semantically into distinct categories may overcome any bottlenecks present in retrieving mnemonic information and consequently allow for parallel processing. Research shows that retrieving two pieces of information can result in a bottleneck (Carrier & Pashler, 1995) which limits the amount of information that can be passed from memory stores to a central processor (Carrier & Pashler, 1995; Rohrer & Pashler, 1998; Nino & Rickard, 2003). Once limited capacity has been reached this results in a bottleneck where only some information can pass through. In such circumstances information for a second source is either blocked or suppressed until processing resources have been freed up from completion of a current task. After processing completion more information can be received from the next source. In such a case information is said to be retrieved serially.

However, some studies show that central processor capacity can be freed-up when information is derived from a similar source. For example, when it is derived from the same semantic (Rohrer & Pashler, 1998) or functional (Logan & Schulkind, 2000) category. This is accounted for by reducing the need to switch between categories. Such a shift in retrieval task means participants must restart the retrieval process for every independent category (Nino & Rickard, 2003). In other words, the effort needed to switch between representational categories consumes a portion of processing capacity which restricts the availability to process other information. Likewise, when no switching is required (i.e., both memories are derived from the same category), information can be retrieved in parallel.

Parallel retrieval has shown to be advantageous for semantic information. This may have a knock on effect for spatial information and specifically exclusivity (which may itself stem from similar limited capacities of a central bottleneck as semantic information). That is, spatial and semantic information may be integrated together which means freeing up of one would result in freeing up of the other. There is some evidence for such integration in working memory where components (i.e., semantic and spatial) of an object are integrated into one unit at encoding (Luck & Vogel, 1997; Lee & Chun, 2001; Vogel et al., 2001). The corollary of removing any bottleneck would mean concurrent cueing of both spatial memories (i.e., PSA-DA) could take place and memories could be retrieved simultaneously. This would increase the likelihood of aggregation compared with the presence of a bottleneck. Thus, if integration of semantic and spatial information occurs then one might see the same benefits attributable to semantic information retrieval as for spatial information retrieval.

Other advantages of clustering spatial information by a semantic category is evident in the literature. Hirtle and Jonides (1985) showed that individuals imposed semantic labels upon spatial information and that this led to psychological clustering of spatial representations. They argued that although imposing semantic categories can result in small biases, generally it improves spatial judgements from memory. They showed individuals' ability to recall spatial information was more accurate within a semantic group than between semantic groups. Thus, memory advantages are localised to judgements of items contained within the same semantic category. Interestingly, Craik and Tulving (1975) also found that individuals recall items better when attention is focused on semantic information rather than physical features.

From Experiment 1 and Experiment 2 it is evident that task difficulty is an issue and the more task complexity can be reduced, either through semantics or familiarity, the greater the potential to observe non-exclusivity. Experiment 3 of the current chapter reduces task complexity in a number of ways. First, it does not use sentences but rather single words. Thus, there is less to remember. Second, it uses a semantically rich target word rather than a Greek letter. This will create a stronger association between the target and anchor point. Third, anchor words are categorically related across all testing conditions.

### 4.1.2 Semantics and distinctiveness

Semantic categories have another beneficial impact upon spatial memory exclusivity other than allowing for parallel processing. From Experiment 1 and Experiment 2 it is clear that being able to connect two related memories is important for accuracy of recall. An aspect that coincides with this is an ability to distinguish between a pair of anchor points and other pairs of anchor points. Thus, allowing for each related memory of a pair to be derived from the same semantic category makes each related pair distinct from other related pairs.

An essential component of memory retrieval is distinguishing between memories, particularly when sources are many and similar. An excellent example of this comes from Hu and Ericsson (2012) who studied the prolific memory expert Chao Lu (current world record holder for recalling the mathematical constant Pi to over 60,000 decimal places). Hu and Ericsson (2012) found that Chao Lu relied heavily on encoding pairs of consecutive images in terms of uniqueness to enable distinction from other chunks of subsequent digits. The ability (strategic or otherwise) to assign uniqueness to sets of memories has been demonstrated consistently in the literature as a fundamental process in retrieval precision (Neath & Brown, 2007). Howe (1998) attributes this to a reduction in interference and potential confusion with other like memories (an example of which is the von Restorff effect [von Restorff, 1933]). Interference between memories can stem from a number of factors such a semantic similarity (Geraci, McDaniel, Manzano, & Roediger-III, 2009), geometric similarity (Bireta, Surprenant, & Neath, 2008), and phonological similarity (Conrad & Hull, 1964).

Guerard, Neath, Surprenant, and Tremblay (2010) investigated whether item discriminability influences serial memory for spatial information. They induced distinctness of memories by manipulating the physical (i.e., shape and darkness) or temporal characteristics (i.e., interval between presentation) of a to-be-remembered sequence of target dots. The results indicated that item discriminability modulates memory performance of spatial information much in the same way as it has in previous research for alternative 'types' of information (e.g., verbal, see Neath, Brown, McCormack, Chater, & Freeman, 2006). The key finding relevant to the current study is that discrimination between sets of memories may overcome any interference observed previously (in the form of exclusivity). This can be achieved by distinguishing pairs of anchor points and therefore memory context from other pairs.

### 4.1.3 Research rationale

This section clearly sets out the objectives for each experiment contained within the chapter.

The aims of Experiment 3 are to:

1. Introduce a semantic relationship between related anchor points
2. Increase the semantic content of the target object and examine the importance of doing so
3. Make pairs of related memories distinct from other pairs
4. Make the relationship between the target object and the anchor points distinct
5. Test whether a trade-off between 'what' and 'where' information (as observed in Experiment 1) remains present once load is significantly reduced

The aims of Experiment 4 are to:

6. Investigate the importance of presentation order of related mem-

ories to establish if memory dominance is present
7. Examine whether separate yet related memories are available at test
8. Test whether perceiving an integrated spatial memory at learning in a single viewing increases the potential to overcome exclusivity
9. Isolate the impact of concurrent retrieval on exclusivity

## 4.2 Experiment 3

Experiment 3 assigns a semantic category to each pair of anchor points to make them semantically linked and also semantically distinctive from all other pairs of anchor points. It also introduces semantic content to the target object and manipulates this on two levels (see Figure 4.1). These are whether the target is drawn from the same semantic category as the anchor points or a semantically neutral category to the anchor points.

### 4.2.1 Design

A 2 (SA-SA vs. PSA-DA) x 2 (categorical target vs. neutral target) mixed design was employed. The first factor was again the test of exclusivity and manipulated the number of anchor points participants were exposed to at learning and test (SA-SA vs PSA-DA), this was a within-subject factor. The second factor manipulated the distinctiveness between the target object and the anchor points it was presented with. This was a between subject factor and was manipulated on two levels (categorical target vs. neutral target). Interference may occur in two instances between related pairs of anchor points and also between the target and each anchor point. The first is dealt with by the overall stimuli employed in constructing the anchor points. The second was dealt with by manipulating whether the entire content of both memories are derived from the same semantic category, or target type varied according to the anchor's category. For example, anchor point one, the target object, and anchor point two were either all derived from the same semantic category or the anchor points were but the target object came from a neutral category (see Stimuli section).

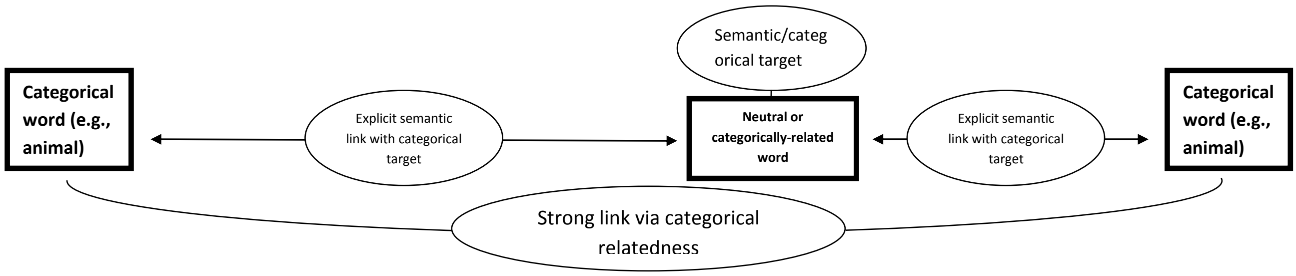


Figure 4.1: Example of design for experiment three

### 4.2.2 Stimuli

The stimuli comprised of 18 sets of categorically related 3-5 letter words (see Table 4.1). This was designed to allow for distinction between pairs of spatial memories by increasing distinctiveness between anchor-point pairs. It also allowed for increased distinctiveness of each singular spatial memory within a pair of memories by varying the categorical relatedness of the target object. A unique category was used for each pair of anchor points that shared a common target word. For example, a target word in location 7 was presented in relation to two anchor points (one anchor to the left and one to the right). These anchor points shared a specific category (e.g., types of musical instrument, fish, countries, etc). This meant each pair was categorically distinct from one another. Additionally, the target was either categorically or neutrally related to the anchor points (e.g., if category = musical instruments, then left anchor = 'Guitar', right anchor = 'Piano', target = 'Violin' *or* 'Banana'). Neutral target words were selected to possess high imagery (M = 5.9, SD = 0.70 out of a possible range 1-7) and high meaningfulness (M = 6.7, SD = 0.80 out of a possible range 1-10) values (Paivio et al., 1968). Research shows better retention for high imagery words (Light & Berger, 1975).

### 4.2.3 Participants & procedure

A total of 42 (24 female; Mean age=24.36; *SD*=2.14; Range=18-31) participants were recruited from Nottingham Trent University and awarded research credits for their time. The experiment was designed and carried out on a computer using E-Prime© software. Subjects were presented with a series of anchor-word trials. Each trial consisted of a target word located a distance from an anchor word at a fixed location (either to the left or right hand side of the screen depending upon condition) and lasted for 14 seconds. The subjects were instructed to remember

| Location | Category | Right Anchor | Left Anchor | Target (categorical) | Target (neutral) |
|---|---|---|---|---|---|
| 1 | Body parts | Elbow | Foot | hand | hope |
| 2 | Furniture | Chair | Table | bed | chief |
| 3 | Fruit | Mango | Banana | apple | slave |
| 4 | Trees | Oak | Birch | pine | board |
| 5 | Bodies of water | Pacific | Atlantic | nile | vest |
| 6 | US States | Texas | Florida | alaska | brain |
| 7 | Birds | Pigeon | Eagle | swan | nun |
| 8 | Musical Instruments | Piano | Guitar | flute | judge |
| 9 | School Subjects | Chemistry | Biology | history | salad |

Table 4.1: An example of a randomly generated stimuli set for Experiment 3

where the target word was located in relation to the anchor word. In between the learning phase and the test phase a short distractor task was employed (counting backwards in 3's) to prevent any short-term memory rehearsal. At test participants clicked using a mouse where on the screen they remembered the corresponding target word to have been located. After completing all location estimations they were given all the anchor words again in the same format as previously and they had to identify which target word was associated with a given anchor word. This meant memory for an object's identity could be examined as a function of memory for its location (as in Experiment 1), but under conditions of lighter processing load.

### 4.2.4 Results & discussion

The results were split into two stages of analysis. The first stage estimated models regarding the effects of anchor type (PSA-DA vs. SA-SA) and target type (neutral vs. categorical) on location accuracy (Dscore). The second stage analysed the impact of target recognition, anchor type (PSA-DA vs. SA-SA) and the interaction between the two on location accuracy (Dscore) (for purposes of comparison with Experiment 1).

The reason why the analysis was split into stages is because only the data where the target was neutral to the anchor points could be used for the interaction analysis and the effect of target recognition on Dscore. This is because when the target was categorically related to the anchor points the object's identity could be deduced from the semantic category of the anchor word cues. For example, when given the cue words 'Guitar' and 'Piano', a subject could simply identify the category as being musical instruments and select the correct target word (i.e., the musical instrument-related target word). This meant no information regarding the relationship between location accuracy and correct object identification could be extracted from the categorically related target word condition. If it had been included in the analysis it would have obscured the relationship between neutral target correctness and location accuracy. This meant to establish the impact of correctly identifying an object on location accuracy categorical target word data was excluded and a set of models were estimated with only the neutral target word data.

The results show all conditions to be better than chance (i.e., Dscore <1) which indicates some information for object location. The mean Dscore for the neutral-target PSA-DA condition was 0.54 ($SD = 0.23$) and for the neutral-target SA-SA condition it was 0.56 ($SD = 0.31$). The mean Dscore for the categorical-target PSA-DA condition was 0.57 ($SD = 0.35$) and for the categorical-target SA-SA it was 0.59 ($SD = 0.26$).

### 4.2.5 Contrasting Dscore performance in Experiment 2 and Experiment 3

Before analysis of Experiment 3 data is reported a comparison between overall performance difference in Dscore between Experiment 2 ($Mean = .73$, $SD = .59$) and Experiment 3 ($Mean = .58$, $SD = .61$) is summarised. Overall location accuracy was increased (Dscore reduced) from Experiment 2 ($t(1474) = 4.410$, $p < 0.001$) (see Figure 4.2). This suggests that the reduction of load by using words instead of complete sentences had a positive effect of recalling location information. This means that when load is reduced, location information can be better attended to and therefore encoded and recalled. This is in line with the literature which shows attention and spatial memory to be related (Lansdale, 1998; Naveh-Benjamin, 1987, 1988; Dayan & Thomas, 1995). This also has implications for the literature on the automaticity of coding spatial information and suggests that the more capacity to allocate attention to a presented stimulus results in greater spatial memory performance. This suggests that effort is involved in processing spatial information but more importantly that the level of effort (i.e., attention) determines the quality of spatial information recall. This is in line with much of the literature (Caldwell & Masson, 2001; Naveh-Benjamin, 1987, 1988; Lansdale, 1998).

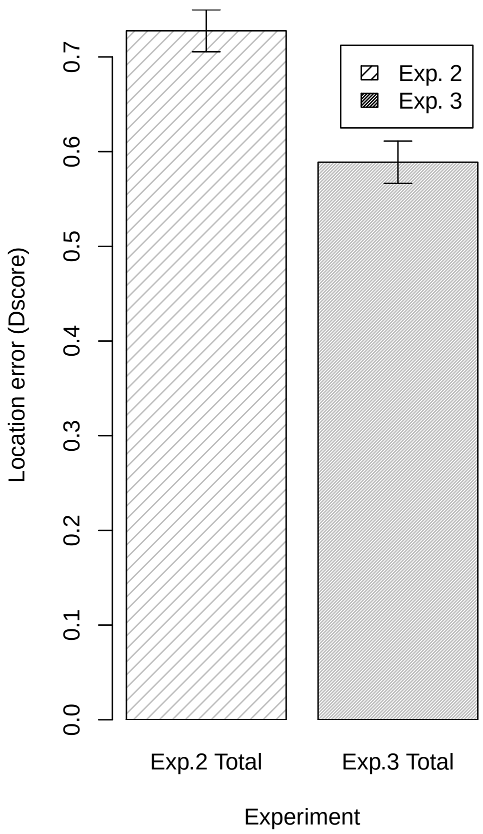


Figure 4.2: Graph showing mean location error (Dscore) across PSA-DA and SA-SA conditions for Experiment 2 and Experiment 3, including 95 % CI

### 4.2.6 Comparisons across anchor conditions for Experiment 3

The first stage of model estimations is presented in Tables 4.2 and 4.3. Table 4.2 shows model comparisons between model one which includes anchor type (PSA-DA vs. SA-SA) and target type (neutral vs. categorical) predicting location accuracy (Dscore) and model two which additionally includes an interaction term (Target type x Anchor type). As can be seen model one was a better fit of the data. Model one showed neither anchor type nor target type to be significant predictors of location error (see Table 4.8). This shows no difference between holding one memory (i.e., SA-SA condition) and holding two related spatial memories (i.e., PSA-DA) for a target object's location. These findings

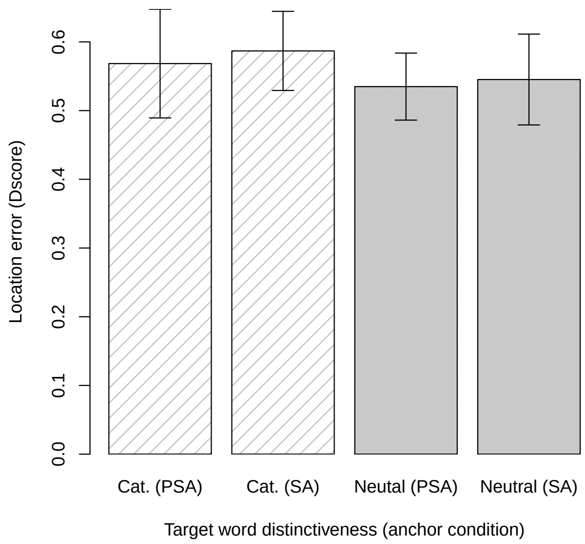


Figure 4.3: Graph showing mean location error (Dscore) across anchor type and target type for Experiment 3, including 95% CI

are comparable to that of Experiment 2 and reiterates the presence of exclusive processing.

| Model | *df* | AIC | BIC | logLik | Test | L.Ratio | *p* |
|---|---|---|---|---|---|---|---|
| 1-way | 5 | 1382.07 | 1405.21 | -686.04 | | | |
| 2-way | 6 | 1382.21 | 1409.98 | -685.11 | 1 vs 2 | 1.86 | 0.17 |

Table 4.2: Summary of model comparison statistics for model one and model two in Experiment 3

This indicates that having categorically related anchor points which are distinct from all other related pairs of anchor points does not offer any observable advantage for the PSA-DA condition over the SA-SA condition. This suggests that semantically-related interference between paired spatial memories does not offer an account of spatial memory exclusivity. The results also demonstrate that a bottleneck of semantic information at retrieval may not be contributing to exclusivity of related spatial information. Additionally, any advantage from having categorically related anchor words was not localised to two memories but rather increased overall performance for the SA-SA and PSA-DA conditions alike.

With regards to interference between the target and anchor points, categorical

| | Estimate | *SE* | *df* | *t* | *p* |
|---|---|---|---|---|---|
| (Intercept) | 0.62 | 0.06 | 713 | 10.95 | 0.00 |
| Anchor (PSA-DA) | 0.03 | 0.04 | 713 | 0.63 | 0.53 |
| Target (neutral) | -0.08 | 0.07 | 40 | -1.10 | 0.28 |

Table 4.3: Parameter estimates for model one in Experiment 3 with anchor type (PSA-DA vs. SA-SA) and target type (neutral or categorically related) predicting location error (Dscore)

or neutral target words have no impact upon subjects' ability to retrieve spatial information from dual-memory cues (i.e., PSA-DA condition). This suggests that discrepancies in the semantic representation between targets and each anchor point do not contribute to exclusivity. If all encoded objects (anchor one, target, and anchor two) are stored within the same semantic category no significant benefits are observed. This suggests that interference between two related target-anchor representations does not account for exclusivity.

#### Exploring memory for an object's identity and location

The second part of the analysis focused on the relationship between recalling an object's identity and recalling its location. Experiment 1 of Chapter 3 found a trade-off effect between these elements of a memory trace. It was hypothesised that this may have been a consequence of excessive load reaching the ceiling limits of memory and preventing the binding of a number of stimuli features, namely an object's identity and its location. Now load has been reduced by using single words instead of sentences as anchor points, this relationship is reassessed.

Two multi-level models were estimated and compared. Multi-level models were employed due to the non-orthogonal predictor TRscore (Baguley, 2012a). The first model included anchor type (PSA-DA vs. SA-SA) and target recognition score (TRscore) as predictors of Dscore. The second model included the same variables as model one but included the interaction term TRscore x Anchor type. Comparisons of model one and two showed the one way model to be a better fit of the data (see Table 4.4). This demonstrates that model two which included the interaction between TRscore and anchor type was not a significantly better fit for the data.

A summary for model one can be seen in Table 4.5. This indicates there to be no interaction of TRscore x Anchor type on location accuracy (see Table 4.5). In this case, it can be seen from model one that if one were to estimate the identity

| Model | *df* | AIC | BIC | logLik | Test | L.Ratio | *p* |
|---|---|---|---|---|---|---|---|
| 1-way | 5 | 646.66 | 666.57 | -318.33 | | | |
| 2-way | 6 | 645.79 | 669.68 | -316.90 | 1 vs 2 | 2.87 | 0.09 |

Table 4.4: Summary of model comparison statistics for model one (TRscore vs. Anchor type) and model two (includes the interaction TRscore x Anchor type) in Experiment 3

of the target object correctly this would aid in recalling the location of the object (reducing error by .32) and does not vary according to anchor condition (PSA-DA vs. SA-SA). In other words, recalling what the target object was whilst in the PSA-DA condition does not hinder location memory accuracy, as was observed in Experiment 1. This suggests that a trade-off between recalling a target's identity and its location is not present in Experiment 3 and shows that knowing what the target was increases memory accuracy across all anchor conditions.

| | Estimates | *SE* | *df* | *t* | *p* |
|---|---|---|---|---|---|
| (Intercept) | 0.79 | 0.07 | 372 | 11.44 | <0.01 |
| TRscore | -0.32 | 0.07 | 372 | -4.86 | <0.01 |
| Anchor type | -0.03 | 0.05 | 372 | -0.56 | 0.57 |

Table 4.5: Parameter estimates for model one in Experiment 3 with TRscore (correct vs. incorrect) and Anchor type (PSA-DA vs. SA-SA) predicting location error (Dscore)

The results showing no effect of a TRscore x Anchor type interaction combined with the overall benefits of recognising the target object correctly support the notion that the 'what'-'where' trade-off observed in Experiment 1 is a consequence of heavy processing load. Likewise, these findings suggest that the reduction of processing load enhances memory ability by allowing elements of the memory to work collaboratively to recall information stored within a memory trace. It also points to constraints on attention when processing demand is high. Under such circumstances it would appear that individuals may be robbed of working memory capacity needed to combine identity and location information. However, when load allows for it both object features are available for later recall. Since the change to stimulus load is most salient at the time of learning it is plausible that the disruption of heavy load occurs at the encoding stage.

## 4.3 Experiment 4

Experiment 4 aims to retain the reduced-load stimuli of Experiment 3 but also to alter the structure of target-anchor presentations. The alteration of anchor and cue presentations could potentially lead to a number of insights. It will help to establish under the current experimental design whether individuals are able to retrieve two spatial memories if they are cued for each memory on separate occasions. This can be achieved by introducing a separate-anchor separate-cue condition. This will enable subjects to learn an object in relation to two anchor points separately, just as before. However, the advantage of separate cueing is that the quality of each memory can be assessed. This is important because the idea of exclusive processing supposes that only one memory is either encoded or retrieved. Thus, if the quality of each memory is assessed to be good (i.e., better than chance) this suggests that two memories *can* be retrieved when they are learnt separately. If this is the case it naturally implicates concurrent cueing as a factor that is preventing the retrieval of one memory. This would put concurrent cueing under the spot light as an explanation of exclusivity. Essentially, if the learning phase is held constant and different cueing strategies are introduced (i.e., separate vs. concurrent), then the impact of each cueing strategy on exclusivity can be assessed.

Not only will a separate-anchor separate-cue condition establish whether two memories *can* be retrieved, but it will also allow for the testing of target presentation order on subsequent recall accuracy. This is important as it may shed some light on any discrepancies between two memories that could result in exclusive processing. Arcediano, Escobar, and Miller (2004) showed that presentation of stimulus x-US and then xy-US causes blocking of y. This suggests that order of presentation may result in a stronger association for the first stimulus than the second. On the other hand there is evidence which suggests because of the way spatial information is stored in memory the second object to be presented may in fact be better remembered than the first. Ellen et al. (1984) propose spatial information is stored in the form of a list of discrete non-spatial items. They argue that the last acquired item (i.e., the most recent) is the best remembered.

Another type of anchor-cue presentation is introduced which introduces the idea of reversed exclusivity. It is plausible that if participants are able to view an already integrated memory this provides certain advantages. For instance, if all components of the two memories are viewed as a complete unit this may allow both memories to be drawn on at test (Evans & Pezdek, 1980). Baguley et al. (2006) employed a similar condition where participants viewed an integrated image at learning (DA-encoding). However, they induced recall by either providing both anchors simultaneously (DA-cueing) or by providing one randomly (SA-cueing). They found that when subjects were tested with one cue randomly their performance significantly deteriorated. They argued this was due to exclusive encoding which meant participants only encoded one memory (i.e., the target in relation to one anchor point). This meant that cuing with one random anchor point at test would result in lower performance in comparison to that of concurrent cueing with both anchor points. In line with this they showed better performance with concurrent cueing than with one random cue. However, they did not test to see if two memories were available in the condition where the participants were cued with a single anchor randomly. This seemed like good grounds to rerun the same learning condition as Baguley et al. (2006) which involved presenting both anchor points and the target together (DA). In order to determine whether only one memory is encoded it was important to offer both cues at test. However, if this was achieved by offering only one of two cues at test (i.e., SA-cueing), as had been used by Baguley et al. (2006), then it is difficult to decipher whether information regarding each memory is retrievable or not. Thus, in the current experiment the test condition was altered and instead of cueing with one anchor randomly (SA-cueing) both anchors were presented on separate occasions (PSA-cueing). This meant the level of spatial information contained within each memory could be assessed.

### 4.3.1 Design

A within-participant design was used where every individual completed a learning and test phase for each condition. The PSA-DA condition was retained from all previous experiments where an individual is presented with each target twice in relation to two different anchor points and then tested given both anchor-cues simultaneously. However, comparative conditions varied instead of the SA-SA condition which had been employed previously. Now conditions either took the form of a dual anchor learning followed by paired single anchor test (DA-PSA) or a paired single anchor learning followed by a paired single anchor test (PSA-PSA).

The DA-PSA condition meant participants now saw a complete representation of a target with two corresponding anchors simultaneously at learning. For example, a left anchor ('Tiger'), right anchor ('Lion'), and target word ('chair') would all be presented on the screen at once. Just as previously, nine target words would be presented in nine unique locations. At test participants would be given the left anchor ('Tiger') or right anchor ('Lion') separately. This meant

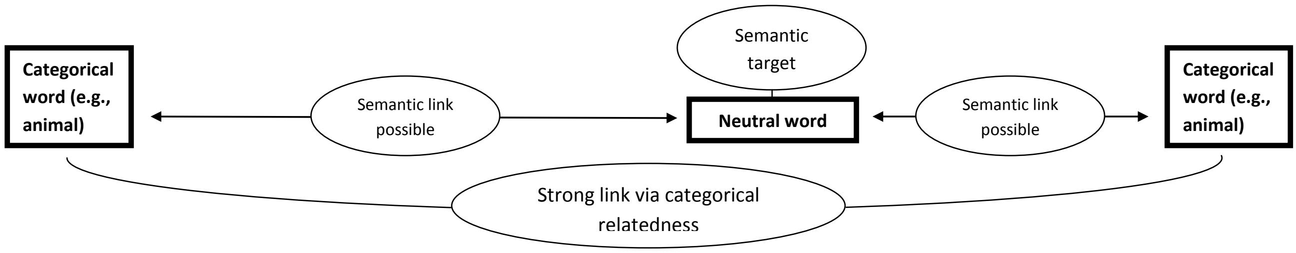


Figure 4.4: Example of design for experiment four

participants had the task of encoding the target's position in relation to both left and right anchors whilst being able to draw on an illustrative representation of the by-product if integration were to occur (i.e., all relations between each anchor point and the common target were combined).

The PSA-PSA condition is an amalgamation of both the PSA-DA and DA-PSA conditions where the participants are presented with the learning phase of the PSA-DA condition (i.e., they see the target in relation to both anchor points separately) and the test phase of the DA-PSA condition (i.e., they are cued for the target object with each anchor point separately). This meant that the participants learnt each location as a unique spatial unit and were then tested on these units independently. This allowed for comparison across each memory for memory dominance and combined with the DA-PSA condition widens the conditions under which exclusivity can be tested.

### 4.3.2 Stimuli

The results from Experiment 3 show that distinguishing between pairs of related memories with categorically related anchor points had little impact upon overcoming exclusivity. Thus, for this experiment it was decided to drop the different categories for each pair of anchor points for purposes of practicality (as each participant would now partake in three conditions). However, to ensure no interference between conditions different categories were used for each.

Materials consisted of a pool of 270 words constituting 15 categories each containing 18 words. From this pool, categorically-defined groups of words were selected for use in the three conditions. Different categories were used for each condition, for example, PSA-PSA = musical instruments, DA-PSA = birds, PSA-DA = countries. Both order of conditions and category-condition pairing were counterbalanced. All target words were deemed to be neutral to the anchor word and were matched on average length, level of semantics, imagery, and pronunciation (Paivio et al., 1968). The 15 categories ranged from 'types of Animals' to 'US States'. The categorical words acted as anchor points and the neutral words were randomly allocated to these anchors to act as target objects. Neutral target words (i.e., not related to the anchor words) were selected to possess high imagery (Mean = 5.9, *SD* = 0.70 out of a possible range 1-7) and high meaningfulness (Mean = 6.7, *SD* = 0.80 out of a possible range 1-10) values (Paivio et al., 1968).

### 4.3.3 Participants & procedure

Participants were recruited from Nottingham Trent University ($N$=62). Each participant received research credits for their time. The experiment was designed and carried out on a computer using E-prime© software. Subjects were presented with a series of anchor-word trials. Each trial consisted of a target word located a distance from an anchor word at a fixed location (either to the left or right hand side of the screen depending upon condition) and lasted for 14 seconds. The subjects were instructed to remember where the target word was located in relation to the anchor word. In between the learning phase and the test phase a short distractor task was employed (counting backwards in 3's) to prevent any short-term memory rehearsal. At test participants clicked using a mouse where on the screen they remembered the corresponding target word to have been located. After completing all location estimations they were given all the anchor words again in the same format as previously and they had to identify which target word was associated with a given anchor word.

### 4.3.4 Results & Discussion

The results show performance in all conditions to be better than chance (i.e., Dscore<1) which indicates some information for object location. The mean Dscore for the PSA-DA condition was 0.74 (*SD* = 0.26). For the DA-PSA condition mean Dscore was 0.80 (*SD* = 0.23). The PSA-PSA mean Dscore was 0.80 (*SD* = 0.23). Figure 4.5 highlights some promising performance gains for the PSA-DA condition over both PSA-PSA and DA-PSA (both representing single-memory recall). To test the differences in mean Dscore performance across all three anchor conditions a linear model was estimated with Anchor type predicting Dscore. The results show that the overall model did not quite reach significance (see Table 4.6). However they do illustrate for the first time that PSA-DA Dscore is lower than the comparable anchor conditions at least for the current sample.

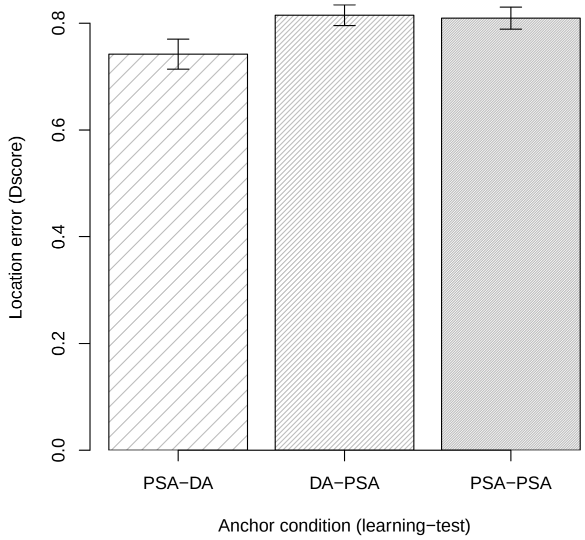


Figure 4.5: Graph showing mean Dscores for all anchor conditions (PSA-DA, DA-PSA, PSA-PSA) for Experiment 4 with 95% CI

| | Estimates | *SE* | *df* | *t* | *p* |
|---|---|---|---|---|---|
| (Intercept) | 0.8517 | 0.0329 | 2707 | 25.86 | p<0.001 |
| Anchor | -0.0297 | 0.0169 | 2707 | -1.76 | 0.0782 |

Table 4.6: Parameter estimates for a linear model with Anchor type (PSA-DA vs. PSA-PSA vs. DA-PSA) predicting location error (Dscore) for Experiment 4

These findings suggest that having two cues presented simultaneously (DA-cueing) to prompt location of an object increase memory accuracy over being prompted for each cue separately (PSA-cueing). This suggests that simultaneous cuing is not responsible for exclusivity, rather is must be attributable to some aspect of encoding two spatial memories. This implies that encoding interference plays a role in reducing the precision of both memories and thus results in a reduction of accuracy when compared with single object location encoding. However, this also offers an advantage when compared with a single memory that has been exposed to similar levels of interference at encoding. Although this is not statistically significant it is illustrative of a trend between dual cueing and single memory cuing. This will be investigated further in the next chapter where repeated exposure over time is employed to see if learning influences integration of spatial information.

### 4.3.5 Analysis of PSA-cueing conditions

This section reports further analysis of both PSA-cueing conditions from the PSA-PSA and DA-PSA conditions. It shows that if participants are cued for their memory of each anchor separately they show to have information regarding both anchor-target relations. Analysis of each memory from the PSA-PSA condition showed that location information for both memories was better than chance (see Figure 4.6). This indicates that two memories are encoded and are available at recall when prompted with each corresponding cue. However, the average accuracy of these two memories is lower than when being cued for both memories concurrently, as in the PSA-DA condition. This tentatively suggests that the dual-cueing of two spatial memories may have some advantages over single memory cuing. However, owing to the fact that the differences between the PSA-DA condition and the other two single memory cueing conditions did not reach statistical significance, these findings are further discussed later in light of more robust experimental evidence in Chapters 5 and 6.

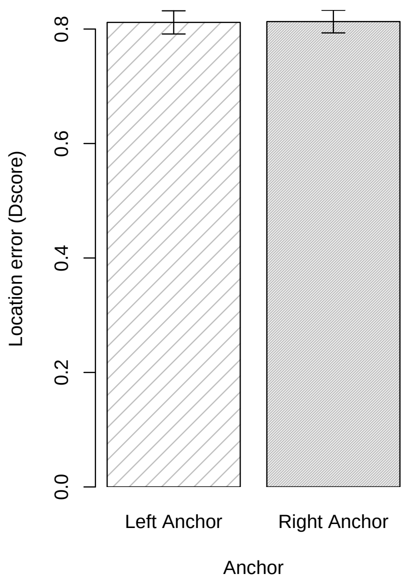


Figure 4.6: Graph showing mean Dscores for left and right anchor cues for the PSA-PSA condition from Experiment 4 with 95 % CI

Analysis of each memory from the DA-PSA condition shows nearly identical findings to that from PSA-PSA. Importantly, it shows that both memories are retrievable at test which suggests both have been encoded at learning. It also shows that no significant difference in terms of accuracy of spatial information between both memories ($t = 0.05$, $df = 59$, $p = 0.96$).

### 4.3.6 Exploring memory for an object's identity and location

This section revisits the relationship between recalling an object's identity and its location. Two multi-level models were estimated and compared. Multi-level models were employed owing to the non-orthogonal predictor TRscore (Baguley, 2012a). The first model included anchor type (PSA-DA vs. PSA-PSA vs. DA-PSA) and target recognition score (TRscore) as predictors of Dscore. The second model included the same variables as model one but included the interaction term TRscore x Anchor type. Comparisons of model one and two showed the one way model to be a better fit of the data (see Table 4.7). This demonstrates that model two which included the interaction between TRscore and anchor type was not a significantly better fit of the data.

| Model | *df* | AIC | BIC | logLik | Test | L.Ratio | *p* |
|---|---|---|---|---|---|---|---|
| 1 | 4.00 | 5306.26 | 5329.88 | -2649.13 | | | |
| 2 | 6.00 | 5306.71 | 5342.14 | -2647.36 | 1 vs 2 | 3.55 | 0.17 |

Table 4.7: Summary of comparison statistics for model 1 and model 2 for TRscore analysis Experiment 4

Model one is summarised in Table 4.8 and shows Target Recognition score (TRscore) to be a significant predictor of location error (Dscore). Regardless of anchor condition, if a participant identifies the target correctly mean location error (Dscore) decreases by .18. This finding it again in line with that observed in Experiment 3 and reiterates that when load is reduced features that comprise an object memory work together to aid in recall of the other feature.

| | Estimates | *SE* | *df* | *t* | *p* |
|---|---|---|---|---|---|
| (Intercept) | 0.86 | 0.02 | 2647 | 35.54 | $<$0.01 |
| TRscore | -0.18 | 0.03 | 2647 | -6.80 | $<$0.01 |
| Anchor | -0.02 | 0.02 | 2646 | -1.16 | 0.25 |

Table 4.8: Parameter estimates for model one with TRscore (correct vs. incorrect) and Anchor type predicting location error (Dscore) for Experiment 4

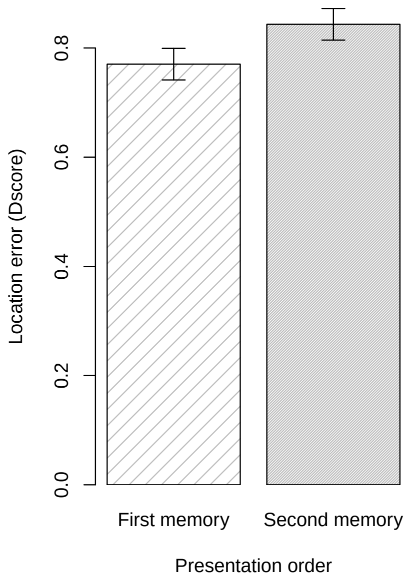


Figure 4.7: Graph showing mean Dscore for the order of cue presentation (first memory = first cue presentation) for Experiment 4 with 95% CI

### 4.3.7 Presentation order analysis

A linear model was estimated to test whether presentation order had an impact upon location memory accuracy through memory dominance. The model includes presentation order (first vs. second) as a predictor of Dscore. The model is summarized in Table 4.9 and shows presentation order not to be a significant predictor of Dscore. This suggests that inequalities in terms of memory accuracy are not a consequence of presentation order. However, again it is worth noting that significance was nearly reached which suggests it is possible that one memory is more accurate than the other.

| | Estimates | *SE* | *df* | *t* | *p* |
|---|---|---|---|---|---|
| (Intercept) | 0.79 | 0.05 | 1001 | 14.97 | <0.01 |
| Second memory | 0.07 | 0.04 | 1002 | 1.85 | 0.06 |

Table 4.9: Parameter estimates for a linear model showing Dscore predicted by presentation order - Experiment 4

### 4.3.8 Distance from anchor point analysis

Owing to the fact that the PSA-cueing condition analysis shows that both memories are encoded, stored and available at recall (at least when cued separately), additional analysis was carried out to examine whether proximity of the target to the anchor point is a factor contributing to a disparity in memory accuracy. This was also considered seeing as anchor position (i.e., left vs. right) or anchor presentation order (first vs. second) generally show no discrepancy in terms of memory accuracy. Research shows that recall accuracy for the location of an object increases as the distance from a reference point decreases (Nelson & Chaiklin, 1980). Thus, further analysis examined whether there was any discrepancy in the accuracy of each memory according to its proximity to an anchor point.

Analysis was carried out on the PSA-PSA data from Experiment 4. This showed that of two related anchor points the anchor that was in closer proximity to the target (i.e., the target was in locations 1,2,3,4 in relation to the anchor point) has a significantly lower Dscore when compared to the anchor where the target was more distal (i.e., in locations 6,7,8,9) (see Table 4.10 and Figure 4.8). This introduces one possible disparity between related memories that may contribute to interference at encoding of two memories. It also demonstrates that one memory *can* be more accurate than the other. This is interesting as subjects clearly do not take advantage of this otherwise having two memories and choosing the more accurate would result in greater memory performance over a single memory, which is not observed.

| | Estimate | *SE* | *t* | *p* |
|---|---|---|---|---|
| (Intercept) | 0.73 | 0.05 | 14.77 | $<0.01$ |
| Distance | 0.20 | 0.06 | 3.25 | $<0.01$ |

Table 4.10: Summary of the comparison between mean Dscores of two cues related to the same target based on distance from anchor point. A cue was considered close if the target was presented in locations 1,2,3,4 and far away if the target was presented in locations 6,7,8,9.

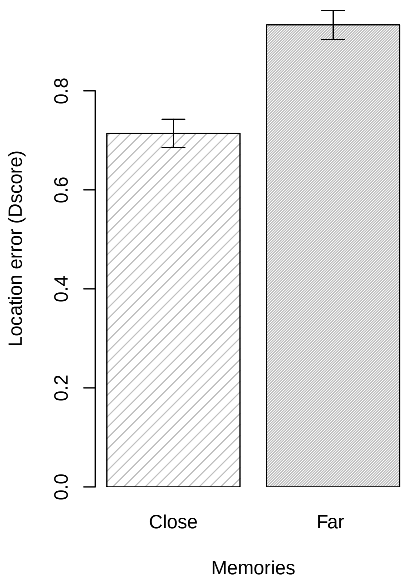


Figure 4.8: Graph showing mean Dscore for each cue where the target was in close proximity to the anchor point and when is was far away from the anchor point. This data was re-analysed from Experiment 4.

## 4.4 General discussion

The main contribution of these two experiments to exclusivity is that they exclude many possibilities that may be producing exclusive processing. These include memory dominance between memories and interference between related memories or between pairs of related memories. In addition, they provide a better understanding of the mechanisms that may contribute to equal performance levels between one and two memory conditions (i.e., PSA-DA = SA-SA) *other* than exclusive processing. In other words, the observed similarities in performance for the PSA-DA and SA-SA conditions may occur from encoding interference stemming from PSA-encoding

### 4.4.1 Interaction between 'what' and 'where' information

The second part of the analysis focused on the relationship between recalling an object's identity and recalling its location. Experiment 1 of Chapter 3 found a trade-off effect between these elements of a memory trace. It was hypothesised that this may have been a consequence of excessive load reaching the ceiling limits of memory and forcing subjects attend to a limited number of stimuli features, namely an object's identity or its location. The load in Experiments 3 and 4 has been reduced by using single words instead of sentences as such the trade-off effect was reassessed and is discussed below.

The findings from both Experiment 3 and 4 show that if individuals are able to remember what the object is they are more likely to recall where that object is with greater accuracy. This suggests that because of the reduction in load, more resources were available to combining (probably in working memory) different features of the visual array. This is in line with the literature which shows intentional learning paradigm (i.e., paying direct attention to spatial information) has a positive impact on location memory (Lansdale, 1998; Naveh-Benjamin, 1987, 1988; Dayan & Thomas, 1995). This finding also has implications for the literature on the automaticity of coding spatial information. Specifically, if effort is required in processing spatial information and that the level of effort (i.e., attention) determines the quality of spatial information recalled then spatial information is probably not processed automatically (Hasher & Zacks, 1979). This is congruent with the majority of research which advocates at least *some* effort is involved in coding spatial information(Caldwell & Masson, 2001; Naveh-Benjamin, 1987, 1988; Lansdale, 1998). It also supports the argument that studies where automaticity is thought to be present have used low effort easy-to-encode targets or coarse grain scoring of location (e.g., Ellis, 1990, 1991; Mandler et al., 1977) (hence, why they incorrectly concluded spatial information was encoded automatically).

The results also demonstrate that when attentional load is reduced and thus resources available 'what' and 'where' information may act collaboratively. This suggests that these two types of information have been integrated into the same memory unit at encoding. This is in line with neurological models which suggest each type of information is processed mostly by different brain regions but also at some stage needs to be integrated. Postma et al. (2004) posited there to be three functional steps to remembering where something is located. First, the object of interest must be recognised. Second, its location in space must be specified, and third, the object's identity and its location must be combined. Hence, the findings from the trade-off effect suggests that individual components of an object can be processed with relatively little effort. This is evidenced in Experiment 1 which showed when load was high only one type of information could be retrieved. However, for those pieces to be retrievable as common features of the same object some form of integration must take place and this process requires more effort.

### 4.4.2 Semantic interference

The results show that semantic interference between related spatial memories does not offer an account of spatial memory exclusivity. Experiment 3 allowed for the explicit recognition that two memories were related by employing distinct semantic categories. However, this recognition did not lead to any advantage for two memories compared with one. Thus, any benefit from having categorically distinct anchor words for each target was not localised to the PSA-DA condition but rather increased the overall performance for SA-SA and PSA-DA conditions alike. This presents similar findings to those of Experiment 2 and reiterates the possible presence of exclusive processing.

With regards to interference between the target and anchor points, categorical or neutral target words have no impact upon subjects' ability to retrieve spatial information from dual-memory cues. This suggests that discrepancies in the semantic representation between a target and each anchor point do not contribute to exclusivity. Hence, if all encoded objects (anchor one, target, and anchor two) are stored within the same semantic category no significant benefits are observed.

The findings from Experiment 3 specifically show that a bottleneck, preventing parallel retrieval of information, does not account for spatial memory exclusivity. These results could be attributable to a number of factors. First, a bottleneck has been relieved for semantic information alone, leaving a bottleneck for spatial information. However, this would suggest that semantic and spatial information were not integrated into a memory trace which is against the prevailing evidence (Luck & Vogel, 1997; Lee & Chun, 2001; Vogel et al., 2001). Second, it could mean that a bottleneck has been relieved for both semantic and spatial information but this has had no impact upon exclusive processing. This implies that exclusive processing may not result from limited capacity at retrieval.

Arcediano et al. (2004) showed that presentation of stimulus x-US and then xy-US causes blocking of y. This suggests that simply based on order of presentation one might be left with a greater association for the first stimulus combination than the second. Results from the presentation order analysis show that differences between first and second order presentation of the stimulus does not significantly impact upon levels of performance. This suggests that seeing a target for the second time does not improve memory for the first target and its relation to the first anchor point. Thus, blocking due to an imbalance in strength of association between two encoded representations is an unlikely cause of exclusivity.

Some authors propose that storing spatial information can be likened to the storing of a list of words. Congruent with this is the idea that the second object to be presented may in fact be better remembered than the first. Ellen et al. (1984) advocate that spatial information is stored in the form of a list of discrete non-spatial items and the last acquired item (i.e., the second memory) is the best remembered. The current findings show otherwise and argue that no effect of stimulus presentation order is evident. Again, this reiterates the argument that when each anchor-target relation is presented it is encoded as a distinct unit and recognition of the first object on presentation of the second does not improve the recalling of spatial information contained within both stimulus presentations. This highlights that the sequential order in which objects are encoded does not cause blocking or disruption of either memory and therefore has no baring on exclusivity. Thus, it appears unlikely that primacy and recency effects observed in the verbal domain relate to spatial information. Hence, the storing of spatial information appears not to be bound by the same mnemonic rules as words encoded from a list.

### 4.4.3 The availability of two spatial memories

The exclusivity model argues that given the opportunity to utilise two spatial memories only one memory can either be encoded or retrieved. Evidence from Experiment 4 suggests that given the opportunity to encode two memories both of those memories can be retrieved. Through the separate encoding and subsequent cueing of two spatial memories it was shown that both memories were retrieved with accuracy levels better than chance. This is incongruent with the idea of exclusive encoding. Also note worthy were the differences between concurrent cueing and separate cueing of both memories. Although the findings did not reach statistical significance they show that concurrent cueing performance was better than separate cueing performance. This is interesting because the learning conditions were held constant which isolated the effects of different cueing strategies. This suggests, albeit tentatively, that concurrent cueing of spatial memories may offer an advantage over separate cueing of each memory. If this is the case then it would also be incongruent with the idea of exclusive retreival of spatial memories being a result of concurrent cueing. If only one memory were retrieved due to simultaneous cueing then no difference between concurrent and separate cueing would be expected. However, the findings of Experiment 4 suggest that a difference may be present.

This is of particular interest because it not only indicates that two memories may be available at test, but also that concurrent cueing of those memories offers some kind of advantages in comparison to separate cueing. Logically, the only way concurrently cueing would see such performance advantages over separate cueing is if subjects were able to utilise two memories in some kind of advantageous manner. For example, separate cueing performance equates to the average accuracy of the two memories. Thus, if memory one had a Dscore of .7 and memory two had a Dscore of .5 then the average memory accuracy would be .6. However, using the same memories as an example, if a subject was provided with both cues simultaneously and were able to achieve a significantly better accuracy score than .6 (i.e., the average of the two memories) then it could be argued both memories were contributing information as to the target object's location. Although these effects did not quite reach statistical significance ($\alpha = 0.05$), the tentative findings reported here will be returned to in Chapter 5 and 6 in the light of more robust experimental evidence.

Baguley et al. (2006) used a scenario where subjects would learn the location of a target object whilst simultaneously presenting corresponding anchor points (DA presentation). They then tested memory for the object by randomly presenting one anchor point. They found significantly worse performance for DA-SA compared to SA-SA and PSA-DA. They argued this was due to a retrieval blocking. It was possible that individuals had only encoded one memory at learning. If this was the case then using the same scenario of anchor presentations at encoding but varying the test condition to include both memory cues would allow for the assessment of each memory's level of performance. The results were similar to that of the condition where memories were encoded separately. Specifically, they showed that two memories are retrievable at test which suggests that both have been encoded at learning. This contradicts the idea that only one memory is encoded when both anchor points and the target are presented altogether and simultaneously at encoding which questions Baguley et al's (2006) original conclusions.

Following on from the presentation order (first vs. second) and anchor (left vs. right) analysis a third possible factor was examined as a cause for accuracy imbalance between related memories. This is important to assess as if it can be shown that individuals possess a memory that is significantly more accurate, but do not select it, it indicates that exclusive processing is not the most optimum startegy. Analysis reported in Experiment 4 found that the distance from which the target was located in relation to an anchor point had a significant effect on location accuracy. Specifically, if the target was positioned in close proximity to an anchor point it would be recalled with greater accuracy in comparison to when it was located towards more distal locations. This is in line with the literature which shows accuracy decreases as a function of distance from a reference point (Nelson & Chaiklin, 1980). These findings suggest that when encoding two related memories one of those memories will be more accurate because it is closer to the anchor point. Owing to the nature of the experimental design the target will always be closer to one of the anchor points and will therefore be more accurately recalled. This provides a potential means for interference between memories. If exclusivity is occurring then selection of one memory over the other is not based on a factor which might offer a more accurate estimate for an object's location. In other words, individuals do not seem to be selecting a memory on the grounds of the target's proximity to the anchor point. If they were doing this then a significant increase in perfromance would be observed in comparison to the single memory condition (i.e., SA-SA).

### 4.4.4 Conclusions

It is clear that besides the findings of Experiment 4 (where dual cueing of two spatial memories appears to offer signs of benefit), exclusivity as tested in the original design (Baguley et al., 2006) remains present. However, there are a number of possibilities that remain to be tested. One possibility is that the task itself is too complex and resources are used up understanding the task which reduces the availability of resources for non-exclusive processing. Another possibility is that although familiar text has been employed, the spatial relations themselves and the connections between anchor points and the target remain novel to the subjects. It is plausible that one presentation of each stimulus is perhaps not enough to transform two related spatial memories into an integrated unit.

# Chapter 5

# Learning and Exclusivity

## 5.1 Introduction

Real life spatial learning typically involves repeated exposure to locations. Therefore, it is more realistic in some ways to study exclusivity and the possibility of overcoming it when individuals are repeatedly exposed to spatial information over time. The spatial memory research area suffers from a dearth of human-orientated work when it comes to learning spatial information over time. Additionally, learning arguably brings together elements of both semantics and expertise under one approach.

The previous two chapters have investigated semantics and expertise through forced means. That is, semantics were derived from generally accepted semantic categories and expert stimuli were employed to take advantage of previous extensive practice (i.e., reading). However, what participants lack is experience of the actual spatial element of the task. The quantities of space (i.e., distance between anchor and target) were only viewed on one occasion (or two in the dual anchor condition assuming participants were able to recognise this again upon second presentation). This chapter includes two experiments which exploit this factor by employing a learning paradigm applied to two further experiments; one over the course of 5 days and one over 10 days.

### 5.1.1 Practice and spatial memory generally

Much research has shown that practice improves spatial memory (Dayan & Thomas, 1995; Naveh-Benjamin, 1987, 1988) and also dual-task abilities (Shaffer, 1975; Hatano et al., 1977; Spelke et al., 1976). Additionally, strategic processing has been shown to proceed with practice such as 'response chunking'. It is argued by some authors that only when such strategies have the opportunity to be implemented would one expect to observe performance greater than serial processing (Nino & Rickard, 2003). Response chunking can somewhat be likened to Rohrer and Pashler's (1998) findings on categorisation. In essence, response chunking places each memory or information trace into a categorical unit which means switching across categories is avoided. More generally it has been shown that subjective strategies can improve spatial memory for large amounts of spatial information (Ellis, 1990). Presumably allowing for greater time with the stimuli and task will have higher potential for such strategy implementation.

Similarly, Kiesel et al. (2009) found that long-term practice prompts the acquisition of visual memories of chess configurations with integrated form-location conjunctions. They concluded that perceptual 'chunking' enabled complex visual processing outside of conscious awareness. Noudoost, Adibi, Moeeny, and Esteky (2005) showed that elements of a target object are important for object recognition when the object is unfamiliar. However, as objects become more familiar over time configural processing of the object as a complete unit occurs. For example, Garling, Lindberg, and Mantyla (1983) gave subjects the opportunity to become familiar with a campus through repeated exposure (by way of guided tours). They found four tours was enough to preserve spatial knowledge between different reference points when tested a month later. This suggests that repeated exposure may not only increase remembering but also reduce forgetting of multiple object-to-reference point relations.

Training has also been implicated as a potential way to release blocking of one cue due to a unbalanced strengthening of one association. Arcediano et al. (2004) suggest that any stimulus cue blocking due to presentation order should be released over time due to the random nature in which stimuli are experienced. For example, on one exposure to two stimuli a subject may view stimulus A then stimulus B. This, according to Arcediano et al. (2004) would create a stronger memory for A. However, if on another occasion stimulus B was presented first this would counteract the initial dominance of stimulus A. Thus, over time one would expect equal memory strength for the two stimuli as viewing order continuously changes. In the current learning experiments each stimulus should, according to randomness, be presented the same amount of times and in different orders. Thus, differences of association strength between first and second order presentation should balance out as learning progresses.

### 5.1.2 Repeated exposure and spatial memory integration

Baguley et al. (2006) acknowledge one possibility that the novelty and abstractness of the stimuli and task may account for exclusivity. They highlight that the combination of spatial information may require consolidation and practice with each separate component. More specifically, they suggest that over time rehearsal of each memory trace may reduce demands on working memory, allowing for the application of resources to integration processes. Baguley et al. (2006) also hypothesize that an alternative benefit of repeated exposure might be the conversion or initial sensory type representations (i.e., visual) into higher-order representational units. This may allow for more abstract manipulation (i.e., integration) of each memory trace.

The idea that repeated exposure and long-term experience are important factors in spatial integration is supported from early work involving animals (Ellen et al., 1982, 1984; Sawa et al., 2005; Blaisdell & Cook, 2005; Tolman, 1948). Poucet (1993) argues that experience with the environment is crucial when transforming independent pieces of information and combining them. For example, Herrman, Bahr, Bremner, and Ellen (1982) employed a three table problem (Maier, 1932) to investigate integration in animals. This problem involves a rat learning an entire spatial array and is then fed on one part of it (i.e., one table). The rat is removed from the feeding table and placed in another area of the array and required to return to the feeding table from which it has just come. This process is carried out repeatedly with the tables being randomly organised every time (so the rat does not learn a 'turn' strategy). Eventually the rat is allowed to explore the environment and the spatial relations contained within it. The test is to see whether the rat is able to make a novel judgement and get from the start table back to the feeding table (Herrman et al., 1982). This was shown to be the case and indicates that repeated exposure allows for the development of higher-order orientation-free representations of space. This means that no matter where an animal is in the array (i..e, a novel location) it can make a judgement not reliant on local cues and reference points, but rather on an aggregation of previous experiences.

Another study has since extended the findings of Herrman et al. (1982). Ellen et al. (1984) allowed rats to explore a series of tables and runways for five consecutive days and found that rats constrained to explore areas independently were not capable of integrating spatial information. However, if rats were allowed to explore connections between areas over successive trials then a conceptual link was established. This, it is argued, demonstrates that rats form cognitive representations over time that quantify constant relationships amongst objects.

If rats only experienced either table or the runways they showed no signs of learning the spatial relations among tables. This evokes the idea that awareness of the relations between spatial objects is required for integrative type performance. More importantly, it indicates that such awareness is built up over time through multiple exposures to all elements of the spatial array.

Ellen et al. (1984) noted that a crucial factor in the attainment of spatial integration is that spatial relations are experienced bidirectionally. This is in response to findings by Maier (1932), who found that bidirectional locomotion must be engaged if locations in an environment are to become related spatially. This is in line with the idea that space is represented as a vector consisting of magnitude and direction information (Collett, Cartwright, & Smith, 1986; McNaughton, Chen, & Markus, 1991; O'Keefe, 1991; Baguley et al., 2006) and bidirectional exposure may cancel out any interference attributed to direction.

Sawa et al. (2005) using a touch screen procedure and Blaisdell and Cook (2005) using an open-field search task both demonstrate evidence for the possibility of spatial information integration in pigeons. The experimental design was such that pigeons would learn a stimulus pairing where the spatial distance was kept constant (e.g., A-B). They would then train the subjects as to the location of a target stimulus in relation to only one of the original stimuli (e.g., A-C). Therefore participants would have no a priori knowledge of the spatial relation between C and B (e.g., B-C). Thus, it is argued that if they are able to estimate C's location given B as a reference cue then they have integrated the representations (A-B + A-C). The measure of integration was whether there was an observable increase in correct estimates of C's location over successive learning trials. Interestingly, Blaisdell and Cook (2005) showed that integration was not apparent until some 7 months after separate paired association had been learnt with the target stimuli. This suggests that integration of spatial information, amongst pigeons at least, is a process which evolves over long periods of time.

Diwadkar and McNamara (1997) found that memory for an object's location to be represented in a viewpoint-dependent manner. They proposed that when participants make judgements from novel views (i.e., different than at encoding), they must normalise such a view to 'fit' with an encoded view. Diwadkar and McNamara (1997) also showed that with training, subjects are able to represent novel views in memory rather than having to normalise the view to fit experienced ones. This suggests that a more viewpoint-independent representation may develop over time. Thus, practice may play a role in enabling individuals to make judgements regarding novel views by relying on integrated representations. Brockmole and Wang (2002) point out that using familiar environments will maximise the chance of finding evidence for simultaneous access of multiple environmental representations.

There is also evidence that processes in the absence of a stimulus that occur over time may be vital. An excellent example of this comes from Ellenbogen, Hu, Payne, Titone, and Walker (2007) who illustrated the importance of sleep when it comes to making inferential judgements regarding learnt stimuli. In their experiment subjects learnt a series of premises (A>B, B>C, C>D, D>E, E>F). Contained within these premises was a hierarchical structure that the subjects were not informed about. Three delay-test conditions were employed which included 20mins, 12 hours (day), and 12 hours (over night) delays. They showed that subjects in the 12 hour night condition were significantly better at recognising the underlying hierarchy compared to both the 12 days and the 20mins (who only performed at chance). The researchers concluded that sleep enabled subjects to recognise and develop weak associative links between separate yet related memory items.

Evidence from neuroscience also implicates different brain region in processing spatial information as it becomes learnt. Using fMRI, Wolbers (2005) showed as learning evolves the role of the hippocampus in spatial memory consolidation diminishes. This suggests the creation of new memories (which the hippocampus has been implicated in) is not necessary any longer and instead the already acquired spatial information is processed in regions which deal which higher-level cognitive processing.

In summary, the evidence that repeated exposure and learning play a role in integrating spatial and non-spatial information is quite compelling.

### 5.1.3 Testing task complexity

The second aim of this chapter is to investigate the role of the experimental design in exclusivity. Specifically, it examines whether task complexity is contributing to poor performance in the dual memory condition (PSA-DA).

Although spatial memory performance was better than chance in the majority of the previous experiments, there are signs of attenuation towards the limits of processing capacity in some conditions. The levels of performance are typically towards the upper end of location error between perfect accuracy and chance. This is particularly noticeable for the two memory conditions (e.g., PSA-DA). This suggests that the task itself may be quite complex and more importantly the effort required to understand both tasks may be unevenly distributed between the one and two memory conditions. Thus, allowing individuals the opportunity to become familiar with the task will help to understand the contribution of task complexity to performance levels in PSA-DA. This, in turn, will have implications for any further conclusions relating to exclusivity.

## 5.2 Experiment 5

Experiment 5 uses the same stimuli and anchor presentation structure to that of Experiment 4. Experiment 4 provided a combination of anchor presentation and test trials where the PSA-DA condition showed signs of outperforming comparative single memory conditions (PSA-PSA and DA-PSA). Hence, if learning increases the opportunity for memory consolidation, then testing it using a scenario which illustrates a trend in that direction is a logical starting point.

The aims of Experiment 5 were to:

1. Test the effects of learning on exclusivity using Experiment 4 anchor comparisons
2. Test the effects of task complexity on exclusivity

### 5.2.1 Design

A within-participant design was used where every individual completed a learning and test phase for each condition over the course of 5 consecutive days. The PSA-DA condition was retained from all previous experiments where an individual was presented with each target twice in relation to two different anchor points and then tested given both anchor-cues simultaneously. However, comparative conditions varied from the SA-SA condition which had been employed previously. Conditions either took on a dual anchor learning/single anchor test (DA-PSA) or a single anchor learning/single anchor test (PSA-PSA) (i.e., the same as Experiment 4).

The DA-PSA condition meant participants saw a complete representation of a target with two corresponding anchors simultaneously at learning. For example, a left anchor ('Tiger'), right anchor ('Lion'), and target word ('chair') would all be presented on the screen at once. Just as previously, nine target words would be presented in nine unique locations. At test participants would be given the left anchor ('Tiger') or right anchor ('Lion') separately. This meant participants had the task of encoding the target's position in relation to both left and right anchors whilst being able to draw on with an illustrative representation of the memory-product if integration were to occur (i.e., all relations between each anchor point and the common target were available and explicit).

The PSA-PSA condition is an amalgamation of both the PSA-DA and DA-PSA condition where the participants are presented with the learning phase of the PSA-DA condition (i.e., they see the target in relation to both anchor points separately) and the test phase of the DA-PSA condition (i.e., they are cued for the target object with each anchor point separately). This means that the participants learn each location as unique spatial units and are then tested on these units independently. This allows for comparisons across each memory for memory dominance. Combined with the DA-PSA condition, these new conditions widen the context under which exclusivity is tested. This will provide greater insight into the underlying mechanisms of exclusivity.

### 5.2.2 Stimuli

Materials consisted of a pool of 270 words. The pool of words was made up of 15 categories each containing 18 words. From this pool, categorically-defined groups of words were selected for use in the three conditions. Different categories were used for each condition, for example, PSA-PSA = musical instruments, DA-PSA = birds, PSA-DA = countries. All target words were deemed to be neutral to the anchor word and were matched on average length, level of semantics, imagery, and pronunciation (Paivio et al., 1968). The 15 categories ranged from types of 'Animals' to 'US States'. The categorical words acted as anchor points and the neutral words were randomly allocated to these anchors to act as target objects. Neutral target words (i.e., not related to the anchor words) were selected to possess high imagery (Mean = 5.9, $SD$ = 0.70 out of a possible range 1-7) and high meaningfulness (Mean = 6.7, $SD$ = 0.80 out of a possible range 1-10) values (Paivio et al., 1968).

### 5.2.3 Participants & procedure

Participants were recruited from Nottingham Trent University and awarded research credits for their time ($N$=10, Mean age = 21.5, 5 female). Five participants were assigned to a learning condition and five to a non-learning condition. The learning condition involved seeing (in a random order) the same anchor-target relations everyday. Thus, the target and its location would remain constant in relation to a specific anchor point everyday. The non-learning condition changed the stimuli everyday. For example, day one might consist of anchor words from the categories 'animals', 'musical instruments' and 'foods', one for each anchor condition. On day two these categories would change to 'tools', 'cities', and 'body parts'. This meant participants would become familiar with the task but not the stimuli. Thus, any significant signs of improvement over five days would suggest the task itself may be placing unnecessary burden on processing. Participants would complete all three anchor conditions (in a random order) each day for five consecutive days. All stimuli were presented on a computer screen and background light was kept to a minimum to prevent any use of external reference points other than those provided as part of the experiment.

All instructions were kept consistent and participants were informed of what they would be tested on (i.e., where the target object was located). The first of the three anchor conditions would then begin which would involve learning numerous anchor-target relations. Each anchor-target trial was timed (with 14 seconds learning time in each trial) and would not cease until all anchor-targets had been presented once. A short distracter task would then begin, where participants were asked to count backwards in three's from a given random number. After this, subjects would be given instructions informing them of the test phase. This phase required each participant to click (using a mouse) on the screen where they remembered the target object to be in relation to whatever corresponding anchor was presented at that time. After completion of the first anchor condition, participants would then do the same for the remaining two anchor conditions.

### 5.2.4 Results & discussion

The results section is split into two sections. The first section deals with the findings from the learning condition when participants received the same stimuli each day and therefore had the opportunity to become familiar with them over time. The second section deals with the non-learning condition where participants were given different stimuli every day for five days.

#### Learning condition

Results show all conditions to be better than estimated chance values (i.e., Dscore$<1$). The mean Dscore across all five days for each condition were 0.25 ($SD$ = 0.13) for the PSA-DA condition, 0.50 ($SD$ = 0.19) for the PSA-PSA condition, and 0.42 ($SD$ = 0.15) for the DA-PSA condition.

Overall Dscores were calculated and subjected to linear model analyses which showed Dscore in the PSA-DA condition to be significantly lower than PSA-

PSA and DA-PSA, and also that there was no significant difference between PSA-PSA and DA-PSA conditions (see Figure 5.1 and Table 5.1).

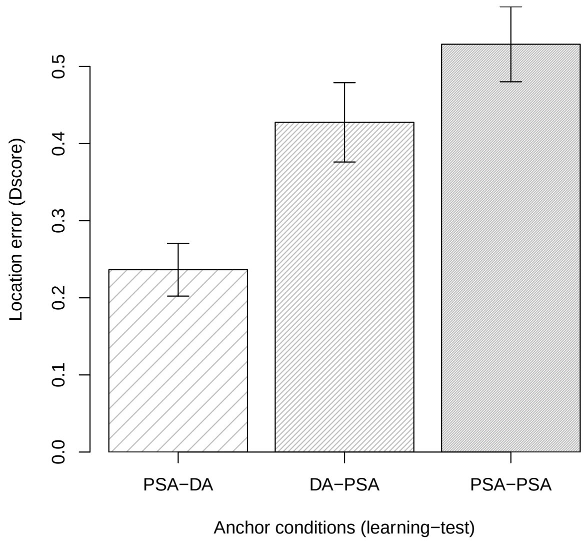


Figure 5.1: Graph showing mean Dscores for PSA-DA (P/D), PSA-PSA (P/P), and DA-PSA (D/P) over all days of learning for Experiment 5 with 95% CI

| | Estimates | *SE* | *t* | *p* |
|---|---|---|---|---|
| (Intercept) | 0.2365 | 0.04 | 5.21 | <0.01 |
| Anchor group (DA-PSA) | 0.19 | 0.064 | 2.98 | <0.01 |
| Anchor group (PSA-PSA) | 0.29 | 0.064 | 4.55 | <0.01 |

Table 5.1: Parameter estimates for a linear model with Dscore predicted by PSA-DA, PSA-PSA, and DA-PSA for Experiment 5

In terms of each anchor condition, results show a significant learning effect for all three conditions across five days (see Figure 5.2). They also show a significant difference between performance on the PSA-cue conditions (PSA-PSA & DA-PSA) compared with the DA-cue condition (PSA-DA) (see Figure 5.2). This shows that participants were better able to recall the location of the target object when they were simultaneously given two cues to help prompt their memory. To ascertain whether such performance gains can be regarded as evidence of additivity or independence both models were estimated with the independence model being the best fit of the data (see Figure 5.2). This reflects that the kind of performance seen in the PSA-DA condition is similar to what one would expect if individuals were able to draw on both memories independently, based on the observed performance of collapsed PSA-cue data (i.e., the average of PSA-PSA & DA-PSA). This suggests that when one memory retrieval fails the second is available for access. This is the first sign of potential for non-exclusive processing.

| Day | $p$-value |
|---|---|
| Day 1 | 0.0625 |
| Day 2 | 0.0625 |
| Day 3 | 0.4375 |
| Day 4 | 0.4375 |
| Day 5 | 0.125 |

Table 5.2: Summary of Wilcoxon signed rank test of the differences between PSA-DA and the other PSA-cue condition (PSA-PSA and DA-PSA) combined for Experiment 5

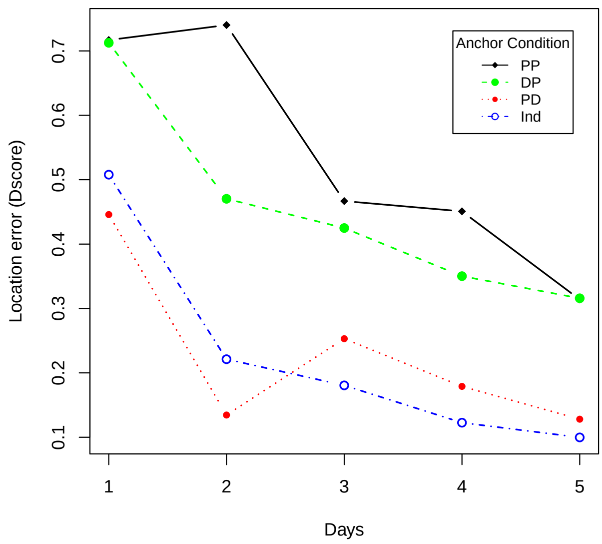


Figure 5.2: Graph showing the effect of having the same stimuli for five consecutive days on location error (Dscore) including an estimated independence model line for Experiment 5

Across both conditions learning does not have any effect on being able to use two cues in comparison to one. Arguably one would expect an increase in difference between the PSA-DA condition and the two PSA-cue conditions if learning was providing a disproportionate advantage to the two memory condition. This was shown not to be the case and in fact the difference between the conditions appears to be converging somewhat as the days succeed (see Table 5.2).

### Non-learning condition

The mean Dscore across all days for the PSA-DA condition was 0.57 ($SD$ = 0.21), for the PSA-PSA condition is was 0.68 ($SD$ = 0.16), and for the DA-PSA condition it was 0.66 ($SD$ = 0.14).

Results from the non-learning condition show no learning effects over five days across all three conditions (see Figure 5.3). To analyse the non-learning effect PSA-PSA and DA-PSA were collasped to form one PSA-cue condition as they jointly represent scenarios of single-anchor cuing.

To asses the effects of learning over time progressively more complex models were estimated which in essence tested whether there was any significant deviation of each condition's slope coefficient across days. If any slopes gradient was significantly different from zero that indicates that some learning had occurred. Thus, as days increase along the x-axis Dscore will decrease along the y-axis (this would be a negative coefficient). Additionally, the models tested whether the y-intercept of each slope (i.e., the grand mean for each anchor condition [PSA-DA, PSA-PSA, DA-PSA]) were significantly different from one another. The progression of model steps to achieve this are set out below.

A number of multi-level models were estimated which together illustrate that neither PSA-cue (PSA-DA and DA-PSA combined) nor PSA-DA slope deviated from zero or their y-intercepts were significantly different from one another (see Table 5.1).

The results show the slope coefficient does not significantly deviate from zero confirming that no learning took place for all the anchor conditions across all days. Model-1 represents a null model and estimates the grand mean for all participants across all days. Model-2 allows the y-intercept (i.e., means) to vary between anchor conditions (PSA-DA vs. PSA-cue) but retains a common slope. The results show a significant difference in mean Dscore across conditions. Model-3 again allows the y-intercept to vary between anchor conditions and retains a common slope but also treats Day as a continuous predictor of Dscore. The results show difference in the y-intercept (i.e., mean) for each anchor condition to remain significant. Importantly, it shows that a the slope coefficient for the grand mean slope for all anchor conditions does not significantly differ from zero (i.e., it is flat) across all learning days. Model-4 estimates the effect of Day on Dscore and keeps the slope and y-intercept common for all groups.

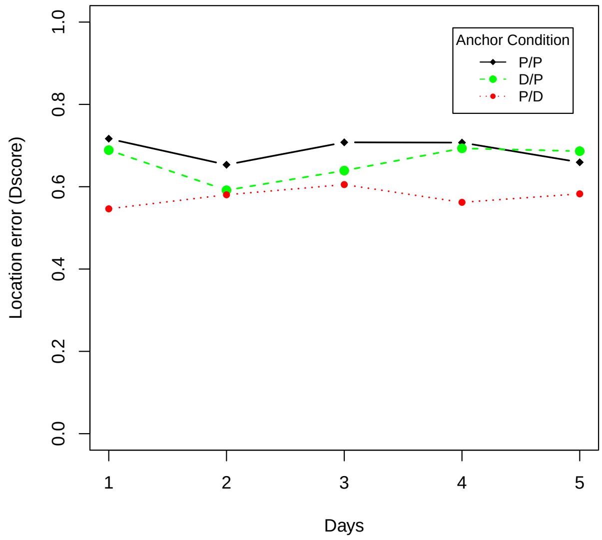


Figure 5.3: Graph showing the effect of having unique stimuli for five consecutive days (i.e., becoming familiar with the task) on location error (Dscore) for Experiment 5

| Model | Estimates | *SE* | *df* | *t*-value | *p*-value |
|---|---|---|---|---|---|
| *Model-1* | | | | | |
| Intercept | 0.62 | 0.05 | 45 | 12.61 | 0.00 |
| *Model-2* | | | | | |
| Anchor | 0.11 | 0.04 | 45 | 2.49 | 0.02 |
| *Model-3* | | | | | |
| Anchor | 0.11 | 0.04 | 44 | 2.47 | 0.02 |
| Day | 0.01 | 0.02 | 44 | 0.63 | 0.53 |
| *Model-4* | | | | | |
| Intercept | 0.62 | 0.05 | 44 | 12.48 | 0.00 |
| Day | 0.04 | 0.16 | 44 | 0.22 | 0.83 |

Table 5.3: Summary of parameter estimates for four models from Experiment 5 non-learning condition. Model 1 predicts the grand mean Dscore for all groups. Model 2 allows the y-intercept (i.e., means) to vary between anchor conditions (PSA-DA vs. PSA-cue) but retains a common slope. Model 3 allows the y-intercept to vary between anchor conditions and retains a common slope but also treats Day as a continuous predictor of Dscore. Model 4 estimates the effect of Day on Dscore and keeps the slope and y-intercept common for all groups

## 5.3 Experiment 6

Experiment 6 is designed to further explore the effects of repeated exposure and learning on location memory. It aims to confirm and extend findings from Experiment 5. Although Experiment 5 demonstrated strong learning effects it is difficult to establish the influences of learning upon the exclusivity effect as it was originally observed (Baguley et al., 2006). The effects of learning cannot be fully discounted until a test of PSA-DA and SA-SA is conducted under learning conditions. This is addressed in Experiment 6.

Experiment 6 also sought to extend the learning period as a factor that may also be preventing the realisation of any learning benefits for two spatial memories. Experiment 6 thus doubled the learning period to ten days and also included a two day consolidation period halfway. As evidence from humans and animals shows the integration of spatial information can involve lots of exposure over lengthy periods of time (Blaisdell & Cook, 2005), this also has the added advantage of allowing for important periods of consolidation such as sleep (Ellenbogen et al., 2007).

Owing to the comparative nature of the test for exclusivity (i.e., PSA-DA vs. SA-SA), the benefits of learning on memory integration must outweigh any general memory accuracy benefits due to learning. In other words, as learning progresses memory will generally improve across all conditions (see Experiment 4 and Naveh-Benjamin, 1987, 1988; Dayan & Thomas, 1995). This means that for any significant improvement to be observed for two memories the integration process must be observable before performance reaches ceiling limits. Hence, another reason why the learning period was extended.

Additionally, because of the striking improvement on location memory witnessed in Experiment 5, the mechanisms that underpin such improvement are examined. This is achieved through the examination of confusion matrices to assess how precision develops for each location across days.

### 5.3.1 Design

A within-participant design was employed where each subject completed all conditions everyday for ten days. Two anchor conditions were examined, the PSA-DA condition and the SA-SA condition. These were the original comparative conditions where exclusivity has been extensively evidenced in this thesis as well as previous work (Baguley et al., 2006).

### 5.3.2 Stimuli

Due to the findings that task complexity was not contributing to exclusive processing the memorability of the stimuli was reduced and the semantic information was removed. This enabled subjects to attribute their own meaning to the stimuli. It also meant the learning period could be extended without the risk of reaching ceiling effects of location performance. The time period extension also allowed more chance for any convergence across conditions to take place.

The stimuli comprised a pool of 470 four-letter nonsense words (see Table 5.4 for an example). From this pool, random sets of words were selected without replacement for all three conditions. This meant 18 words were selected for the SA-SA condition and 27 words were selected for the PSA-DA condition. This was carried out for each participant.

| Location | Left Anchor | Right Anchor | Target |
|---|---|---|---|
| 1 | rarp | hign | ount |
| 2 | onde | boag | leld |
| 3 | slox | oock | arvs |
| 4 | koun | zimb | kwee |
| 5 | jewd | tirp | yieg |
| 6 | rirb | glou | ghiz |
| 7 | danz | rhof | zonc |
| 8 | donc | dreg | sylb |
| 9 | bleg | rarg | sykt |

Table 5.4: An example of a randomly generated stimuli set for Experiment 6

### 5.3.3 Participants & procedure

Participants were recruited from Nottingham Trent University and awarded research credits for their time ($N$=10, Mean age = 21.9, 6 female). Unlike Experiment 5 where participants were divided into 'learning' and 'non-learning' conditions, all ten participants took part in the learning condition. Owing to the striking non-learning findings from Experiment 5 it was decided that further exploration of the non-learning condition was not required. This also gave the experiment more power to detect any differences between anchor conditions. All stimuli were presented on a computer screen and background light was kept to a minimum to prevent any use of external reference points other than those provided as part of the experiment.

All instructions were kept consistent and participants were informed of what they would be tested on (i.e., where the target object was located). The first of the two anchor conditions would then begin which would involve learning numerous anchor-target relations. Each anchor-target trial was timed (with 10 seconds learning time in each trial) and would not cease until all anchor-targets had been presented once. A short distracter task would then begin, where participants were asked to count backwards in three's from a given random number. After this, subjects would be given instructions informing them of the test phase. This phase required each participant to click (using a mouse) on the screen where they remembered the target object to be in relation to whatever corresponding anchor was presented at that time. After completion of the first anchor condition, participants would then do the same for the remaining anchor condition.

Participants returned every day for ten days with a two day consolidation break in the middle (i.e., after five days). Testing was kept constant every day with little variation concerning the time of day across all participants for the entirety of the learning period.

### 5.3.4 Results & discussion

The mean Dscore across all ten learning days for the PSA-DA condition was 0.51 ($SD$ = 0.29). For the SA-SA condition it was 0.51 ($SD$ = 0.30). As can be seen in Figure 5.4 a striking learning curve is observed, where Dscore (location error) decreases overtime, thus, location accuracy increases. Across ten days of learning, location error was significantly reduced from a mean Dscore of 0.87 down to 0.26. As is also apparent there was no marked difference between SA-SA and PSA-DA over the ten day period. This supports the conclusions from Experiment 4 (Chapter 5) that learning plays little function in enhancing the performance of multiple spatial memories over a single memory. For purposes of comparison to Experiment 5 the independence model has been calculated and included in Figure 5.5. This shows a clear disparity between performance in the PSA-DA condition and what is predicted by the independence model.[1] The results also highlight that allowing subjects to attribute their own meaning to the stimuli and group it in a way most easily processed or integrated does not aid in aggregating spatial information.

[1]The independence model estimates performance based on SA-SA. It states that if failure of memory occurs a second attempt of retrieval from the other memory is made. It is calculated using the following formula:

$$1 - ((1 - Dscore) * 2 - (1 - Dscore)^2)$$

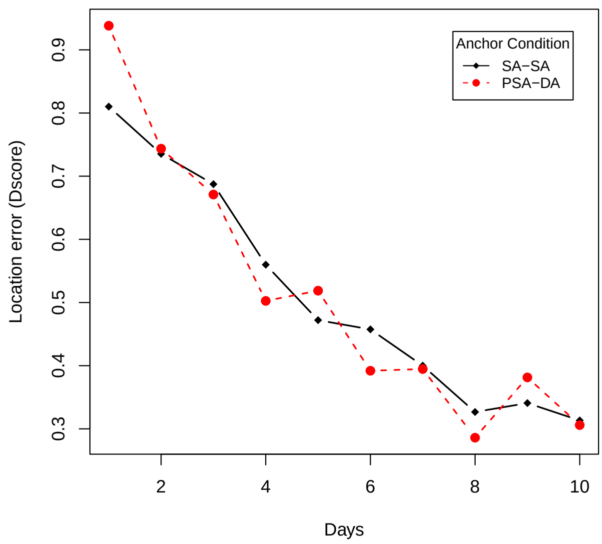


Figure 5.4: Graph showing the effect of learning multiple object locations over a ten day learning period on Dscore for PSA-DA and SA-SA conditions for Experiment 6

| Model | *df* | AIC | BIC | *F* | *p* |
|---|---|---|---|---|---|
| Linear model | 3 | -23.30 | -22.40 | | |
| Non-linear model | 4 | -39.13 | -37.92 | 34.62 | <0.01 |

Table 5.5: Summary of model comparison statistics for a linear and non-linear model estimating Dscore predicted by Day for Experiment 6

Two models were estimated to capture the increments in spatial memory performance over time, a linear and a non-linear model. The non-linear model (i.e., in this case a second degree polynomial) was a better fit for the data (see Table 5.5 and is represented in Figure 5.6). As can be seen, performance gains start very rapidly over the first 3-4 days of learning and then begins to tail off at around day 6. Performance also begins to plateau around day 9-10. This suggests participants were reaching the ceiling limits of performance. However, it could also be attributed to the fact that participants knew it was a ten day learning study and therefore performance may have waned owing to a drop in motivation.

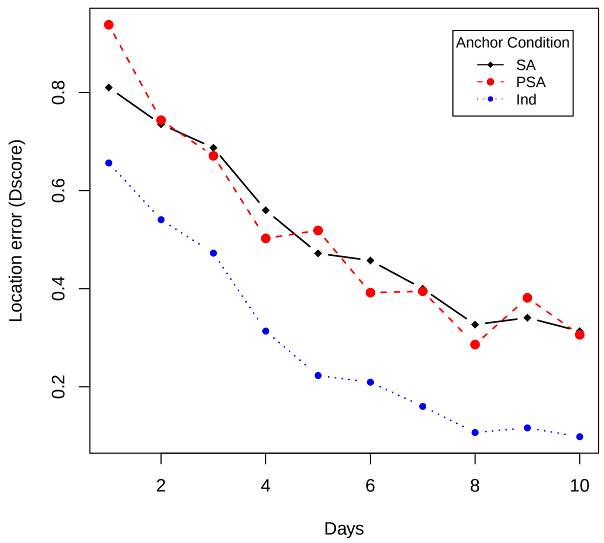


Figure 5.5: Graph showing the effect of learning multiple object locations over a ten day learning period for PSA-DA and SA-SA conditions. The graph includes a line reflecting the level of performance as predicted by the independence model - Experiment 6

| | Estimates | *SE* | $t$-value | $p$-value |
|---|---|---|---|---|
| (Intercept) | 1.0017 | 0.0322 | 31.09 | <0.01 |
| Day | -0.1382 | 0.0135 | -10.27 | <0.01 |
| Day$^2$ | 0.0070 | 0.0012 | 5.88 | <0.01 |

$R^2$ = 0.9845; Adjusted $R^2$ = 0.9800

Table 5.6: Parameter estimates for a non-linear model predicting Dscore by Day for Experiment 6

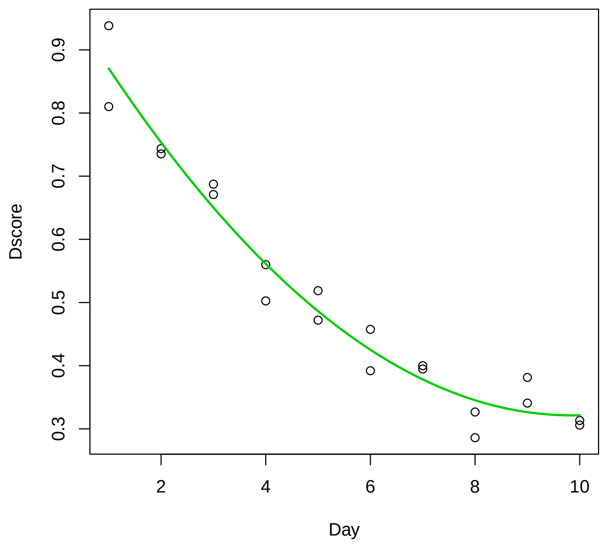


Figure 5.6: Graph showing a fitted polynomial learning curve estimating Dscore across ten days of learning from Experiment 6. The line represents both PSA-DA and SA-SA data combined

### 5.3.5 Analysing the development of precision over time

The purpose of this section is to model the types of learning strategy for acquiring information about multiple objects' locations over a ten day period. It will graphically illustrate the pattern of errors for all nine target objects for each day of learning. This will offer an insight into how individuals 'pick up' fragments of spatial information over time.

The use of confusion matrices allows for the modelling of distributional changes in the accuracy of participants' responses (see Chapter 2, section: *The use of confusion matrices*). This means one can examine two underlying possibilities of multiple object-location learning. The first possibility is that participants learn a few objects precisely and then add to this 'pot' of precise memories each day. The second is that individuals encode all objects in a less precise manner and then increase precision for all memories across each day. These hypotheses can be tested by plotting the distribution of a confusion matrix for each day.

Under the first possibility, one would expect spikes in the matrix. That is, responses which equate to precise locations of a few objects would appear across the diagonals (or nearby) of the matrix from day one. The frequency of these spikes would increase as learning progressed. Under the second possibility, one would expect a flat and low distribution of responses from day one which would move inwards towards the diagonals slowly each day. Eventually this would result in a mountain range-like distribution.

To illustrate the patterns of response accuracy surface plots were employed. These are powerful tools when assessing the distribution of matrix format data. Thus, Figure 5.7 shows the distribution of responses for day one. In order to interpret the plots it is useful to imagine the square base of the plot as the confusion matrix itself. The diagonal from the far corner to the closest corner represents perfect accuracy. As one moves outwards from this line responses become less accurate until they are positioned in either left or right hand corner of the plot which signifies the largest amount of location error (i.e., deviations from where the object was presented).

On examination of each surface plot in relation to its previous plot, the distribution begins reasonably flat and slowly progresses inwards away from the outer corners toward the central diagonal. This culminates in relatively large amounts of accuracy across all target objects, illustrated by the mountain range like distribution on days nine and ten. This is in line with the second hypothesis and suggests that individuals are learning each object's 'rough' location every day and then building on that precision henceforth.

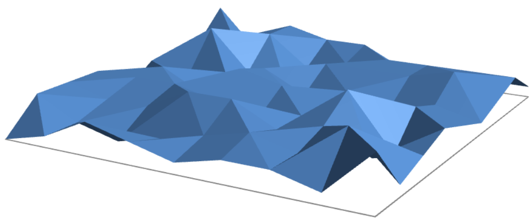

Figure 5.7: A surface plot representing the distribution of responses for day 1 of Experiment 6. The shading illustrates the vertical height of the surface and thus the volume of responses. As responses accumulate vertical height of the plot increases. As responses decline the surface area moves vertically downwards towards the base of the plot

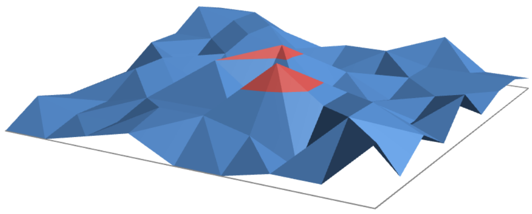

Figure 5.8: A surface plot representing the distribution of responses for day 2

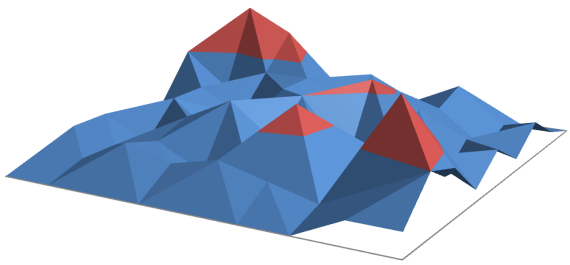

Figure 5.9: A surface plot representing the distribution of responses for day 3

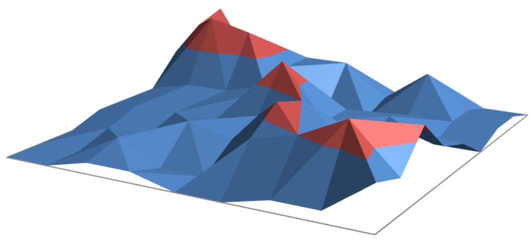

Figure 5.10: A surface plot representing the distribution of responses for day 4

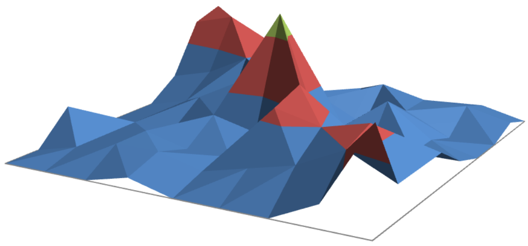

Figure 5.11: A surface plot representing the distribution of responses for day 5

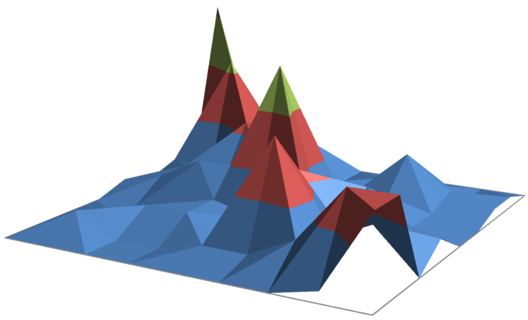

Figure 5.12: A surface plot representing the distribution of responses for day 6

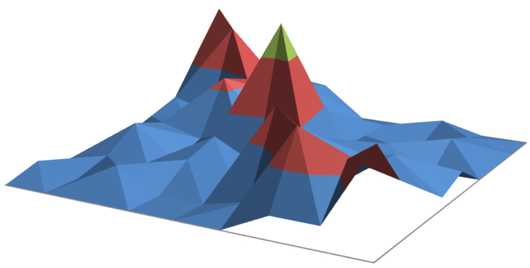

Figure 5.13: A surface plot representing the distribution of responses for day 7

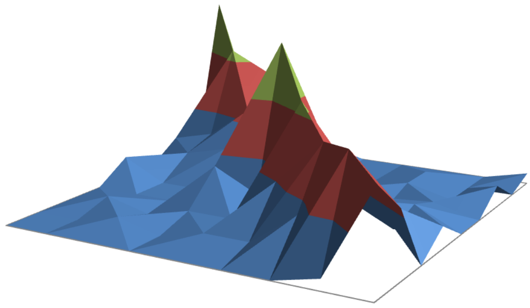

Figure 5.14: A surface plot representing the distribution of responses for day 8

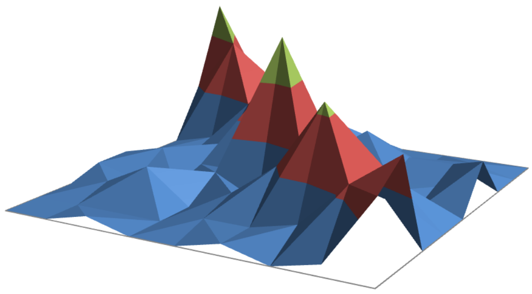

Figure 5.15: A surface plot representing the distribution of responses for day 9

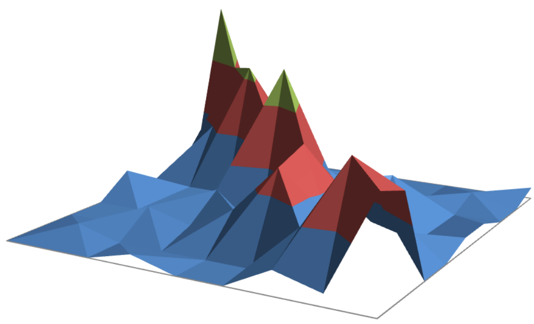

Figure 5.16: A surface plot representing the distribution of responses for day 10

## 5.4 General discussion

### 5.4.1 Learning and exclusivity

The results from Experiment 4 and 5 are conclusive and demonstrate that repeated exposure to the same location information does not overcome exclusivity. Across both experiments no observable advantage was shown for having two memories of where an object is located in comparison to one. This suggests that the repeated exposure of spatial relations did not enable any kind of consolidation or transformation of information into higher-order units. This is reflective of exclusivity in that only one memory is encoded or retrieved which would make consolidation superfluous.

After exposure to the same stimuli for either five or ten consecutive days it is implausible that participants did not recognise two memories as being related. This suggests acknowledging that two memories point to the location of the same target is not enough to encourage integration. It would appear that memories act exclusively even when their relation to a common target object has been specified explicitly. The neutral nature of the stimuli used in experiment five and also the period of learning gave subjects the time and semantic freedom to attribute subjective meaning to the stimuli, and thus, to organise it in a way that may be conducive to aggregation. The results show that no such advantage was observed and performance remains in line with that predicted by the exclusivity model.

The findings are also in stark contrast to previous research, particularly the work showing integration over time in animals (e.g., Ellen et al., 1982, 1984; Sawa et al., 2005; Blaisdell & Cook, 2005; Tolman, 1948). Much of the animal research has focused on path integration and shown that if two routes are learnt (A-B, B-C) then a novel connecting route can be inferred (A-C). This suggests that the previously learnt routes have been integrated and thus a judgement can be made based on this integrated knowledge. This evidence makes the findings of this research even more striking because the subjects do not necessarily have to even make a novel judgement (i.e., A-C), rather they just have to make a judgement regarding two learnt 'routes' (i.e., A-B, B-C, where's B given A & C?).

Nevertheless, the major difference between the current research and the previous research on animals is the test of exclusivity (non-exclusivity in the previous case). In the current work comparative conditions are employed whereby performance is compared to a control condition made up of encoding and retrieving a single spatial memory. In comparison, animal research seeks to establish whether integration is possible not whether it is more or less effective to make one judgement from memory (e.g., where is B given A?). This difference is also witnessed in other animal research where rats are required to take a novel route from one table to another (Ellen et al., 1984; Herrman et al., 1982). Thus, it begs the question whether the type of comparison between conditions may go some way to accounting for finding exclusivity.

It is also entirely possible that selection from two memories is not required. Collett and Collett (2000) showed that only in unfamiliar environments is path integration employed. When in familiar environments landmarks dominate and are nearly always used. This could be equated with the current findings and suggests that integration is simply not necessary. Therefore, any one landmark will suffice and is just randomly chosen.

These findings do not indicate that learning does not play any role in spatial memory integration, rather that repeated exposure does not play a role in overcoming exclusivity under the current paradigm. There is some evidence suggestive of no benefits of practice. For example, Nino and Rickard (2003) found practice effects on two retrievals from a single cue to not overcome the retrieval bottleneck and put forward a serial model for dual-task performance. However, a bottleneck has been shown to be unlikely to account for the current findings (i.e., Experiment 3). Additionally, unlike Nino and Rickard (2003) the current experiments seek to understand the benefits of retrieving one item from two cues, not two items from one cue.

There is also the possibility that the learning process has started the procedure for integration but did not have enough time for it to come to fruition. Time delays have been shown to influence such a process. Blaisdell and Cook (2005) showed that integration was not apparent until some 7 months after separate paired association had been learnt with the target stimuli. Garling et al. (1983) illustrated that the benefits of repeated exposure to a campus was evident one month later. This suggests that integration of spatial information is a process which may evolve over longer periods of time. However, just considering the role of medium term learning as in the current experiments the evidence suggests five or ten days of learning does not show signs of integration for the learnt stimuli.

The findings of this chapter extend the boundaries within which exclusivity remains present. It shows that even with the benefits of learning to become familiar with the stimuli and importantly the relational locations of the target, the ability to develop and apply strategies over time, the opportunity for consolidation periods of inactive learning, and the chance to make explicit connections between all elements of the stimuli, exclusivity remains immutable. The general performance increase for all conditions in Experiments 5 and 6 (excluding the non-learning condition of Experiment 5) indicate that exclusive processing still allows for improvement of spatial memory over time. This suggests that by learning fragments of information for where an object is location (i.e., one of two memories) builds a redundant set of memories that offer adequate performance. This supports the argument that exclusive processing may be a mechanism to avoid unnecessary effort. That is, to avoid the effort involved in either processing two memories or attempting to integrate both when one memory is good enough.

### 5.4.2 Task complexity

The findings from Experiment 5 show that unbalanced task effort between the PSA-DA and other less complicated conditions (i.e., SA-SA) is not contributing to poorer PSA-DA performance in comparison. The fact that no observable change in performance for the PSA-DA condition over the course of five days suggests that even when subjects completely understood the task and became familiar with the procedure, this did not improve their spatial memory performance. This means that performance levels can be attributed to elements that comprise the task rather than the task itself.

### 5.4.3 Practice effects and spatial memory performance

The findings from this chapter quite conclusively show that becoming familiar with the locations of objects, through practice, significantly improves memory for those objects over time. This is in line with evidence that shows improvement in spatial information retrieval with practice (Naveh-Benjamin, 1987, 1988; Dayan & Thomas, 1995). It is in stark contrast to research which indicates no practice improvements (Ellis, 1990, 1991; Mandler et al., 1977).

The significant impact of learning on performance also provides additional support to the idea that spatial information is not processed completely automatically. Hasher and Zack's (1979) criteria state that practice should not result in any performance gains if a process is to be considered automatic. Thus, the current findings are in contradiction to this and indicate that spatial processing is not automatic by rather it is effortful.

However, some spatial coding can be achieved with minimal processing effort.

For example, Naveh-Benjamin (1987) showed no difference between intentional and incidental learning conditions for relative judgements. This suggests that coarse spatial information, that used to make relative judgements (e.g., 'left of A'), is processed with little effort. However, for precise spatial judgements to happen more effort is required. This is perhaps reflected in the second learning experiment (Experiment 6) which shows precision to increase over time, presumably by incrementally applying effort to processing each target evenly every day.

### 5.4.4 Spatial precision over time and multiple objects

The analysis of location precision over time echoes ideas that already exist in the literature. The idea of increasing precision over time is in line with the categorical-coordinate model as proposed by Kosslyn (1987). This model states that category information (i.e., 'left of A') is encoded on initial viewing and then coordinate information as to the exact location is encoded. This suggests that the only qualitative difference between categorical and coordinate information is the level of granularity. It also suggests that metric information is fine-tuned over time which supports the idea that there is a continuum between categorical and coordinate representations rather than these two representations being two separate computations (Niebauer, 2001).

Niebauer (2001) argues stages exist in between switching from categorical to coordinate representations, where categorical processing is initiated and from this coordinate information can be derived. Thus, categorical encoding may represent a preliminary step in specifying space with more precise coordinate processing following. This also reflects the categorical adjustment model which states that fine-grained information as to the exact location of an object is constrained within a broader category of space (Huttenlocher et al., 1991).

A neurologically based model supports this idea and may also help to account for the increments in precision observed in Experiment 6. Dynamic Fields Theory (DFT) states that neurons in working memory establish spatial information over time due to activation of neighbouring neurons (Spencer, Smith, & Thelen, 2001; Spencer, Simmering, Schutte, & Schner, 2007; Schutte, Spencer, & Schoener, 2003; Schutte & Spencer, 2009). Through repeated exposure, excitation of neurons becomes self-sustaining, precluding the need for continuous presentation of the stimuli. Thus, the neurons in working memory leave a transient firing trace in long-term memory. As this process is iterated neuronal firings become less coarse and more precise. This implies that initially spatial information is represented with little relative precision and that this precision is gradually increased over time.

The findings from Experiment 6 may be explained by applying the above models of spatial memory learning. This suggests that when participants view the location of an object they code it in a coarse manner. This specification of space can be fine-tuned upon every viewing of the spatial relations between the target and a local reference point.

### 5.4.5 Anchor presentation structure and exclusivity

Perhaps the most insightful findings from this chapter relate to the difference between the PSA-DA, PSA-PSA and DA-PSA conditions, as observed in Experiment 5. In contrast to Baguley et al. (2006) this experiment shows an advantage for simultaneous cueing of two spatial memories.

This immediately begs the question, if spatial memories are exclusive why would two cues be advantageous? According to the exclusivity model encoding or retrieval of only one memory is attempted. This means that the prompting of both memories with both cues should offer no advantage, unless two memories *are* retrievable. However, if two memories are retrievable, then why is dual anchor cueing consistently poorer than single anchor cueing (i.e., PSA-DA vs SA-SA)?

One way to try and interrogate this further is to examine what is contributing to i) the benefits of dual-cueing as seen in Experiments 4 and 5 and ii) what is contributing to no observable advantage of dual-cueing as seen in Experiments 1, 2, 3, and 6. These are examined and discussed further in Experiments 7a and 7b of the next chapter.

### 5.4.6 Conclusions

It is clear from Experiments 1, 2, 3, and 6 that when comparing PSA-DA performance and SA-SA as a test of exclusive processing this shows no advantages from having two memories over one. According to previous work this is a consequence of there being only one memory available in the PSA-DA scenario. The contributions of the experiments contained within this thesis are convincing of the fact that exclusivity is not overcome by the methods employed here. Therefore it would be superfluous to some degree to keep investigating the route of overcoming exclusivity. Instead it might be more informative to examine the cases highlighted in Experiment 4 and 6 where exclusivity can not account for the findings. Arguably, exclusivity may be difficult to overcome because the assumption that only one memory has been encoded is not the most appropriate explanation of performance levels witnessed between PSA-DA and SA-SA. Therefore, the final empirical chapter will attempt to understand the breadth and application of the exclusivity model to both the findings of this thesis and those of previous findings.

# Chapter 6

# Encoding disruption and spatial memory performance

## 6.1 Introduction

This chapter revisits the exclusivity model and its ability to account for findings reported in earlier chapters and in previous work. The results of two experiments and further analysis of previous experiments (Experiment 3 and 4) are contained within this chapter. This chapter aims to add further weight to the findings of Experiment 4 and 5 which show DA-cueing to offer an advantage under conditions when two related memories have been encoded and stored. Upholding the idea that DA-cueing offers some advantage automatically implicates PSA-encoding as a processing stage leading to later recall disadvantage (otherwise PSA-DA should outperform SA-SA, which it does not). The rationale for this chapter is to clarify, by way of isolating processing stages (e.g., encoding), why two spatial memories (i.e., PSA-DA) might equal the performance of a single spatial memory (i.e., SA-SA), other than exclusive processing per se.

It is quite possible that exclusivity may be occurring at one or both stages of memory. That is, exclusive encoding, where individuals only encode one spatial memory, or exclusive retreival, where only one spatial memory is retrieved. One line of evidence at odds with an exclusive encoding account emerges from Experiment 4. Analysis of memory for a target object given both anchor points separately shows both cues provide information for an object's location (Experiment 4). This suggests that exclusive encoding is not likely to be occurring. If it were occurring then a significant detriment of at least one of the memories as measured at recall would be expected because only one of the memories was encoded.

The lack of evidence for exclusive encoding does not preclude the possibility of exclusive retreival of spatial memories. The evidence from Experiment 4 shows that two spatial memories are retrievable, however, this observation was achieved by testing each memory separately (i.e., through PSA-cueing). This means that exclusive retreival of spatial information may still be occurring but might be isolated to the concurrent cueing (i.e., DA-cueing) of memories, a retreival problem which would be avoided by cueing each memory separately.

However, other evidence is at odds with the idea of exclusive retreival. If both memories are encoded, stored and therefore available (as has already been demonstrated in Experiment 4) there should be no difference between cueing these memories separately or together. In other words, if a subject is given a target (T) in relation to two anchor points on separate occasions (A and B) and they encode both memories (e.g., A-T and B-T), then cueing with A and B simultaneously or with A then B separately, should not have any effect on recall performance (i.e., if the participant only attempts recall of one of those memories). In fact, it *could* be argued that simultaneous cueing would cause some kind of interference and therefore lower performance levels would be expected compared to that of cueing each memory on separate occasions. On the contrary, the results of Experiment 4 and 5 show concurrent cueing to be an advantage. This suggests that individuals are not simply retrieving one memory in isolation but rather there is some kind of additive effect in the sense that they are drawing on information from both available memories is occurring.

The above findings indicate that retreival of both memories is possible when cued separately and a benefit is gained when cued concurrently. This suggests that both memories are encoded, stored, and retrievable under both separate and concurrent cueing conditions. Thus, the fact that concurrent cueing seems to offer some kind of advantage over separate cueing suggests for one thing that something must be occurring elsewhere in the processing stage other than that of retrieval. Additionally, whatever is occurring it must introduce some kind of detriment to memory performance in order to bring two spatial memories performance, which sees a concurrent cueing advantage, in line with that of a single spatial memory.

The results from Experiment 4 and 5 specifcially show that compared to PSA-PSA, PSA-DA offers better memory performance. This difference in performance is attributable to the test contingencies (PSA-cueing vs. DA-cueing), seeing as this is the only factor that varied between conditions. The apparent DA-cueing advantage taken together with the consistent finding of equal performance between PSA-DA and SA-SA begs the question as to why does PSA-DA consistency see performance levels the same as SA-SA if DA-cueing is advantageous?

One possible explanation is that *PSA-encoding* has a detrimental impact on memory performance which DA-cueing cannot wholly rectify. However, as yet no test of the encoding contingency's impact (i.e., PSA-encoding) has been carried out. That is, if PSA-encoding is having a detrimental impact on memory performance then it would be beneficial to introduce PSA-encoding into the SA-SA condition, a condition which typically sees performance levels equal to that of the PSA-DA condition. This way a comparison can be made between performance levels for a new single memory condition, which introduces PSA-encoding (i.e., PSA-SA condition), and that of the PSA-DA condition. Thus, if PSA-SA leads to poorer performance compared with both the SA-SA condition and the PSA-DA condition then it would add weight to the argument that the reason why two memories (i.e., PSA-DA) nearly always equal that of a single memory (i.e., SA-SA) is because the encoding of two related memories (i.e., PSA-encoding) has a detrimental impact upon both encoded spatial memories. This would by extension go some way to explaining why although DA-cueing sees advanatges in some instances (e.g., PSA-DA vs. PSA-PSA), but in others it seems to be attenuated by some factor (e.g., PSA-DA vs. SA-SA).

This chapter aims to test the hypothesis that PSA-encoding is responsible for the equal levels of performance between the PSA-DA condition and the SA-SA condition, an observation that has previously been argued to represent exclusive processing of spatial information (Baguley et al., 2006). In this chapter the learning context will be isolated and scrutinised as a factor contributing to a decrement in PSA-DA performance bringing performance in line with SA-SA performance.

## 6.2 Experiment 7a

This experiment is designed to hold the learning phase (PSA) constant and vary the retrieval phase to assess to impact of introducing PSA-encoding to the SA-SA condition. Owing to the previous findings which show equal performance between PSA-DA and SA-SA, a comparison between PSA-SA and PSA-DA will be made. The consequence of a comparison between PSA-DA and PSA-SA will also lead to insights as to the role of DA-cueing. For example, if PSA-DA outperforms PSA-SA then it could be argued that DA offers some kind of benefit at retrieval for spatial information. It would also support the previous findings comparing PSA-DA with PSA-PSA which suggests DA-cueing, in some contexts, is more effective as a means of recall compared with PSA-cueing.

### 6.2.1 Design

Experiment 7a is a within-participant design and uses a combination of learning-test anchor conditions not previously employed. The anchor conditions consist of paired-single anchor viewing followed by dual-anchor test (PSA-DA) and paired-single anchor viewing followed by random single-anchor test (PSA-SA). This provided a test of whether having the opportunity to retrieve two memories was better than the opportunity to retrieve one.

Baguley et al. (2006) used PSA-DA and SA-SA in Experiment 1 and DA-SA and DA-DA in Experiment 3. However, they did not offer a comparison of conditions that allowed for the contribution of PSA-encoding to be examined. PSA-encoding was always followed by DA cueing in Baguley et al. (2006) which meant PSA was never isolated for the purpose of examination. What is interesting is the comparison between DA-DA in Baguley et al. (2006), which showed equal performance to that of PSA-DA and SA-SA. This implies that if DA-cueing is found to be advantageous in the current experiment then it would appear that what ever is occurring in the PSA-encoding condition is also likely to be occurring in the DA-encoding condition.

### 6.2.2 Stimuli

The stimuli were taken from Experiment 5 which comprised of a pool of 470 four-letter nonsense words (see Table 6.1 for an example). From this pool, random sets of words were selected without replacement for all three conditions. This meant 27 words were selected for the PSA-SA condition and 27 words were selected for the PSA-DA condition. This was carried out for each participant.

The reason why these stimuli were used was to establish the benefit of cueing each memory simultaneously. This meant non-words were used as anchors because if categorically related anchors were employed (as have in previous experiments) then participants in the PSA-SA condition might be able to cue their second memory via the semantic connection with the presented cue. In other words, if a participant had learnt Apple-chair and Banana-chair, then upon

| Location | Left Anchor | Right Anchor | Target |
|---|---|---|---|
| 1 | rarp | hign | ount |
| 2 | onde | boag | leld |
| 3 | slox | oock | arvs |
| 4 | koun | zimb | kwee |
| 5 | jewd | tirp | yieg |
| 6 | rirb | glou | ghiz |
| 7 | danz | rhof | zonc |
| 8 | donc | dreg | sylb |
| 9 | bleg | rarg | sykt |

Table 6.1: An example of a randomly generated stimuli set for Experiment 7a (taken from Experiment 6)

the cueing of 'chair' with 'Apple' they may be able to cue the second memory 'Banana' from the cue of 'Apple'. This would disrupt any performance gains attributable purely to dual-anchor cueing as the subject may be able to induce dual-anchor type cueing themselves.

### 6.2.3 Participants and procedure

Participants were recruited from the University of Leicester and paid £6 for their time ($N$=26, mean age = 29.37, $SD$ = 11, 16 female). The same procedure as Experiment 4 was employed. The experiment was designed and carried out on a computer using E-Prime© software. Subjects were presented with a series of anchor-word trials. Each trial consisted of a target word located a distance from an anchor word at a fixed location (either to the left or right hand side of the screen depending upon condition) and lasted for 14 seconds. The subjects were instructed to remember where the target word was located in relation to the anchor word. In between the learning phase and the test phase a short distractor task was employed (counting backwards in 3's) to prevent any short-term memory rehearsal. At test participants clicked using a mouse where on the screen they remembered the corresponding target word to have been located.

### 6.2.4 Results & discussion

The results show Dscore for both conditions to be better than chance (i.e., Dscore<1). The results show significantly better performance (i.e., lower Dscore) for the PSA-DA condition ($Mean$ = 0.82, $SD$ = 0.28) compared with the PSA-SA condition ($Mean$ = .97, $SD$ = .27) (see Table 6.2 and Figure 6.1). This first shows that when PSA-cueing is introduced into the SA-SA condition performance gets worse. Second, this indicates that having two cues at test is an advantage in comparison to having one. This supports the argument that the differences in previous findings between having two cues at test and only one (i.e., PSA-DA vs. SA-SA) is a consequence of something other than the test phase. More specifically, it suggests that equal PSA-DA and SA-SA performance may be accounted for by a disparity in the encoding phase of the test. This implies that PSA-encoding has significantly detrimental effects upon the encoding of two spatial memories that SA-encoding avoids. This arguably must have something to do with the process of encoding two related memories.

Although Experiment 7a makes a comparison between PSA-DA and PSA-SA it does not provide any direct comparison of PSA-SA and SA-SA. Thus, a more direct comparison between PSA-SA and SA-SA is needed to strengthen the argument that it is the PSA-encoding stage of the PSA-DA condition that renders location performance the same as SA-SA. This is addressed in Experiment 7b. Additionally, it is also important to test the robustness of the findings from Experiment 7a owing to the relatively small sample size as well as the close to chance performance observed in the PSA-SA condition.

| Condition | SA Dscore (*SD*) | DA Dscore (*SD*) | $t$ | *df* | $p$ |
|---|---|---|---|---|---|
| Exp.7a PSA-DA vs. PSA-SA | .97 (.27) | .82 (.28) | 2.34 | 25 | $< 0.05$ |

Table 6.2: Table showing mean Dscore and *SD* for the PSA-DA and PSA-SA condition of Experiment 7a. The table also shows summary statistics of mean comparisons between PSA-DA vs. PSA-SA

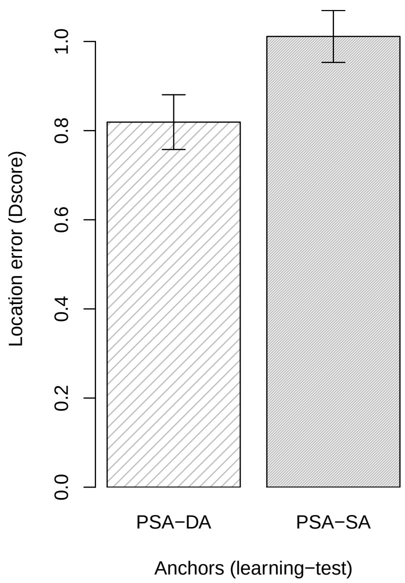


Figure 6.1: Graph showing mean Dscore with 95 % CI for the PSA-DA and PSA-SA condition for Experiment 7a

## 6.3 Experiment 7b

Experiment 7b was designed to test the robustness of the findings from Experiment 7a. In order to achieve this Experiment 7b used a larger sample size, and different (more easily processed) stimuli. Specifically, Experiment 7b employed the same stimuli to that which had been used to gather data for Experiment 3. This offered two primary benefits. First, Experiment 3 saw good levels of overall location memory performance. Owning to the close to chance levels of performance observed in experiment 7a it was important to establish the same findings with more convincing levels of general memory performance. Second, it allowed for a control comparison of PSA-SA with previously established performance levels of SA-SA (taken from Experiment 3 where the same stimuli, design, and procedure had been used). This allowed for direct isolation of the PSA-encoding condition and a more concrete testing of the hypothesis that PSA-encoding introduces some kind of detriment observable in later location memory performance.

### 6.3.1 Design

Experiment 7b used the same anchor conditions as Experiment 7a (e.g., PSA-DA vs PSA-SA). This was done to establish generality of the findings and thus to add support to the idea that in some circumstances two cues are an advantage for retrieving two spatial memories. It also used data from Experiment 3 to provide a control comparison. This meant two within conditions were used (PSA-DA and PSA-SA) as well as one between condition (SA-SA: taken from Experiment 3). The between condition (PSA-SA vs SA-SA) allowed for the testing of the hypothesis that PSA-encoding is negatively impacting upon performance in the PSA-DA condition.

### 6.3.2 Stimuli

Experiment 7b adopts the stimuli used in Experiment 3 (see Table 6.3). The stimuli comprised categorically related anchor words that were unique to each target word. The target word was neutral to the anchor points. For example, a set of paired anchor points might be drawn from the category musical instruments (Guitar, Piano) and the target word would be neutral relative to this (table).

| Location | Category | Right Anchor | Left Anchor | Target (categorical) | Target (neutral) |
|---|---|---|---|---|---|
| 1 | Body parts | Elbow | Foot | hand | hope |
| 2 | Furniture | Chair | Table | bed | chief |
| 3 | Fruit | Mango | Banana | apple | slave |
| 4 | Trees | Oak | Birch | pine | board |
| 5 | Bodies of water | Pacific | Atlantic | nile | vest |
| 6 | US States | Texas | Florida | alaska | brain |
| 7 | Birds | Pigeon | Eagle | swan | nun |
| 8 | Musical Instruments | Piano | Guitar | flute | judge |
| 9 | School Subjects | Chemistry | Biology | history | salad |

Table 6.3: An example of a randomly generated stimuli set for Experiment 7b (taken from Experiment 3)

### 6.3.3 Participants & procedure

Participants were recruited from the University of Leicester and paid £6 for their time ($N$=30, mean age = 21.9, $SD$ = 9.32, 20 female). The same procedure as experiment 7a was employed. The experiment was designed and carried out on a computer using E-Prime© software. Subjects were presented with a series of anchor-word trials. Each trial consisted of a target word located a distance from an anchor word at a fixed location (either to the left or right hand side of the screen depending upon condition) and lasted for 14 seconds. The subjects were instructed to remember where the target word was located in relation to the anchor word. In between the learning phase and the test phase a short distractor task was employed (counting backwards in 3's) to prevent any short-term memory rehearsal. At test participants clicked using a mouse where on the screen they remembered the corresponding target word to have been located.

### 6.3.4 Results & discussion

The results show performance levels that were better than chance for all conditions (i.e., Dscore<1). The findings also show that memory performance was generally much better than in Experiment 7a. This is in line with the performance levels observed previously with the same stimuli (i.e., in Experiment 3). This meant ceiling effects owing to task difficulty could be eliminated as a contributing factor to the findings of Experiment 7a. Importantly, the results show the same decrement in performance for the PSA-SA condition (*Mean* = .86, *SD* = .35) compared with the PSA-DA (*Mean* = .59, *SD* = .27) condition as observed in Experiment 7a (see Figure 6.2 and Table 6.4). Additionally, results show a significant difference between the PSA-SA condition (*Mean* = .86, *SD* = .35) and the SA-SA condition (*Mean* = .58, *SD* = .25). This demonstrates that when PSA-encoding is introduced into the SA-SA condition performance is significantly impaired.

| Condition | Dscore (*SD*) | Dscore (*SD*) | $t$ | *df* | $p$ |
|---|---|---|---|---|---|
| PSA-DA vs. PSA-SA | .86 (.35) | .59 (.27) | 4.11 | 29 | $< 0.01$ |
| PSA-SA vs SA-SA | .86 (.35) | .58 (.26) | 2.99 | 48 | $< 0.01$ |

Table 6.4: Table showing mean Dscore and *SD* for the PSA-DA, PSA-SA and SA-SA for Experiment 7b. The table also shows summary statistics of mean comparisons between PSA-DA vs. PSA-SA and PSA-SA vs. SA-SA

Together, these two comparisons can provide important insights into exclusivity. As has been shown in Experiments 7a and 7b, subjects in the PSA-SA condition perform significantly worse than in the PSA-DA condition. This is attributable to the test contingency (i.e., DA vs SA). This reiterates the benefits of concurrent cueing. When compared with the SA-SA condition, participants' performance in the PSA-DA condition are equivalent. This ensures that there is no spurious difference between these two conditions and that performance levels are equal between the conditions, which is in line with results consistently found

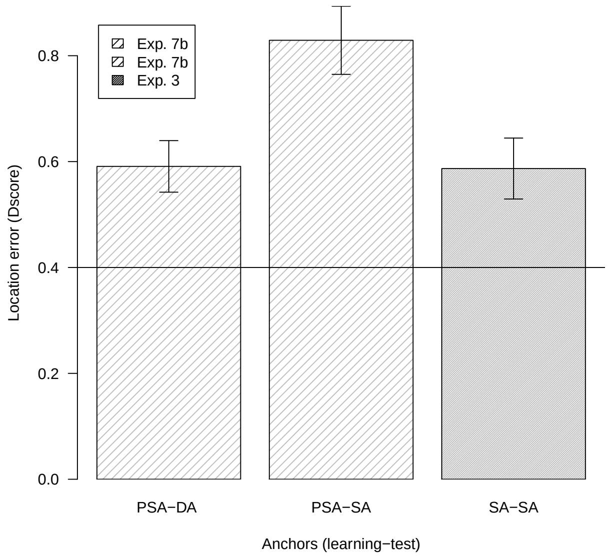


Figure 6.2: Graph showing mean Dscore for PSA-DA and PSA-SA from Experiment 7b and SA-SA from Experiment 3. An independence line is plotted which indicates the levels of performance expected according to the independence model.

in this thesis and previous work (Baguley et al., 2006). Also, the comparison between PSA-SA and SA-SA, where the only difference is the learning condition, shows greater levels of location memory in the SA-SA condition in comparison to the PSA-SA condition. This suggests that the PSA learning contingency has a detrimental impact on location memory performance. Together these findings strengthen the proposition that the positive influence of DA-cueing (i.e., PSA-SA<PSA-DA) may be counteracted by the detriment induced by PSA learning (PSA-SA<SA-SA) and result in equal performance between one and two spatial memories (i.e., PSA-DA = SA-SA).

## 6.4 General discussion

There are two findings in this thesis which are in stark contrast to the idea of exclusive processing. Together these findings isolate different stages of spatial information processing (e.g., encoding and retreival) as potential explanations for the performance levels consistently observed in this thesis and that of previous work. This chapter contributes to findings from Experiment 4 which together highlight the improbability that strict exclusive processing is occurring at either encoding or retreival. This chapter specifically contributes to an alternative explanation which suggests the encoding of two spatial memories has a tangible and impact upon the spatial information contained within each memory. Specifically, it isolates the PSA-encoding condition as the most likely site for memory degradation.

### 6.4.1 Paired memory encoding detriment

The findings from this chapter make an important contribution to testing the robustness of exclusivity as a model of multiple spatial memory performance. It is evident from Experiments 4 and 5 that exclusivity has a problem explaining why in some circumstances dual-cueing (DA) of memories offers a significant benefit. The current chapter examined this further and suggests another possibility that would account for single and multiple memory performance.

The findings from Experiment 7a and 7b implicate the encoding of related spatial memories as the stage at which performance detriment occurs. Both experiments show that if the encoding stage is held constant (i.e., PSA), then dual-cueing offers an advantage over separate single anchor cueing (SA). Experiment 7b also shows that single memory encoding (SA-encoding) avoids the problems of paired memory encoding (PSA-encoding). This adds further weight to the argument that the encoding of two memories is responsible for the performance levels that have been observed between PSA-DA and SA-SA. Although the mechanisms that are responsible for a detriment from PSA-encoding are still unclear, it is likely to stem from some kind of interference from encoding two memories which are regarded as distinct units.

In Experiment 1 of Baguley et al. (2006) they showed that repeated exposure of the same anchor-target relation *improved* performance. The important difference between Experiment 1 from Baguley et al. (2006) and the current experiment (either 7a or 7b) is that in the current experiments the anchor/cue differed every time the target was presented (i.e., PSA), whereas in (Baguley et al., 2006) the anchor-target presentation remained identical. This suggests that the number of presentations in the PSA-encoding condition are not a contributing factor to location memory detriment for PSA-encoding. This highlights that the cause of interference in PSA-encoding is the changing of the cues between each viewing of the target. This suggests that when individuals encode two related spatial memories they encode them as distinct units of information, otherwise similar results to Baguley et al. (2006) would be expected and the PSA-encoding condition would prove to be a slight advantage. This means that interference between distinct or incompatible elements of each paired memory are likely to be responsible for the PSA-encoding detriment. Considering the components which differ between related memories this interference may well stem from how spatial information is stored in vector form (i.e., direction and magnitude of space). In other words, during some point in the encoding of two related memories the absolute quantities of space (i.e., large vs. small) and direction (i.e., left->right vs. right->left) interfere and result in degradation of the quality of information stored in each memory.

## 6.5 Conclusions

These findings suggest that if exclusivity is to remain as a dominant model of location memory it must explain why in some circumstances dual-cueing offers an advantage over separate single anchor cueing. If only one memory is retrieved then concurrent cueing of both memories should have no impact on performance compared with single anchor cueing. On the other hand, any new model must account for the decrease in performance when compared with only one memory.

The results show that having categorically related anchor points does not help to prompt one memory from the other by categorical prompting alone. This would be in line with the idea that two memories are retrievable but are held in distinct representations which prevents the cueing of another memory from a different representation. This is also supported from the findings of Experiment 1 of Baguley et al. (2006) which showed repetition of anchor-target relations to improve memory. Thus, if paired related memories are considered one and the same then a similar performance gain should be observed in the current experiments which it was not. This suggests that related memories are stored as distinct units even though they share a common target object. Additionally, that the distinction of each memory (perhaps magnitude or direction) may become interfering factors when attempting to encode two memories which are related via a common target object.

This chapter adds further support to the idea that exclusivity as a model might not be entirely appropriate as to account for all the findings of this thesis. There are a number of results which implicate the possibility of different underlying mechanism that may be occurring other than exclusive processing. However, these findings also imply a reason why exclusive processing is preferred. If interference is inherent with encoding two spatial memories from different perspectives (perhaps stemming from a change in cue) then any strategy to avoid this interference (i.e., encode only one memory) would be effective. This suggests that a reformulation of the exclusivity model may be required or a new model proposed. This does not dismiss the idea that both strategies (i.e., exclusive processing or degraded join memory processing) are employed as and when required.

# Chapter 7

# Conclusion

This thesis aimed to explore how related sources of spatial information interact and provide an estimation for an object's location. It began with the assumption that exclusive processing may be a component of spatial memory. This is inherently interesting for a number of reasons. First, the processing of spatial information exclusively is counterintuitive with respect to how individuals recollect their spatial environment, that which appears as a coherent and malleable representation. Therefore, it is rare to be presented with the opportunity to study a phenomenon that is in stark contrast to personal experience. Second, it offers an example of a process that appears to be at a functional junction between effectiveness and accuracy. At first glance exclusivity seems primarily to hinder the retrieval of spatial information. However, as with many processes that appear maladaptive there quite often lies an economical rationale in their presence (e.g., forming stereotypes or spatial biases based on hierarchy). This is motivation enough to pursue a line of enquiry into the role of exclusivity in human spatial memory.

This thesis set forth a number of empirically grounded means with which to overcome exclusive processing. However, exclusivity as a model has largely remained resistant to such manipulations. Thus, the initial objective may well have been to overcome exclusivity, but a body of evidence is mounting which suggests an exclusivity model can account for the mechanisms that underlie the processing of multiple objects. This thesis not only provides evidence of the robust nature of the exclusivity model but also how objects are learnt over time, the influence of expertise processing, and the influence of semantic information on location memory. The findings also give grounds to propose an alternative theoretical account of exclusivity which offers the field testable predictions for future endeavour.

This chapter will take the following format. First, it will summarise and discuss the implications of the current findings in light of spatial memory generally. Second, it will focus on the evidence in support of exclusivity and the role it may play in object-location memory. Third, it will highlight the evidence that does not fit with the idea of exclusive processing and propose a brief sketch of an alternative model.

## 7.1 Summary of all experimental findings

The first part of this discussion will aim to bring together the totality of the findings that compile this thesis. This is a good opportunity to provide a diagrammatic overview comparing all experimental results. This is easily achievable due to the consistent nature in which location memory performance has been measured. Thus, a forest plot has been constructed showing the mean differences in location memory performance (Dscore) between the PSA-DA condition and a range of comparative conditions. Each comparative condition is highlighted to the right of each experiment (see Figure 7.1). The dotted line represents a no effects line reflecting no difference between mean Dscore. Each square represents the size and direction of the difference between mean Dscore (i.e., effect size) across experimental conditions.

As can be seen from the graph there is moderate variation across the range of experiments carried out. Experiment 5 and Experiments 7a and 7b show the largest effect sizes that deviate from the no effect line. However, the trend across the majority of experiments suggests no major deviation from exclusivity, supporting previous findings (Baguley et al., 2006). To sum up, under the typical design for testing exclusivity (PSA-DA vs. SA-SA) no individual experiment showed a clear advantage of two memories for an object's location over one.

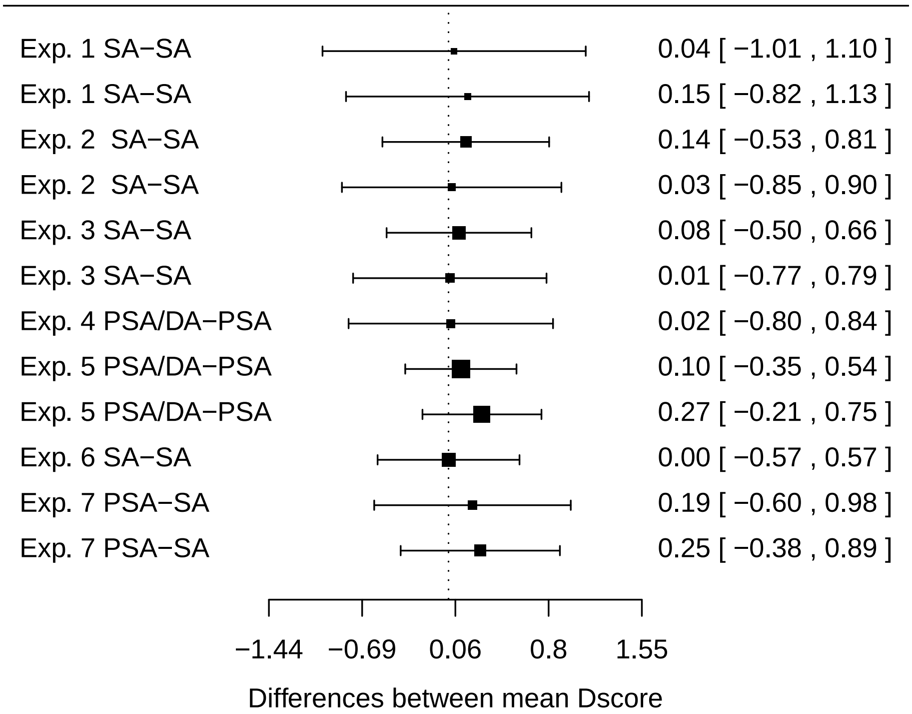


Figure 7.1: Forest plot showing effect sizes (difference between mean Dscore for PSA-DA vs. SA-SA; PSA-PSA; PSA-SA) across all experiments. The difference in Dscores is presented to the right of the graph with corresponding *SE*. The dotted line represents no difference between means (i.e., exclusivity). Plots to the right of this line indicate larger effect sizes.

## 7.2 Discussion of the finding in light of spatial memory generally

This section summarises the findings in light of spatial memory generally. It does not focus on exclusivity or the encoding and retrieval of two spatial memories, but rather how the findings contribute to the broader literature on spatial memory. Within this section the ideas of automaticity of spatial information, precision for object location over time, and the role of semantic information for spatial memory enhancement are discussed.

### 7.2.1 The role of automaticity in coding spatial information

This thesis provides evidence that spatial information is not processed automatically. According to Hasher and Zack's (1979) criteria a process can only be considered automatic if it is not impacted by attentional limits. It was evident throughout this research that location memory and therefore the coding of spatial information is significantly dependent upon availability of resources. Experiment 1 demonstrated a trade-off effect between recalling location or content information with regards to a target object. This, it was argued, was a consequence of employing a large quantity of text that had to be attended to for purpose of later recall (i.e., because it acted as a cue at test). The high level of cognitive capacity used to memorising the text led to a trade-off between recalling the identity *or* location of the object.

This is not to say that no information was encoded for location when an object's identity was recalled but rather one element (i.e., location) was recalled at a cost to the other (i.e., object identity). This indicates that effort of processing had a significant impact upon the quality of recall. In this instance it may have prevented binding of what/where information in working memory. The method of quantifying location memory employed in this thesis allowed for such interpretation. For instance, location memory was assumed to take a continuum form where it could vary from being exact to inexact. This meant that the amount or quality of spatial information that has been encoded could be assessed across memories. In much of the previous research location memory was assessed solely on the proportion of correct responses (e.g., Mandler & Parker, 1976). Applying correct responses as a means to measure location memory could potentially obscure an ability to capture location information. Thus, the current findings not only demonstrate that location information is dependent on processing effort but also that a finite amount of resources need to be available to bind features of that object and determine the quality of stored spatial and non-spatial information.

This is interesting because it suggests that only when resources are available and allow for the binding of object features (probably in working memory) can those features act together to enhance recall of other features of the object. For example, if binding does not take place cueing with one feature does not automatically cue all other features. It also suggests that features of an object can be encoded with varying levels of strength (strength here relates to the ratio of probability of recall to accuracy) and the degree of strength for each component is dependent upon availability of resources at encoding.

Another contention with regards to the automatic encoding of spatial information is whether practice effects should be evident. If a process is thought to be automatic then practice should not influence its performance (Hasher & Zacks, 1979). The findings from Experiments 5 and 6 provide strong evidence that spatial information can be dramatically improved upon through practice. If spatial information was encoded without effort then the initial level of performance (e.g., for day 1) would remain constant over the entirety of the learning period. However, the results from both learning experiments show steep improvements in recalling location information. The absence of learning in the non-learning condition of Experiment 5 adds weight to the idea that it is the coding of spatial information that is being improved upon rather than familiarity of the task.

These findings indicate that although some (probably more coarse) estimations of space may be encoded with little effort, in order for fine-grain estimations to occur effort is certainly required. This point highlights that when assessing such characteristics as spatial coding automaticity, the nature of the task (and the capacity of the response measure to discriminate between levels of precision) really determine the level of effort required to make a spatial judgement. For example, given a task where only coarse levels of location accuracy can be discriminated (owing to the method of measurement), one would expect perfectly acceptable location responses with minimal effort. However, if the measurement method allows for discrimination between the finest levels of location judgement then one would expect more effort is required to make such estimations. In essence, this highlights that location memory precision and availability of resources/effort are related on some continuous level.

It is clear that practice has a striking impact on location memory performance. General models of practice effects have been proposed (e.g., Logan & Schulkind, 2000 and Rickard, 1997) which argue that as practice progresses the need for algorithmic computations for retrieval are reduced through the process of direct memory retrieval. More specific to object location memory, Dynamic Fields Theory (DFT) states that neurons in working memory specify spatial information over time due to activation of neighbouring neurons (Spencer et al., 2001, 2007; Schutte et al., 2003; Schutte & Spencer, 2009). Through repeated exposure, excitation of neurons becomes self-sustaining, precluding the need for continuous presentation of the stimuli. Thus, the neurons in working memory leave a transient firing trace in long-term memory. As this process is iterated neuronal firings become less coarse and more precise. This suggests that initially spatial information is represented with limited precision and that this precision is gradually increased over time. Although the mechanisms behind practice and spatial memory have not directly been examined in the thesis, how spatial memory increases over time has been investigated. Specifically, a number of experiments sought to provide insights into the allocation of resources across multiple objects over time. The results of this analysis are agreeable with neuronal models. These findings are discussed in the next section.

### 7.2.2 How are multiple object locations learnt over time?

Through the modeling of confusion matrices it was possible, arguably for the first time, to assess how memory precision for multiple objects evolves through repeated exposure. The results from Experiment 6 demonstrate that over a ten day learning period precision arises in roughly equal increments across all target objects. This begs the question of why might learning evolve in this way?

There are a number of possible explanations for this. One explanation is that it could reflect the limits of encoding fidelity upon a single viewing of an object under the current design (i.e., time constraints). That is, the level of precision the task allows for upon each viewing of the object. It is most likely that the level of resources available for coding spatial information will determine the level of stored precision from each stimulus exposure. Hence, if the availability of resources is high enough, multiple objects may be encoded *exactly* with just a single exposure. In the situations when exact encoding is not possible the rate of improvement will vary across different tasks, however the incremental process may not change. For example, in a task where longer viewing time is allowed, each stimuli exposure may result in higher levels of precision per viewing and thus aggregation of an approximation to exactness would develop at a faster rate. Thus, with each viewing granularity of coordinate information may be superimposed upon the previous day's memory trace. Over time this may act in a cumulative manner which results in the kind of development of precision observed in Experiment 6 (see Dynamic Fields Theory in the previous section).

The speed at which increments in precision progress is therefore determined by the availability of resources. This suggests that incremental-type learning evolves out of necessity in situations where certain factors preclude encoding exact location. These factors could be anything that affects the amount of available resources for processing an object. An example of this would be the number of objects that are to be recalled. Research shows that as the size of an object array increases, subsequent location accuracy decreases (Shadoin & Ellis, 1992). The literature also shows that spatial information can quite often be represented in an organisational manner that leads to biases (Hirtle & Jonides, 1985; Stevens & Coupe, 1978). This suggests that the opportunity to process an object exactly on one occasion rarely arises in everyday exposure to multiple objects. On the other hand, with successive viewings of a single object such biases can be rectified by accessing an existing representation and matching that to an object's actual location. There is neurological support for this idea in the form of place cells, where a neuron only fires in a specific location. Upon revising that location a 'neuron matching' occurs between current firing rates and previous firing rates (O'Keefe & Dostrovsky, 1971; O'Keefe & Nadel, 1979). The benefits of repeated *retrieval* for long-term memory retention is also well established in the behavioural literature (Roediger, 2000; Karpicke & Roediger, 2007). This emphasises the importance of retrieving existing spatial information as a mechanism for building more precise location memories over time.

It is argued that because object locations are often encoded as inexact a scenario with multiple to-be-remembered objects would benefit from an incremental strategy. The alternative is to focus on a select number of objects which will be a waste of resources because of distortions that are inherent with object location generally. Thus, it might be more prudent to spread resources across a number of objects and rely on repeated exposure to resolve inaccuracies implicit in encoding. In essence, given the general inexactness of object-location memory an incremental strategy is required when multiple objects are encoded.

The incremental nature of spatial precision also implies that capacity is shared amongst objects. On the presentation of multiple objects it appears more prudent to encode a limited amount of spatial information for each object than a greater amount for fewer objects. This is probably because with the alternative strategy (i.e., encoding a few items with great precision) there is a cost of impairment to all other objects. The application of an incremental strategy may be effective because it reduces the risks of making extreme errors. This would be beneficial in situations when uncertainty with regards to the importance of each item is a factor. For example, if an individual had to process a collection of objects with no obvious goal (as in the current experiments) then it is wise to make sure at least some information is available for each object in case one of those objects turns out to be of importance post hoc.

This idea is strengthened by the type of experimental design employed in this thesis. Subjects are expecting to recall information with regards to all objects so it would be a maladaptive strategy just to remember a few items more accurately. Of course, under the current paradigm all memories are averaged and therefore this strategy does not offer any specific advantage. However, subjects are not made aware of such calculations. As far as the participants are concerned they are being tested for their memory of each object from a series of objects.

The ideas relating to incremental learning strategies suggest that task factors can influence the rate of precision development over time. Hence, if more precise location information can be processed on one exposure then the rate of precision increments will increase compared with a situation where only small amounts of spatial information are available. This highlights that factors pertaining to the learning context can impact general capacity to encode location information. This idea is strongly supported by the findings of this thesis. The next section highlights such factors. Specifically, it focuses on the role of semantic content of the learning context and spatial memory performance generally.

### 7.2.3 How do semantics lead to improvements in spatial memory accuracy?

Although the overall findings of this thesis show no significant benefit of semantics in overcoming exclusivity, they do show improvements for general location memory. The results show that enhancement of certain semantic aspects of the stimuli typically have a positive effect on location memory performance.

In Experiment 1 participants were presented with either English or Turkish sentences as stimuli. Owing to the similarity in the characters used for each language (i.e., a Latin based alphabet), the only varying factor was the semantic content. The findings showed significantly better recall when the participants viewed English sentences than when they viewed Turkish sentences. English stimuli could have offered a number of benefits for the participants, such as a richness of processing (Craik & Lockhart, 1972). More specifically to spatial memory, the processing of semantically rich stimuli may allow the spatial component of the visual array to be better integrated into the memory trace. Thus, when processing English sentences existing schemas in LTM can be drawn on (Chase & Simon, 1973). An existing schema could be a single word from the sentence that has some prior salient meaning for the participant. The introduction of semantic content may allow the object along with corresponding location information to be integrated into information that was more likely to be recalled owing to a pre established knowledge base of English words (i.e., lexicon). Thus, the English sentences' primary advantage in comparison to the Turkish sentences was that the semantic content of the English sentence allowed for stronger retrieval pathways (via pre-existing knowledge) for the encoded information. This advantage also must apply to information that is encoded alongside the semantic information (i.e., an object's location).

As the experiments progressed semantic content was applied in more elaborate ways, resulting in parallel gains for spatial location memory. Although semantic information was employed in different ways in Experiments 2 and 3, arguably they benefited from the same mechanisms; that of memory distinctiveness. Experiment 2 employed nursery rhymes which meant that each memory for a target object was associated with a different nursery rhyme. Inevitably, the components that distinguished the nursery rhymes from each other (e.g., semantic theme and words) also distinguished each memory from one another. This meant any information that was encoded alongside the semantic content also became more distinct.

A similar semantic advantage was apparent in Experiment 3 where the anchor points were made up of single words sampled from unique semantic categories (e.g., types of musical instrument). Here the distinctiveness was contained solely within the anchor point. Thus, unlike Experiment 2 there was no information associated with the target object other than one word, which made up the entirety of the cue. Owning to the significant performance gains seen in Experiment 3 compared with Experiment 2, this suggests that a crucial feature that benefits from distinctiveness is the anchor point. This indicates that the benefit of distinctiveness lies in the retrieval cues' ability to prompt recall of the correct target object. This is presumably because recognition of the anchor is the primary means of object retrieval. Only after an anchor point has cued retrieval is the distinctiveness of the object valuable. Thus, if interference between anchor points occurs resulting in an identification failure at test, there is no possibility of target recall at all. Memory distinctiveness has consistently been shown to aid in memory performance for a number of different types of information (Geraci et al., 2009; Bireta et al., 2008; Conrad & Hull, 1964), it appears spatial information is no exception to this.

These collection of findings suggest two mechanisms that underlie the benefits of semantic content in spatial memory. First, the integration of spatial and semantic information at the point of encoding (Vogel et al., 2001) allows for stronger retrieval pathways via pre existing semantic knowledge in long term memory. This presumably triggers information contained within a memory trace, a component of which is location. Second, semantic information helps to distinguish between memories regarding an object's location (anchor point distinction being of primary importance followed by target distinction). The corollary of memory distinctiveness is a reduction in memory interference.[1] The anchor point is also emphasised as a feature of the visual array that benefits in particular, namely because of its role in cueing object information at retrieval.

[1]It is not proposed (at this point) that interference is a consequence of any particular component of a memory unit, instead it is suggested that such interference may arise from many factors, semantic content being just one. In essence such interference is the converse of distinctiveness. It is also worth noting that distinguishing between related spatial memories is more complicated (discussed above) because it involves a common object.

## 7.3 Discussion of the finding in light of exclusivity

This section summarises the findings in light of exclusive processing specifically. It focuses on exclusivity and the encoding and retrieval of two spatial memories in light of the findings.

### 7.3.1 Expertise and exclusivity

Prompted by one study that has implicated expertise as a means of overcoming exclusivity (Harding, 2006), the current research sought to expand this idea further. Although the original study suffered from a number of methodological weaknesses (e.g., small sample size, small effect size), it provided a plausible starting point from which to scrutinise exclusivity further. The overall findings from this investigation are in contrast to the previous work. This is not to say the expertise employed in previous work does not offer some advantage that was not initiated under the current work. What the current research does provide however, is evidence that expertise processing in the form of text expertise is not enough to circumvent any limitations of the memory system that might be contributing to exclusivity. Additionally, subsequent experiments carried out in this thesis, those not specifically related to expertise, attest to the robustness of exclusivity. This makes it more probable that the previous work on expertise may well be the result of spurious findings.

Experiment 1 employed stimuli that are processed with little effort and in a holistic manner (e.g., text). However, it was clear that the effortlessness typically associated with text processing hindered location memory. Although text is processed easily, the recollection of text is a more arduous task. Experiment 2 however ensured that the memorisation of text was not needed (by employing highly familiar sentences). This offered the benefit of holistic text processing (i.e., expertise) but also reduced the amount of information (i.e., load) to be encoded for later recall. This meant that load could be reduced isolating the effect of expertise processing in a more reliable manner and one that would be more in line with previous work using musical stimuli. The null effect of expertise even after a reduction in load suggests, at least, that expertise processing in this instance cannot be generalised to spatial information. It also suggests that the general benefits of possessing expertise may not be transferable across multiple features of the stimuli. Hence, although reading is regarded as an effortless process and involves the coding of some spatial information (i.e., distance between letters and words), other elements introduced to the stimuli may not be processed in the same effortless manner (i.e., the location of a Greek symbol placed above the text).

Research shows that levels of expertise can be a crucial factor in determining the benefits such as chunking, holistic, and effortless processing. Bilalic, McLeod, and Gobet (2008) found experts' abilities to differ substantially from non-experts' but only with the greatest level of expertise. They found that medium-level expert attainment can sometimes harm processing capabilities by limiting their flexibility to problem solve. On the other hand extreme levels of expertise can block the recognition of other lower-order relations. For example, Gobet and Simon (1996) showed that expert chess players were poorer at recalling chess configurations when the configuration was random. This was attributed to a collection of pre-existing templates of chess configurations that were interfering with the encoding of a random configuration. Thus, it is quite possible that text expertise led to a greater ability to recognise a sentence as being a whole unit but this concealed lower-order information (i.e., the elements making up each memory) such as the location of the object. The literature highlighted above also illustrates the delicate balance between having too much expertise and not having quite enough. This reiterates the limited circumstances in which expertise may offer advantages.

### 7.3.2 Semantics and exclusivity

One hypothesis as to exclusivity's presence is that some form of retrieval blocking may have been occurring. This was tested through the application of previous findings concerning parallel and serial processing (Logan & Schulkind, 2000; Rohrer & Pashler, 1998). These findings highlight the possibility that an information bottleneck may be responsible for retrieval blocking (Carrier & Pashler, 1995; Rickard & Bajic, 2004). This idea proposes that there is a central processor that has limited capacity and is involved in dictating the amount of information passed from memory. The relieving of additional effort inherent in retrieving information from distinct categories has been shown to overcome such bottlenecks (Rohrer & Pashler, 1998; Logan & Schulkind, 2000). This is due to the freeing up of processing capacity that is usually consumed by such peripheral capacities as switching (Nino & Rickard, 2003). Thus, if concurrent cueing of spatial memories was responsible for a bottleneck type effect, then freeing up processing capacity may have helped to overcome any retrieval blocking of spatial information.

Semantic categories were employed to alleviate any information bottlenecks in the retrieval of multiple memories. Specifically, the use of semantic categories reduced any extra processing load by allowing both memories to be stored in the same semantic category. Thus, two anchor points related to the same target object shared a common category. This meant that although each representation of an object's location was encoded on separate occasions, both memories would be stored within the same semantically defined memory unit. The findings from Experiment 3 in particular suggest that this approach was not successful in overcoming exclusivity. It is argued on the grounds of these findings that limited capacity of retrieval processing does not prevent the retrieval of more than one spatial memory, resulting in exclusivity.

Based on these findings it is put forward that exclusivity may not be a consequence of capacity limitations per se. In other words, it is not likely that two memories are wanted to be retrieved or integrated but are prevented in doing so owing to a finite capacity of the cognitive system. However, instead of being capacity driven there is a possibility that exclusive processing may be strategy driven. This would make exclusivity the result not of a cognitive capacity failure but rather a frugal higher-level strategy. That is, for some purpose not yet considered, exclusive processing may prove profitable. Any costs incurred from exclusive processing may lead to gains elsewhere such as memory strength or robustness through the avoidance of interference.

This is an important point as this possibility has not yet been considered elsewhere in the literature. Often for a process to be considered efficient it must have some advantage that outweighs any expense. It is assumed that exclusive processing incurs a cost by way of potential memory accuracy (i.e., if integration takes place). However, whether this cost is counteracted elsewhere which offers advantages greater than those incurred through exclusive processing is of great interest. Recent findings show that processes can be preferred not because they yield the most accurate or fastest results, but simply because they require the least amount of mental effort (Lehle, Steinhauser, & Huebner, 2009; Huebner & Lehle, 2007). Thus, if the effort of retrieving two spatial memories is outweighed by the potential gains in location memory accuracy then a preferred strategy would be just to retrieve one memory whose level of accuracy is adequate enough for a given task.

### 7.3.3 Learning and exclusivity

A learning experiment is an extremely powerful tool for testing the resilience of exclusivity. Owing to the role of repeated exposure in spatial memory integration it was a crucial avenue of investigation (Ellen et al., 1982, 1984; Sawa et al., 2005; Blaisdell & Cook, 2005; Tolman, 1948; Poucet, 1993). Not only does repeated exposure offer familiarity with the stimuli generally but importantly it allows individuals to become familiar with the spatial relations that are integral to the stimuli. Learning also offers a reduction of reliance on working memory (Garavan, Ross, Li, & Stein, 2000). Owing to the temporal nature of learning, opportunities for consolidation such as sleep were also available (Ellenbogen et al., 2007). More obvious advantages are apparent in that every time a participant is presented with a two memory test condition (DA-cueing) they are able to view the correct combination of anchor points. This would have been evident at the test stage for all trials every day.

Despite all of the aforementioned advantages, the findings show no advantage for holding two spatial memories over one. This indicates that if memories are acting exclusively, this is not a consequence of a lack of exposure to the stimuli or not enough time to develop resources amenable to non-exclusive processing. There are a number of possibilities as to why this is the case. It is possible that the encoded spatial information is still represented in a sensory-like form as hypothesized by Baguley et al. (2006). Remaining in such a form may prevent more abstract manipulation of each memory in a way that enables aggregation. This could be attributable to the length of time employed in the experiments. Research using animals has shown integration is not evident until several months after initial stimuli exposure (Blaisdell & Cook, 2005; Garling et al., 1983). However, evidence from humans shows integration is quite possible using time periods much shorter than those of the current experiments (Molet et al., 2011, 2012; Escobar et al., 2001). Thus, the length of time can probably be discounted as a factor not allowing for non-exclusive processing.

Not only do the findings provide no evidence of integration but also they do not demonstrate any evidence for independence. The independence model proposes that two memories are available but they are not selected in any kind of beneficial way. Thus, any advantage for holding independent spatial memories stems from the increased probability of retrieving at least one memory compared with exclusivity where only one memory can be relied upon in total. This is quite a sobering finding and suggests that in the event of repeated exposure to related anchor-target relations two memories are still not accessed, even independently.

The findings from the learning experiments clearly show no signs of non-exclusivity. However, what is of great interest is that even under potential conditions of exclusivity, learning is still able to progress. What is more, exclusive processing seems to allow for a progression of accuracy (i.e., learning) at the same rate as that of a single memory. This suggests that whatever factor is determining the retrieval of one exclusive memory that factor is systematically applied each day during the learning period (i.e., the same memory is selected each day), else learning might not develop at the same rate as one memory.

For example, if individuals switched between memories each day then plausibly precision would only increase at half the rate to that of a single memory where the same memory *has* to be selected each day because it is the only available memory. However, an interesting alternative strategy is to encode information from both memories (in a fragmentary type manner). In such a case the quality of information encoded from each memory is perhaps reduced but this strategy has the advantage that twice as many cues are available at test. Such a strategy must store multiple traces of information for each target that are made available at recall (this alternative strategy is discussed later in the guise of a fragmentation account).

## 7.4 An exclusivity account of object-location memory

The consistent lack of evidence from expertise, semantics, and learning to support non-exclusivity leaves two plausible scenarios regarding exclusivity and object location memory. One, exclusivity is a resilient component of object-location memory where only one memory can or is relied upon. Two, a different type of processing might be occurring and thus accounting for the observed levels of performance. The first type of processing (exclusive) will be discussed below. A second possibility of processing (fragmentary) will be addressed later.

If exclusivity is to be considered a robust feature of object-location memory, its presence must be justified. Thus, why might exclusivity be occurring? The findings from this thesis support the notion that exclusivity is not occurring as a result of a cognitive capacity deficit preventing non-exclusivity. In other words, it is not likely that individuals are attempting something other than exclusive processing (i.e., integration) but cannot because capacity does not allow for it. However, it seems more in line with the findings that a strategy is implemented owing to the effects of finite cognitive capacity. Exclusive processing may be considered a top-down process dictated by a higher-order strategy rather than a bottom-up capacity limitation. Processing load has been continuously reduced via changes in the amount and type of information to be processed. Overloading of retrieval information (i.e., a bottleneck) has been diminished. Working memory load has been reduced, and task complexity has been discounted. Together this evidence indicates that the overloading of cognitive capacity, whether at encoding or retrieval, is not responsible for exclusivity. This suggests that it may not be the amount or type of information involved but rather how that information is processed.

According to a strong form of exclusivity, only one memory is encoded or retrieved. This allows for a number of different processing styles to account for the findings under the remit of an exclusivity model. Given the range of encoding and retrieval presentations it is difficult and perhaps implausible to fit a global exclusive processing strategy to every condition. It is argued that exclusive processing may take many forms which adapt to the level of interference and availability of resources according to encoding and cueing contexts. In the next section a number of processing stages where exclusivity could take place (encoding and retreival) are discussed as possible explanations of why exclusive processing may take place.

### 7.4.1 Exclusive processing and interference avoidance

The overarching hypothesis presented here for exclusive processing is one of interference avoidance. In turn, interference itself is proposed to be a result of the manner in which spatial information is represented. This is in contrast to exclusivity being a consequence of cognitive capacity limitations. The findings of Experiment 7a and 7b indicate that interference is a result of the PSA-encoding condition. Comparing the findings of Experiment 7a and 7b with Experiment 3 of Baguley et al. (2006) it is likely the PSA-encoding sees a decrement in terms of performance owing to interference between viewing the same object but in different contexts (i.e., with two different anchor points). Specifically, Baguley et al. (2006) showed that if anchor-target relations were repeated small performance gains were observed. Thus, the number of trials or presentations cannot account for PSA-encoding decrement but rather the change in anchor points between separate presentations of a target. The reason why different anchor points might disrupt the encoding of spatial information is discussed below.

In order to understand how spatial information is represented in a manner not conducive to integration (i.e., non-exclusivity), it is useful to compare situations where different sources of non-spatial information lead to superadditive performance levels (i.e., non-exclusive). The findings from Rubin and Wallace (1989) point to an explanation of why superadditivity (or independence) is not observed with spatial information. They show that two *clues* as to a target word (i.e., 'it rhymes with dead' and 'it's a colour') offer better recall of the target word (i.e., red) than the sum of the two combined clues together. This is attributable to the fact that each clue significantly narrows down the possibilities as to the target's identity. Hence both clues are 'pointing' to the same piece of information for retrieval. Thus, if this was occurring in the current experiments then non-exclusivity would be observed. However, this was not found which suggests that each related memory is considered as being distinct from the other memory and together both memories may not 'point' to the same piece of information (i.e., an object's location).

The fundamental difference between the Rubin and Wallace (1989) example is that the word 'red' is not dependent upon the cue to define it, unlike spatial location. If 'red' were reliant on something to specify it, it would change depending on what it was being cued by. For example, if 'red' presented together with 'banana' led to the retrieval of 'APPLE' and 'red' presented together with 'table' led to the retrieval of 'CHAIR', then cueing with 'banana' and 'table' would create interference because it is unclear whether to retrieve 'APPLE' or 'CHAIR'. In this instance the cue has defined what is in need of retrieval. The nature of locations work in a similar way. Locations are not absolute but are defined by a reference point. Thus, to cue an object in a location is to define that object's location. For instance, given two reference points positioned at varying distances from a target will create two different definitions of that object in terms of space. This means that each anchor-target relation contains a unique source of information that points to a target location. Although there might be a common feature pertaining to both anchor-target relations (i.e., the objects' identity), this is not the information that is being cued for. Rather, it is the quantity of space that is needed in order to acquire the location of the object (not the identity of the object itself). Since there are two cues for each target object there are two distinct pathways (i.e., two quantities of space) which share a common element. In essence, the difference in anchor points may create interference because the spatial information contained within each memory is unique and therefore incompatible with one other.

This explanation of interference is in line with the proposition that space is represented as a vector consisting of magnitude and direction information (Collett et al., 1986; McNaughton et al., 1991; O'Keefe, 1991; Baguley et al., 2006). Owing to the design of the experiments contained within this thesis (i.e., having anchor points either side to the left and right of the target object), this always resulted in different magnitudes and direction contained within each memory. For example, if a target was located in position 7, this would result in a left-anchor memory comprising a magnitude of space of 6 units (i.e., 1-7) and a direction of left to right. In comparison, a right-anchor memory would comprise a magnitude of space of 2 units (i.e., 7-9) and a direction of right to left. This highlights an inconsistency of representational information that is unique to spatial information in comparison to situations where non-exclusivity is observed. Owing to the findings that implicate the *encoding* of spatial information as a potential point of memory degradation, it is plausible that the encoding of unique yet related elements of space (i.e., magnitude, direction, and object identity) are responsible for such degradation by way of interference. Exclusive processing as a means of avoiding such interference is discussed in the next section.

### Avoiding interference at encoding

Exclusive processing can potentially prevent interference in the PSA-encoding condition by encoding just one anchor point. The idea that only one memory is encoded (*encoding exclusivity*) out of efficiency is in line with some of the findings from this thesis. The results show that processing spatial information with any accuracy is an effortful process. Specifically, the more effort involved in encoding spatial information the better the recall accuracy will be. Experiment 1 showed that the amount of resources available will often determine the level of accuracy at which spatial information is stored. Owing to the heavy demands of the stimuli (i.e., unfamiliar text) mixed with the act of processing two memories, Experiment 1 showed that spatial information can be sacrificed for other types of information (i.e., object identity). Thus, if resources are compromised a trade-off arises which significantly reduces the quality of information contained within a memory trace. Additionally, evidence from Experiment 5 and 6 shows that significant performance gains occur when exposure to spatial information is repeated daily for a period of time. This suggests that the fine-tuning of previously acquired information requires a large amount of time and effort investment.

These findings indicate that a strategy that reduces load may also reduce interference and thus increase accuracy. Therefore, a strategy to reduce the effort involved in discriminating between two similar memories (i.e., interference) might play a fundamental role for encoding exclusivity. If resources are spread across the encoding of two memories then the amount of information will be reduced for some memories. Thus, exclusivity may have evolved to prevent the need for resource-sharing between two effortful processes (i.e., the encoding of two spatial memories) and reduce the potential for interference. This is a prudent strategy if individuals are able to easily recognise that two parts of a pair of related memories share a common target.

Findings from Experiments 2 and 3 where the connection between related anchor points was strengthened showed performance gains for the PSA-DA condition compared with the performance of PSA-DA in Experiment 1 (i.e., with weaker connections between anchor points). This increase could be attributed to the fact individuals can recognise that two memories are related and therefore can discount one of the memories as being redundant. In essence, the benefit of introducing distinctive pairs of anchor points may be one of allowing for redundancy, not integration. More specifically, being able to recognise that two anchor points are related increases the awareness of their incompatibility and potential interference.[2] This means that an individual can focus on encoding one of the memories because they are aware that either one will provide enough information as to the target's location. Additionally, the encoding of a second memory will double the amount of mental effort which will increase load of resources such as working memory capacity and result in deterioration of memory quality. The application of such a strategy creates one more robust memory resulting in similar performance to that of a single spatial memory.

Exclusive processing can account for the finding that PSA-DA outperforms PSA-SA. In line with the above explanation that only one memory is encoded to avoid interference, the removal of a cue at test will predict a decrease in performance in the PSA-SA condition compared with PSA-DA. For example, in the PSA-DA condition it does not matter which memory is encoded, both are available at test to cue which ever memory has been encoded. Whereas, in the PSA-SA condition if only one memory is encoded and a random cue offered at test there is a 50% probability that the cue at test was not the one encoded.

Exclusive processing of related pairs of spatial information could be considered adaptive. Specifically, encoding exclusivity may prevent further decreases in performance by avoiding any attempt to process a second incongruent memory. In turn, this may increase the robustness of the memory that *is* stored.

### Avoiding interference at retrieval

The second processing strategy is *exclusive retrieval*. In essence, this is where only one memory (once encoded) is later recalled. When cued separately (i.e., PSA-cueing) both memories are shown to have been encoded, stored, and retrievable. This isolates concurrent cueing as the stage where retreival exclusivity may take place. It also provokes the question of why when given two cues simultaneously for an object's location individuals simply choose to retrieve one and do not attempt the retrieval of a second memory, even though both memories have been shown to be available? The findings from this thesis can provide

[2]This type of cue redundancy should be distinguished from that of Jones (1987) who states if one cue is successful in retrieving a memory trace then so is the other, i.e., P(A or B) = P(A). However, the term cue redundancy used in this thesis suggests that only one cue is necessary because it is the only one associated with the memory trace. Thus, the presence of a second is superfluous.

a number of insights about what might be occurring at retreival. First, findings suggest that concurrent cueing does not encourage exclusive processing by straining capacity limits.[3] Results from Experiment 4 and 5 show that the reduction of load and increase in ease of parallel retreival do not improve performance of two memories and therefore indicate that exclusivity is still apparent.

Second, exclusive retreival is more likely a consequence of the manner in which spatial information is represented rather than a capacity issue. In other words, there must be some kind of cost in retrieving a second memory that outweighs the possibility that the second memory is more accurate. This suggests that the retreival of a second memory may interfere with the already retrieved information from the first memory. Similarly, the already retrieved information from the first memory may cause interference with information contained within the second memory. Analogous to the hypothesized interference at encoding it seems plausible that such an explanation of interference can equally be applied to the retreival stage. Owing to the fact that both memories are represented as distinct units of information yet share a common element, conflict in the magnitude and direction of spatial information contained within each memory may well be the cause of retreival interference. That is, once information has been retrieved regarding one anchor point any attempt to retrieve further conflicting information from the second anchor point may be resisted due to the potential interference or confusion between two incongruent sources of spatial information.

Although the second memory may well be more accurate the cost of attempting it's retrieval, given that information has already been retrieved from a similar yet different memory, may lead to degradation of both memories even further. Thus, the preventing of the retrieval of a second memory means that at least one memory remains in tacked (i.e., the first memory[4]). In other words, the amount of interference (or confusion) from retrieving a second memory outweighs the potential increase in accuracy a second memory may offer.[5]

In essence, the argument for exclusive retreival is based on the same idea of interference avoidance as encoding exclusivity. Additionally, given the evidence which shows both memories are retrievable when cued separately, this suggests that both memories are encoded. This severely limits the possibility of exclusive encoding and emphasises that if exclusivity is occurring it is most likely happening at retreival and is a consequence of simultaneous cueing. In terms

[3] Experiments 4 & 5 also provide evidence that failed retrieval is not due to memory blocking

[4] First in terms of retreival not encoding or presentation

[5] This strategy may also incorporate other factors such as mental effort, although interference is considered as the primary motivation here.

of the type of interference that is sought to be avoided, the level of potential detriment to both memories upon retreival of the second most likely exceeds the possibility that the second memory is more accurate.

### 7.4.2 Which memory is encoded or retrieved?

The previous explanations as to why only one memory is encoded or retrieved does not offer any clarity regarding what determines access to one memory. Based on the findings of Experiments 1, 2, 3, and 6, that show no difference between the PSA-DA and SA-SA condition, the determining factor of which memory is encoded or retrieved cannot be related to memory accuracy. If the most accurate memory was accessed then performance equivalent to that estimated by the independence model would be observed (i.e., PSA-DA performance would be greater than SA-SA). Memory access must be determined by a component that would not offer any increase in performance. Thus, on concurrent presentation of each memory's corresponding cue, one memory is retrieved based on an encoded salient factor which has no connection with the accuracy of the object. The primary component of the stimuli that offers any form of saliency differential is the anchor points (seeing as the target is a common element no distinction can be made between the two memories based on this). To encode a memory by way of anchor saliency could be regarded as a wise strategy because the anchor is the only element available to prompt retrieval of a memory at test. It would after all be more reliable to focus encoding on an element of the stimuli presentation that has the highest probability of retrieving the memory and thus all the information therein (including spatial information). In the case of the current design this salient feature is likely the anchor point at encoding and hence cue at retrieval.

### 7.4.3 Section summary

Although exclusive processing is contrary to the idea of spatial integration (Molet et al., 2012, 2011; Sturz et al., 2006; Blaisdell & Cook, 2005; Sawa et al., 2005), it is clear that under certain circumstances mechanisms that bring performance in line with exclusive processing may be the preferred manner in which spatial information is processed. Exclusivity appears to be an efficient mechanism on two levels. First, in the encoding of two spatial memories it enables the avoidance of processing redundant information, reducing interference. Also, owing to the manner with which spatial information is organised, it avoids the cost of having to switch between distinct units. Such switching of course would only arise if two memories were encoded, which exclusive processing avoids. It is also argued that the preference of memory selection (i.e, which anchor-target relation is encoded and which one is made redundant) is based on something other than memory accuracy. This is likely to be a feature of the presentation that is most memorable to the individual (e.g., cue salience). This is also a wise strategy because the anchor is the only retrieval pathway for the target object. As to the question of integration, the strong effects of learning on spatial memory accuracy question the incentive to resolve exclusivity and therefore integrate information. Why increase the heavy burden of processing and integrating two memories if the potential increase in performance is negligible (i.e., outweighed by the costs)? The most plausible answer based on the evidence is to treat each memory exclusively and encode or retrieve only one.

### 7.4.4 Is the exclusivity model still appropriate?

The previous section took the approach that exclusivity was a component of spatial memory. This section highlights some findings which currently are difficult to explain assuming exclusivity. The majority of the findings contained within this thesis supports the idea that two spatial memories are equal to one. However, whether this equality can be completely explained through the notion of exclusive processing is discussed. This section highlights the findings that are incongruent with the idea of exclusive processing.

Although possible scenarios of exclusivity have been described above, there is evidence which strongly suggests that exclusivity (at least in the strong form), may not be accounting for the equal performance seen between one and two spatial memories. The findings strongly suggest that *exclusive encoding* is not likely to be taking place, as both memories are available at recall. This leaves *exclusive retrieval* as the most plausible form of exclusive processing. However, there is evidence which also questions the likelihood of exclusive retreival. The fact that dual anchor cueing offers an advantage at recall signifies two things. First, concurrent cueing does not appear to be the place where exclusive retreival is occurring. If it were then cueing with each anchor on separate occasions would result in greater memory performance because any disruption from concurrent cueing is avoided. However, the evidence is in contrast to this and suggests that concurrent cueing in fact offers an advantage and shows better levels of performance in comparison to cueing each memory on separate occasions. Second, this indicates that concurrent cueing allows information to be used in a beneficial manner which unattainable for separate cueing. Taken with the above evidence that both memories are available, this must mean that information from both memories is being used to make a location judgement and not only that but the way in which this information is being used results in a more accurate judgement than simply the average of those two memories if cued separately (as is calculated for PSA-cueing conditions).

In summary, the probabilistic model (i.e., exclusivity model) which predicts performance of two memories is equal to one is undeniably true and is supported strongly by the findings of the experiments contained within this thesis. Certainly the idea that the average of two memories is equal to that of one memory (i.e., this is what the exclusivity model states [memory 1 + memory 2 / 2 = memory 1 | memory 2]) seems irrefutable. However, the process by which that average is obtained is questionable. The interpretation of the model as exclusive processing (i.e., either the encoding or retreival of only one of two possible memories) is therefore dubitable. Neither exclusive encoding nor exclusive retrieval are consistent with all of the findings contained within this thesis. Some findings support the idea of exclusive encoding or retreival whereas others are incongruent with it. Most notably are the findings which show that information cued by both anchor points is available at retrieval, suggesting both anchor-target relations must have been encoded. This suggests exclusive encoding cannot be occurring and consequently implicates concurrent cueing as a factor leading to the possibility of exclusive retrieval (where the current cueing of both memories results in blocking of one memory). However, given the findings which implicate PSA-encoding as a detrimental stage of processing, if exclusive retrieval were occurring and individuals were randomly selecting one memory at recall then one would expect worse performance for two memories compared with one, which is not observed. These inconsistencies with the idea of strictly exclusive processing are formulated into a theoretical model as set out in the next section.

## 7.5 A fragmentation account of object-location memory

This next section sketches an alternative model to that of exclusivity. This model is different to exclusivity because it states that two memories can both be encoded and retrieved. Exclusivity, it is argued, may arise out of efficiency to avoid the encoding or retrieval of information that causes interference and reduces memory performance. In contrast, a fragmentation account assumes both memories are degraded by interference but are available for recall. The fragmentation account is similar to the exclusivity model in that it supports the notion that two memories are not better than one. However, it also extends this and proposes that potentially they could be better than one.

The underpinnings of a fragmentation account do not stem from the question, why is exclusivity occurring? but rather, how can an individual comparatively process twice as much information, yet perform the same? In essence, this is what is happening in the PSA-DA condition compared to the SA-SA condition.

The core of the fragmentation account relies on the idea that fragments of information are stored from multiple related memories. Such fragments have been shown to be available at retrieval, as demonstrated in Experiments 4 and 5. The fact that information pertaining to each cue is retrievable at test is not surprising given evidence from previous research. For example, although spatial information has been shown not to be encoded automatically (according to Hasher and Zack's (1979) criteria), it is clear that on most occasions *some* spatial information is encoded incidentally (Logan, 1998; Ellis, 1990, 1991). Even accepting that the quality of this information may well be poorer it is still processed none-the-less. Thus, upon presentation of a visual stimulus some spatial information *will* be encoded. If with the presentation of multiple anchor points some spatial information is encoded regarding each one, this means that two fragments regarding a single object's location are available. It is the manner with which fragments are utilised at recall that offer an explanation of 1) why concurrent cueing is advantageous and 2) why two spatial memory performance equals that of one spatial memory.

### 7.5.1 Problems with the exclusivity model

The exclusivity model assumes that the encoding of one spatial memory yields equal levels of accuracy as the encoding of two spatial memories. That is, when an individual learns an object's location in relation to one anchor point they learn it with the same level of accuracy as when they learn an object's location in relation to two separate anchor points. Under the exclusivity model the *expected* performance for two memories is based on the *observed* performance of one memory. This therefore assumes that the process of learning two memories does not diminish the level of accuracy contained within those memories in comparison to learning a single memory.

The evidence suggests that this assumption is incorrect and in fact the process of learning two memories degrades the quality of information stored in each memory. In this respect the exclusivity model may need reformulation. For instance, when an individual learns a series of objects as the number of objects increase the probability of recalling every object within that array decreases

(Vogel et al., 2001; Luck & Vogel, 1997). This is simply because there is only a limited number of objects one can encode and recall given a limited amount of exposure. For example, taking a hypothetical scenario where individuals can recall on average 7 items, if an individual were presented with 15 items one would expect on average the recalling of around 7 items. However, this form of measurement fails to capture occasions where individuals may 'kind of know' the correct item (but not to the point of absolute correctness).[6] This example highlights a unique facet of spatial information measurement which does not overspill to areas of *absolute* recall ability (i.e., memory for objects). This difference makes spatial information conducive to measurement on a continuum which has the potential to lead to important insights.

The method employed in this thesis allows one to measure the *amount* of spatial information contained within each memory and hence quantify 'near-misses'. This is important as it affords the assessment of not only absolute correctness but also inexact information. This enables an examination of the distribution of encoded spatial information across all memories not just correct ones. When this information is examined it shows that by increasing the number of to-be-remembered memories this significantly impacts upon the amount of information (or degree of accuracy) contained within each memory (see Experiment 7b). In essence, the findings show that information appears to be diluted across the total number of to-be-remembered anchor-target relations (i.e., memories). Logically, this makes sense. If an individual was shown 3 to-be-remembered anchor-target relations the level of location information (i.e., accuracy) encoded with those memories would be greater (on average) than if an individual were presented with 6 anchor-target relations. Thus, the level of location information contained within a memory is a function of the total number of anchor-target relations (i.e., memories). The potential processes behind such dilution are expanded upon in the next section.

### 7.5.2 Dilution across multiple spatial memories

Although the idea of spatial encoding dilution may appear to represent the capacity limit of memory, it is argued that such dilution is more specifically a consequence of interference (of which, capacity is determined by). After all, the level of interference will have a functional relationship with the number of objects, similar to that of general capacity. In other words, the more to-

[6]This is similar to what has occurred previously in the object-location literature (see Naveh-Benjamin, 1987, 1988). That is, percentage of correct responses were considered an adequate measure of memory ability. However, by using such a quantification occasions where memory is good but just not correct are disregarded.

be-remembered items (i.e., anchor-target relations) the increased likelihood of making an encoding error due to interference with similar items.[7]

Previous research supports this idea and proposes that the quality of a response may not be a consequence of limited memory capacity per se but rather the accumulation of errors (Vogel et al., 2001). The predominate type of error under the current design has been shown to be a result of encoding two related yet distinct spatial representations (i.e., two memories with a common target object). In this case errors are plausibly a consequence of the interference or confusion from encoding incompatible vector information. Thus, if the discrimination of items[8] is a function of the number of items in the stimulus array (Luck & Vogel, 1997), then an increase in the number of items will result in a reduction in discrimination. Inevitably such a reduction would lead to a larger accumulation of interference errors. Thus, in the context of encoding and storing memories regarding a common target's location, the greater the number of memories will equate to a respectively larger number of errors (or inversely a dilution of information).

The idea of an accumulation of errors or dilution of information is quite an interesting take on spatial memory. It suggests that capacity for spatial information is limitless and that with the encoding of more incongruent vector information comes the accumulation of more errors. Rather, what *is* limited is a finite number of object-location thresholds which return enough spatial information for exact spatial judgements (to a required level of fidelity). That is, the accumulation of errors for a certain number of object locations'[9] is minimal as to produce a response that corresponds with the encoded (or absolute) position of an object in space (dictated by the level of measurement precision). In other words, some objects are recalled exactly simply because the amount of errors is less than that required for the response. For example, if an object were encoded to be located in a room with few errors then that object may be recalled exactly in terms of whether is was recalled as being in the correct room. However, if the response demanded the position of the object within the room and the amount of errors were greater than the precision required by the response, then the recalling of

[7]Some authors argue that interference and capacity are indistinguishable given that one's ability to recall items it's highly related to their capacity to distinguish between items (Neath et al., 2006; Neath & Brown, 2006, 2007). However, in the current research it is important to differentiate between these two concepts as it is argued that the amount of information is not responsible for the degradation but it is rather the type of information (i.e., spatial) that creates interference. This is important because experimental manipulation (Exp. 3) has altered the distinctiveness of non-spatial components of each memory (e.g., the semantic content of the anchors) with no effect. This emphasises the interference caused by spatial information contained within a memory specifically over information per se.

[8]items is defined as vector information

[9]This has been shown to be around 3-4 objects (Cowan, 2001; Cowan et al., 2005; Broadbent, 1971; Vogel et al., 2001)

the target would be deemed as incorrect.

### 7.5.3 The additive effect of fragments at retreival

The fragmentation account proposes that the interference between encoding different yet related memories is not avoided but rather recompensed by relying on both sources of information to re-construct an object's location. The next component of the fragmentation account focuses on how two diluted memories might work together at recall to produce a location estimate that is the equivalent to a single non-diluted memory and better than cueing two diluted memories separately.

An explanation for how fragments (or diluted memories) can work together beneficially (i.e., demonstrated with DA-cueing advantage) comes from a multi-trace account of memory (Hintzman, 1986). This account argues that only traces of the individual episodes are stored and that aggregates of traces acting in concert at the time of retrieval represent the category as a whole (Hintzman, 1986). Thus, DA-cueing activates more fragments pertaining to the location of the object, in comparison to PSA-cueing which would only active fragments associated with a single anchor point.

This is important as the activation of more fragments narrows down the possibilities regarding what information is required from remaining stores of fragments.[10] In other words, the benefit of simultaneous cueing may allow for higher degrees of resolution of accumulative errors created at encoding. Owing to the fact that error is arguably a result of vector information interference between related memories, simultaneous cueing (i.e., DA-cueing) may allow for the resolution of more vector-related errors (resulting in greater levels of accuracy) compared to single-cue presentation (i.e., PSA-cueing). In essence, being able to draw on more memories at test may allow for the cancelling out of a greater number of errors related to the target object, resulting in a more accurate location response.

### 7.5.4 Long-term learning under fragmentation processing

Fragmentary processing may lead to long-term robustness of both memories. Owing to the learning studies which clearly demonstrate performance increases overtime, suggests that the level of interference could be resolved (or at least

[10] If one were to assume that each memory is made up of error and location information, then the error associated with one memory may be counteracted with location information from the second memory

reduced) with repeated exposure. This would then leave two intact and useful memories that can be drawn on with reduced encoding interference (maybe as a consequence of reduced encoding effort). This would offer long-term benefits of concurrent cueing in a manner that would surpass performance of only one memory, much in the same way that verbal information has the ability to demonstrate superadditivity (Rubin & Wallace, 1989).

In line with a fragmentation account, findings from Experiment 6 suggest that information encoded for *all* anchor-target presentations is built up over time. This is potentially a more robust strategy than exclusive processing as it reduces the risk of making extreme errors (i.e., not having any information regarding some items). This is prudent if small errors made for each memory can begin to be resolved through learning and repeated exposure, as hypothesized previously. If this were the case then fragmentary processing would lead to having two usable memories for an object's location as opposed to one. This might be beneficial in real life scenarios when objects employed as anchor points at encoding are removed or change place at retreival (i.e., they cannot always be relied upon). Therefore, to encode an object in relation to as many objects as possible (even if only in a fragmentary type manner) may be beneficial in situations of uncertainty.

Fragmentation processing may also offer long-term benefits in terms of eliminating wastage of information (as it uses information from both memories). The impact of this loss of information is probably negligible in the initial stages of learning (i.e., no differences between PSA-DA and SA-SA) but has the potential to increase over time.

In terms of integration and how we build coherent representations of space, the fragmentation account offers a unique view as to the processes that may underlie such representations. Aligned with the fragmentation account the process of integration is not so much a feature of LTM consolidation where higher level abstractions of information form an integrated unit through an off-line process. In contrast, the fragmentation account is allied with the idea that integration may well be an on-line process. Owing to the findings which indicate that individuals may well use information from both memories to 'piece together' where an object was located (by eliminating errors), this suggests that with repeated 'piecing together' one might expect the process of piecing together to become more automatic with time (i.e., achieved with less effort and faster temporal completion). This process would at least give the subjective experience of an integrated spatial representation. This suggests that drawing on two sources of spatial information separately might be apparent to begin with but over time the disparity in drawing information from two sources becomes negligibly, eventually becoming small enough to give the impression of a single integrated unit.

### 7.5.5 Summary of the fragmentation account

This account argues that fragments of information are encoded at varying levels of precision upon presentation of the stimuli. The average level of precision of each memory is the inverse of the accumulation of errors. Errors are a result of interference between components of spatial representation (i.e., magnitude and vector information) and are therefore a function of the number of spatial memories to be encoded. Thus, the first few presentations may be encoded with the same level of precision as the SA-SA condition, however as the learning phase progresses (specifically, PSA-encoding) the amount of errors increases and the quality of information that is encoded decreases. This process leaves stores of memory fragments pertaining to each object. Upon concurrent cueing of the target object memory fragments are drawn upon allowing for an estimation of a target object's location through a process of error elimination.

## 7.6 Exclusive and Fragmentary processing

In summary of the two accounts put forward in this thesis, it is quite possible that both of these mechanisms may well be implemented as processing strategies. That is, on some occasions elements from each memory are encoded and used to estimate an object's location (fragmentary) on other occasions one memory is encoded (or retrieved) and the second memory is not encoded (or retrieved) and becomes redundant (exclusive). In order to discriminate between occasions when each strategy may be employed further research is needed. However, overall it has to be noted that the evidence derived from these experiments suggest that exclusive processing in the strictest sense (either one memory is encoded or retrieved) is improbable, at least in the majority of cases. The fact that information from both memories is available and retrieved, together with the evidence which shows two cues presented simultaneously are an advantage, strongly indicates that information is encoded and stored for both memories (on average) and information from each memory is drawn upon to make an object location judgement.

## 7.7 Methodological issues

### 7.7.1 Individual differences

The first potential methodical issue is that individual differences have not been examined explicitly in this thesis. It is quite possible that individuals may apply an exclusive processing strategy or a fragmentation processing strategy or a mixture of the two. However, assessing this idea with rigour is beyond the remit of this thesis in terms of practicality. This should therefore be the focus of future research. It should be noted that repeated measures design was employed throughout the experiments in this thesis which meant individual differences were controlled for.

### 7.7.2 Stimuli choice

The stimuli employed throughout this thesis were employed for a number of reasons (highlighted in the main body of the thesis). However, it could be argued that when dealing with object location memory, words do not constitute objects in the classic sense. Thus, it may be prudent to extend some of the crucial findings of this thesis using images rather than words. However, it should be highlighted that previous work into exclusivity has employed more object-like stimuli (e.g, aerial images of buildings) and has produced similar findings to those of this thesis.

### 7.7.3 Ecological validity

The question of ecological validity follows on from the previously highlighted issue of stimuli choice. The stimuli were not relatable to every day experiences of object location. This means that although the experiments provide a situation where the underlying processes may be similar to real life, they preclude the richness of a real task involving object location. This perhaps limits to a degree the application of the findings. However, employing abstract stimuli was a necessary methodological choice to first allow for comparisons with previous work on exclusivity and second to enable control over semantic manipulations of the stimuli, which would have been more difficult using real-life spatial arrays.

## 7.8 Implications for future research

This thesis proposes two competing models which account for object-location memory performance on a series of experiments. Each model has the capacity to account for a number of findings from this thesis and that of previous work. This contribution provides the field of spatial memory with two empirically founded models on which to build. There are specifically two avenues for future work that would be fruitful for either model.

### 7.8.1 Proposal 1 - vector interference

It has been proposed that interference is occurring at encoding or retrieval owing to the disparity between magnitude and direction of information stored within each spatial representation. This disparity has been attributed to the fact two different anchors are used to specify the same target location. The employment of two anchor points in this way creates different quantities of space and direction for each memory. Thus, future research should look to test this prediction by maintaining constancy of the distance and directions for each anchor-target presentation. It is quite possible that because of the distinct nature in which spatial representations are stored, that access from one representation to another creates a decrement in later recall performance. Additionally, research should examine the contribution of each element of a vector (i.e., magnitude or direction). This would be important in understanding how simultaneous viewing of multiple objects may create more memorable anchor-target relations compared with other anchor-target relations (i.e., they are more aligned in terms of vector information and therefore create less interference). Thus, any increase in performance from a reduction of vector related manipulations may support the idea of vector interference.

Another possibility is to allow for the resolution of such interference by the individuals themselves. One method of achieving this is to increase exposure to the stimuli (either through repetition or increasing presentation time) to try to reduce interference. The experiments in this thesis assume a linear relationship between the presentation time and number of objects encoded and recalled. However, as with other processes in the cognitive systems quite often when load is increase the amount of time needed to encode such information equates to a non-linear relationship (e.g., exponential or power function). The reasons why an exponentially greater amount of time is required may be for the reasons stated above; that more objects introduce a greater probability of confusion and interference with all other objects. Thus, if exposure time were increased to enable a matching of accuracy for every spatial memory encoded (e.g., if in the PSA-DA condition 18 memories were created with equal amount of accuracy as that observed in the SA-SA condition), then one might expect the advantage for DA-cueing to become apparent. Only then would one would expect to see some kind of advantage for holding two spatial memories over one.

A final possibility to investigate the function of interference with the number of memories would be to match the number of *anchor-target relations* between the PSA-DA condition and the SA-SA condition, rather than the *to-be-remembered objects*. Thus, one might find that the first few presentations in the PSA-DA condition are encoded with the same level of accuracy as the SA-SA condition. However, as the learning phase progresses (specifically, PSA-encoding) the amount of errors increases and the quality of information that is encoded decreases.

### 7.8.2 Proposal 2 - cue salience

A second avenue of investigation concerns the exclusivity model. Previously it has been proposed that exclusivity may be dependent on a method of cue selection employed by the subject. It was suggested that a cue may be selected on some salient aspect other than the level of accuracy contained within the associated memory. If cue saliency was shown not to play a role than a rethinking of memory choice would be needed if exclusivity remained defined as a one memory account of multiple object location performance. Thus, such an investigation might either add support to a one memory encoding account or provide support for an alternative explanation (hence, the fragmentation account).

## 7.9 Final remarks

The research contained within this thesis makes an original contribution to the field of spatial cognition. It has empirically scrutinised the idea of exclusive processing of spatial information and presents findings predominantly in support of the idea that two memories are not better than one. At first glance exclusive processing could be considered counterintuitive and maladaptive to spatial memory. However, the evidence shows that exclusivity may have developed as a matter of economy by the human memory system. It is argued that the processing of spatial information is effortful and any strategy that reduces load in an efficient manner is preferable. However, a second model has been proposed which helps to account for the findings which are inconsistent with the idea that only one memory is encoded or retrieved.

The work contained within this thesis presents a number of important contributions to knowledge. It provides solid evidence that interference is generated when encoding multiple related (i.e., but non-identical) presentations of location information. It also demonstrates that such interference results in subsequent detriment of spatial information. Through the modeling of spatial estimations regarding multiple objects, this thesis imparts a unique insight into how information is built up over time. It has highlighted a learning strategy that involves incrementally fine-tuning of coordinate information across multiple objects. This has widespread theoretical implications that extend past the field of spatial cognition and into the general domain of learning and cognitive psychology. Finally, this body of work puts forward important avenues of investigation for future scientific endeavours. It recommends that vector interference be examined in order to develop a more inclusive model of exclusivity. It also provides a fragmentation account of location memory which provides alternative directions for future scientific research.

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# Thesis output

Material from this thesis has been presented in four conference papers and one journal publication in preparation:

Based on Experiment 1:

Dunn, J. T., Baguley, T., Lansdale, M., Horsley, R., 2010. The Role of semantics and expertise when integrating two spatial memories for a single object. Poster presentation, *BPS Annual Conference Cognitive section*, Sept 2010, University of Cardiff.

Based on Experiment 2 and 3

Dunn, J. T., Baguley, T., Lansdale, M., Horsley, R., 2012. Spatial memory exclusivity: Investigating the effect of semantics and distinctiveness on location memory integration. Oral presentation, *International Conference on Spatial Cognition*, Rome - La Sapienza University of Rome.

Based on Experiment 5:

Dunn, J. T., Baguley, T., Horsley, R., Lansdale, M., 2012. The effects of stimuli repetition exposure on spatial memory independence. Poster presentation, *International Conference on Thinking*, July 2012, Birkbeck College and University College London.

Based on Experiment 6:

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