Testing the exclusivity effect in location memory

Abstract

There is growing literature exploring the possibility of parallel retrieval of location memories, although this literature focuses primarily on the speed of retrieval with little attention to the accuracy of location memory recall. Baguley *et al*. (2006) found that when a person has two or more memories for an object's location, their recall accuracy suggests that only one representation can be retrieved at a time (exclusivity). This finding is counter-intuitive given evidence of non-exclusive recall in the wider memory literature. The current experiment explored the exclusivity effect further and aimed to promote an alternative outcome (i.e. independence or superadditivity) by encouraging the participants to combine multiple representations of space at encoding or retrieval. This was encouraged by using anchor (points of reference) labels that could be combined to form a single strongly associated combination. It was hypothesised that the ability to combine the anchor labels would allow the two representations to be retrieved concurrently, generating higher levels of recall accuracy. The results demonstrate further support for the exclusivity hypothesis, showing no significant improvement in recall accuracy when there are multiple representations of a target object's location as compared to a single representation.

Acknowledgements

This work was supported by a Nottingham Trent University bursary award to the first author and an Economic and Social Research Council [grant number RES-062-23-1414] award to the third author. The authors would also like to thank Professor Mark Lansdale for his contribution to the early stages of this project.

Introduction

Memory for object location is an everyday process. An example of this can be seen in giving directions: we can easily provide directions to other locations that are not visible on both a small ("Your keys are on the table.") and a large scale ("The library is opposite the student union."). Research into memory for object location has received increased interest in recent years, with a central theme being whether multiple representations of space can be accessed in parallel to locate a target object and if so, how these representations interact.

It has been suggested (Mou & McNamara, 2002) that it is not possible to describe an object's location in space without relating the object to a point of reference. Broadly speaking there are two main ways in which we can represent an object's location in space: egocentric frames of reference or allocentric frames of reference. Egocentric frames of reference are person-centred and describe locations in relation to the observer. Allocentric frames of reference differ from egocentric frames of reference in that they describe location in relation to in-scene objects other than the observer. A number of studies have investigated the interplay between allocentric and egocentric representations of space (e.g., Wang, Johnson, Sun and Zhang, 2005; Xiao, Mou & MaNamara, 2009; Mou, Liu & McNamara, 2009). Wang, Johnson, Sun and Zhang (2005) suggested that when there are multiple representations for a target's location (allocentric and egocentric); it is likely that these will interact to produce increased performance (an increase in the speed of retrieval). Other research has shown that participants favour allocentric frames of reference if the stimulus array is regular (where the target objects are arranged to form a logical grid) or egocentric frames of reference when the items comprising the array are displayed in an irregular fashion (Xiao, Mou & MaNamara, 2009; Mou, Liu & McNamara, 2009). As well as exploring the interplay of allocentric and egocentric frames of reference in memory for object location, scholars have also explored the interactions between multiple allocentric representations. For instance, Brockmole and Wang (2002) explored switching between multiple representations of space. They asked participants (all current Professors at the University of Illinois, for at least 2 years prior to testing) to make judgements about the location of objects in two familiar environments: 1) the Psychology building, and 2) their own office. The stimuli used were designed to reflect the actual positioning of target objects in relation to the points of reference (i.e. the relative position of another building on campus, or the location of the bin in the participant's office). The participants were shown schematic images outlining the location of target objects around a point of reference and were asked to indicate as quickly as possible whether or not the target object was displayed in the correct location (using response keys labelled yes and no). The results indicated that there was a time cost associated with switching between the different representations of space, suggesting that the different representations were not accessed concurrently. The average relative time cost associated with switching between these representations was approximately 110ms.

The notion of parallel retrieval in memory has also been explored using non-location based stimuli. For instance, Rohrer, Pashler and Etchegaray (1998) found that when they asked participants to recall words from two lists concurrently, inter-item response time

(time between retrieved items) was faster when the words were from the same category (e.g., animals) than when they were from two different categories (e.g., animals and fruits). This finding suggests that when the recall items were from the same category they were processed in a parallel fashion but when the items were from different categories (e.g., an animal followed by a fruit) they were processed in a serial or exclusive fashion. Concomitantly, Maylour, Charter and Jones (2001), have shown that there is no improvement in the number of words retrieved in a limited time (30 seconds) when participants are asked to list words from two categories (e.g., words beginning with *p* or *s*) as compared with a single category (words beginning with *s*); thus demonstrating that there is no benefit of retrieving information from multiple categories over a single category. However, Logan and Delheimer (2001) demonstrated that participants were able to parallel process semantic memory information using a dual task paradigm. In their experiment they presented participants with two target items (which could be either a word or a non-word), separated by a stimulus onset asynchrony of 0, 250, 300 or 1000 ms, and asked them to sequentially respond to target item one then target item two, by making a judgement as to whether the given item was a word or a non-word. They found that participants were faster to respond if both words came from the same category (e.g., both non-words), suggesting that they were processing the second word in semantic memory before they had completed the judgement about the first word. Logan and Delheimer (2001) further explored this finding using an episodic memory task. Participants were provided with a list of 12 word items to learn, and then tested in a similar dual task paradigm (i.e., sequential judgements about whether item one was a target word (from the learned list) or a decoy word, followed by the same judgement for item two). Again they demonstrated that participants were faster to respond if the two words came from the same category (e.g., both target words) as opposed to different categories. The findings reported here suggest that parallel retrieval of multiple memories is possible, at least in some instances.

All the literature discussed thus far has explored parallel retrieval in memory using time as the dependent variable with little research focusing on the *accuracy* of location memory judgements. However, recall accuracy is important for two main reasons. First, precision of recall cannot be determined from time alone (and studies that use time as a measure tend to work only with exact recall). Second, accuracy is usually the measure of primary interest in applied work. We would also argue that conclusions are strengthened by converging evidence using different measures rather than focus on just one. Therefore, it is recall *accuracy* not speed that will be the focus of the remainder of this paper.

As Mou & McNamara (2002) indicated, it is not possible to describe an object's location in space without relating it to a point of reference. Therefore, consider a scene where a target object is flanked by two points of reference (points A and B). In this example, it is possible to describe the target object's location in relation to either point of reference A or B separately, with each providing a distinctly different representation of the target's location in space.

Baguley *et al*. (2006) hypothesised that there were three distinctly different ways in which to model the possible interactions of these representations and their effect on accuracy for recalled location. These processes were exclusivity, independence and superadditivity:

- *Exclusivity:* only one spatial representation can be accessed at any one time (A or B but not both). Critically, if one memory representation were to fail to retrieve the target object's location, the second memory trace cannot then be used in reserve.
- *Independence*: both spatial representations can be accessed concurrently but are mutually independent, potentially yielding greater recall accuracy than would be observed under exclusivity (A or B). Independence differs from exclusivity in that failed retrieval of A may be followed by attempted retrieval of B (and vice versa).
- *Superadditivity*: there is integration or summation of the two spatial representations, leading to increased accuracy in recall relative to independence

Such definitions have been outlined elsewhere in the literature (i.e., Rohrer *et al.,* 1998; Maylor, Charter & Jones, 2001) but Baguley *et al*.'s (2006) are specialised for location memory where information about inexact recall is as important as exact recall.

In order to explore these recall processes, Baguley *et al*. (2006) utilised a classic long term memory paradigm with an encoding phase, distracter task and then a retrieval phase. The stimuli were designed to look like aerial images, where the target objects were silhouettes of buildings as if seen from the sky. There were nine different building silhouettes and each was partnered to a pair of reference points (anchors) - text boxes with a location name written inside (e.g., Venus or Crater). Baguley *et al.*'s (2006) experiment had four main types of anchor conditions. These were: (1) the dual anchor condition (where anchors were displayed on both sides of the target), (2) left or (3) right anchor condition (where the target was flanked by a single anchor, on the left or right respectively) and (4) a paired single anchor condition (where the participants encoded the target object's location as per the left or right anchor conditions but were presented with a dual anchor stimulus at retrieval) (see Figure 1 for an example of these conditions). Each target object was presented in 1 of 9 independent locations, although the stimuli were orthogonally arranged so that each participant saw each target object and each location only once. Participants were asked to view the scenes (in either an intentional or an incidental learning paradigm) and then to use the points of reference to recall the location of the missing target building that corresponded to the displayed point(s) of reference (using a mouse click in the recalled target's location). The dependent variable in this study was the accuracy of the location memory judgements. The results from both the incidental and intentional paradigms indicated there was no advantage to having two anchors when recalling target locations. They interpreted this finding as consistent with exclusivity of memory traces. That is to say their participants were as accurate when a single memory trace could be accessed (left and right anchor conditions) as when it was possible to access two traces (in dual or paired single anchor conditions).

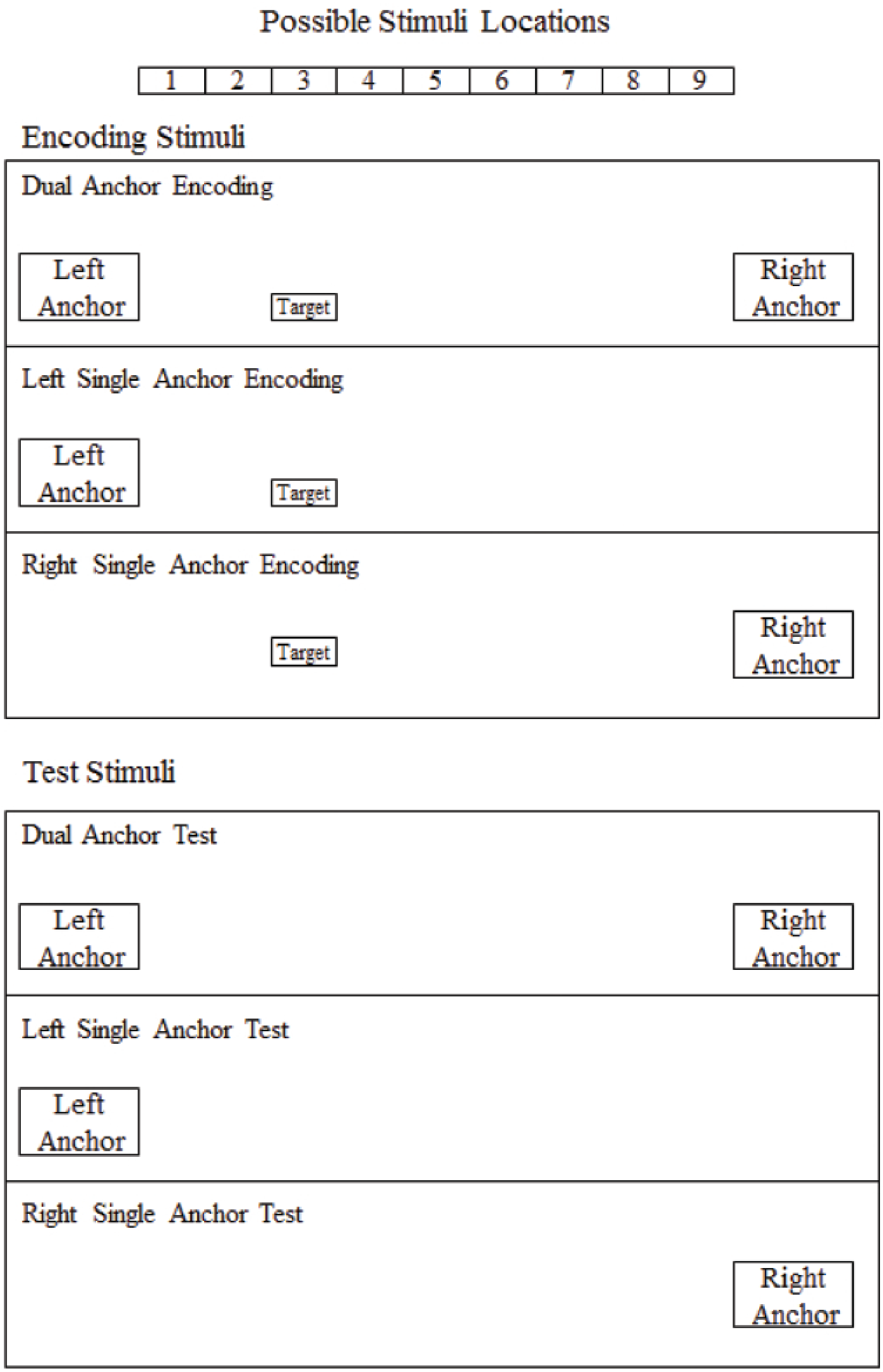


Figure 1. An illustration of the experimental conditions in Baguley *et al.* (2006)

The exclusivity finding is counterintuitive and there is evidence in the literature that greater overlap of information between encoding and retrieval should improve memory performance (e.g., Morris, Bransford & Franks, 1977; de Winstanley, Bjork & Bjork, 1996; Meier & Graf, 2001). In addition, non-exclusive recall has been reported in the wider memory literature (Logan and Schulkind, 2000; Logan and Delheimer, 2001). However, exclusive recall has been shown in both location memory (Brockmole and Wang, 2002) and other areas of memory recall (Rohrer *et al.,* 1998; Maylor, Charter & Jones, 2001). Therefore, if time is not a limiting factor and participants are instructed to recall a target object's location accurately *not* quickly, it ought to be possible for participants to utilise multiple representations of target location and subsequently generate recall accuracy consistent with either independence or superadditivity.

One explanation of exclusive recall in Baguley *et al*.'s (2006) experiment is that as the anchor labels were only weak semantic associates, the participants were not binding and accessing multiple representations at retrieval in the paired single anchor and dual anchor conditions. This is consistent with the wider memory literature, where parallel retrieval of multiple memories has been demonstrated within strongly associated same word categories (Rohrer *et al.*, 1998; Logan & Schulkind, 2000; Logan & Delheimer, 2001).

The aim of the present study was to provide an encoding environment that was more likely to lead to the participants combining the anchors, and hence accessing multiple representations of space at retrieval, thus leading to retrieval accuracy in line with independence or superadditivity. We attempted to do this by selecting anchor labels (three-letter, monosyllabic words) that could be read consecutively to form a strongly associated six-letter combination in a dual anchor condition (for example, [EGG]+[CUP] = [EGGCUP]). Recall performance could then be compared with that of single anchor conditions and with a dual anchor weakly associated (control) condition. This weakly associated condition employed three-letter, monosyllabic words that when read consecutively formed only weakly associated six letter combination (for example, [SUN]+[CUP] = [SUNCUP]). It was predicted that where participants could combine the anchor labels to form a strongly associated combination at encoding, they should be able to access more than one representation at retrieval and hence demonstrate recall accuracy consistent with either independence or superadditivity.

Method

Design

The experiment had a 5 × 9 mixed factorial design. There was a single between participants factor (anchor condition with five levels: left anchor, right anchor, strongly associated dual anchor, weakly associated dual anchor and a paired single anchor) and a single within participants subjects factor (location with 9 levels: locations 1 to 9). The dependent variable was the incidental recall of the target's location. This was used to calculate the root mean square deviation corrected ($RMSD_{corrected}$) for each location at each level of the condition factor.

Participants

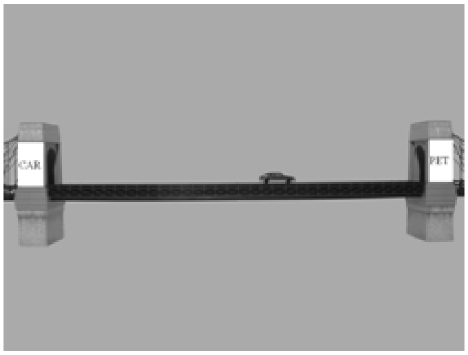
Ninety (22 male; 68 female) participants naive to the true aims of the research took part in the experiment. The participants were Psychology staff and students (who received course credits) from Nottingham Trent University. The mean participant age was 20.69 years (*SD* = 4.68). The sample contained 87 right handed and 3 left handed participants. The participants were all fluent English speakers with normal or corrected normal vision and they were all verbally screened for colour blindness.

Stimuli

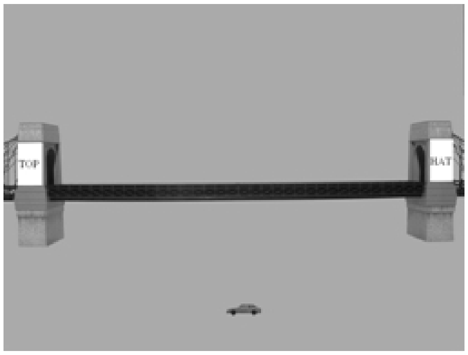
The stimuli were colour photographs (bitmaps) of a modified Hornby grand suspension bridge (OO/HO scale (1:76.2); model number R 8008). The bridge had two towers with a long stretch of road between them. The bridge was modified to remove obvious cues to location (see Figure 2 for an example scene). The distance between the bridge towers was divided into 9 equal spaces (which were not visibly marked). To ensure that the anchors were distinctly different a white opaque text box was displayed on each bridge tower. Each text box contained a single 3-letter (monosyllabic) word. In the dual anchor conditions the words were arranged in pairs so that they could be combined to form either a strongly associated 6-letter combination (strongly associated dual anchor condition) or a weakly associated 6-letter combination (weakly associated dual anchor condition), as set out in Table 1. In the paired single anchor condition, the participants saw both a left anchor stimuli and right anchor stimuli for each car colour, although the left and right anchor stimuli were not presented consecutively.

Table 1. The anchor label words and combinations for each condition.

Left Anchor Cue	Right Anchor Cue	Dual Anchor Strongly Associated Cues	Dual Anchor weakly Associated Cues
[BAT]	[MAN]	[BAT][MAN]	[TEA][MAN]
[CAR]	[PET]	[CAR][PET]	[SUN][CUP]
[EGG]	[CUP]	[EGG][CUP]	[PEG][DAY]
[GUN]	[DOG]	[GUN][DOG]	[CAR][DOG]
[PEG]	[BAG]	[PEG][BAG]	[TOP][WAX]
[SUN]	[DAY]	[SUN][DAY]	[EAR][POT]
[TEA]	[POT]	[TEA][POT]	[BAT][BAG]
[EAR]	[WAX]	[EAR][WAX]	[GUN][PET]
[TOP]	[HAT]	[TOP][HAT]	[EGG][HAT]



Dual Encoding



Dual Retrieval

Figure 2. An example of the bridge scenes.

The word pairs were selected to maximise word frequency (using the Kucera-Francis (1967) and Thorndike-Lorge (Leech, Rayson & Wilson, 2001) word lists) and word imagability (using Wilson, 1988). Furthermore, the combinations were selected to preserve phonetic structure (for example, phonetically [TOP]+[HAT] reads as [TOPHAT] but [DIG]+[ITS] does not sound like [DIGITS]). This was to promote the amalgamation of the anchor labels in the dual strongly associated condition and subsequently produce the maximum likelihood of anchor combination during encoding and retrieval. The selected words were displayed in size 18, Times New Roman font. The 9 weakly associated anchor label combinations were generated by changing the order of the two columns for the left and right stimuli, so that each anchor label was displayed on the same anchor (left vs. right) but with a different partner label (e.g., [SUN] + [CUP]).

The target objects in the current experiment were 9 Hornby Ford Sierra cars (OO/HO scale, model number R271). Each car was 60mm in length and 20mm in height. Each car was painted a different colour and the colours used were black, blue, green, grey, orange, purple, red, white or yellow. Each car colour was partnered to a particular pair of words and these pairings remained constant throughout the experiment. Thus, every participant saw the orange car with the anchor labels [SUN] and [DAY], though the car could appear in any of the 9 locations in any given trial.

The photographs were taken with a Canon Powershot A520 camera (supported on a Benbo Trekker MkII tripod with a three way head), with an exposure ISO 100, 1/25 sec at f8. The background was a Savage Widetone white paper backdrop on a studio background support system. Three standard *Redhead* studio lights (800W each) with dichroic filters were used to light the scene and to remove any shadows in the image. Each of the bridge scenes were photographed with a car in each of the nine target locations, travelling in both a left-to-right direction and a right-to-left direction.

The images were later edited, using Adobe Photoshop CS2 version 9, to ensure that the background had a uniform grey appearance (red, green and blue value of 170 for all three constituent colours). The single anchor conditions were constructed by replacing the bridge tower with the grey background and fading the edge of the road using a motion blur of 60 pixels. The stimuli were displayed on a 19" flat scene monitor that had a refresh rate of 60 hertz and a screen resolution of 1024 x 768 pixels (which was the same resolution as the stimuli).

Procedure

The experiment scripts were generated using the Eprime 2.0 computer programme on a Pentium 4 computer running Microsoft Windows XP, and were used to control the display times, randomisation of the stimuli and to record the participant's responses. The experimental procedure was divided into two stages; stimuli familiarisation and the location memory task.

Stimuli Familiarisation

To prevent confusion, the participants were pre-exposed to the target car colours before the location memory task. A target car colour name (e.g., blue) was presented in the centre of the computer screen for 3 seconds and was then immediately replaced by an image of the corresponding car. The target car remained on screen until the participant pressed the space bar and the process was repeated for each target car colour. Upon completion of the stimuli familiarisation task, the participants were verbally screened about their ability to distinguish between all of the target car colours and only continued to the location memory task if they believed they could confidently differentiate between these colours.

Location Memory Task

The location memory task, which employed an incidental learning paradigm, was divided into two phases that were separated by a distracter task. In phase one, 9 bridge scenes were sequentially presented to the participants. The participants were asked to read aloud the anchor label(s) (three letter words) and to state the car's colour (this ensured that the participants had attended to all the relevant parts of the scene). There was no time limit for each picture and the participants were instructed to press the spacebar when they were ready to view the next image. To prevent potential confusion (caused by a target car colour appearing in multiple locations) participants saw every target car colour and each location only once. The order of display was arranged using an orthogonal Latin Square with participants arbitrarily allocated to rows of the Latin Square. Immediately after the completion of phase one, the participants were instructed to reverse count in multiples of 3 from 999 for 30 seconds. This task prevented short-term rehearsal of the information displayed in phase one, thereby ensuring that the participants were relying on long-term memory in phase two.

In phase two, the participants were again presented with the bridge scenes they had seen in phase one, however, this time the target car was presented below the bridge. The participants' task was to use the scenes to recall and indicate the location of the target car (by a mouse click along the bridge in the recalled location). The images were displayed in a random order and each picture remained on the screen until a response had been made. There was a 2 second inter stimulus interval (ISI) between each response and the presentation of the next test image.

Results

General pattern of recall across anchor conditions.

Owing to the mounting evidence indicating that near miss errors in location memory can still represent important information about memory retrieval (Huttenlocher, Hedges & Duncan, 1991; Lansdale, 1998; Lansdale, Oliff & Baguley, 2005), the data collected were used to calculate the root mean square deviation corrected ($\text{RMSD}_{corrected}$) values for each participant. This value is computed as

$$RMSD_{corrected} = \frac{1}{m}\sum_{m=1}^{m}\sqrt{\frac{D^2_{observed}}{D^2_{chance}}}\ ,$$

where *m* is the number of trials, D_{observed} is the observed deviation from the target location and D_{chance} is the expected chance deviation under random guessing (the mean absolute deviation for that location). $\text{RMSD}_{\text{corrected}}$ is a sensitivity score that takes into account both exact and inexact recall when considering memory for object location. If the $\text{RMSD}_{corrected}$ has a value of 1, memory is at chance recall. Above 1 it shows worse than chance recall and below 1 it indicates better than chance recall. To assess evidence for exclusivity, independence or superadditivity, it is necessary to compare the observed $RMSD_{corrected}$ scores with modelled scores expected under both exclusivity and serial independence. Baguley *et al*. (2006) used a measure of proportion of location information transmitted (*T*) to derive these predictions from observed levels of memory in the single anchor conditions. For a single sample *T* can be estimated as:

$$T = 1 - RMSD_{corrected}$$

Under exclusivity the expected performance is identical to that for single anchor presentations, and (assuming that recall of left and single anchor presentations is equally likely) can be estimated from the average of the observed performance in the left and right single anchor conditions:

$$T_{exclusive} = \left(T_{left} + T_{right}\right)/2$$

Under independence the expected performance is given by the sum of the left and right hand anchor performance minus their product:

$$T_{independent} = T_{left} + T_{right} - T_{left} \times T_{right}$$

Translation back into an $RMSD_{corrected}$ score is trivial (as $RMSD_{corrected} = 1 - T$).

Mean observed $RMSD_{corrected}$ scores (for all five anchor conditions), and $RMSD_{corrected}$ expected under exclusivity and independence models, are presented in Figure 3 along with two-tiered 95% confidence intervals (Baguley, 2012). The inner tier is adjusted so that non-overlapping intervals imply differences in means with approximately 95% confidence and the outer tier is a conventional 95% CI for each mean. The outer tiers in both dual anchor conditions and the paired single anchor condition all overlap with the predictions of the exclusivity model (the average of the right and left levels of recall) and none include the level of recall expected under independence. The left and right anchor conditions are included in the plot for completeness only, as recall in these conditions can only be exclusive owing to the absence of the second anchor. The average $RMSD_{corrected}$ values for each location can be seen in Figure 4. These are presented separately for left and right anchors, but combined for the dual and paired single anchor conditions for convenience.

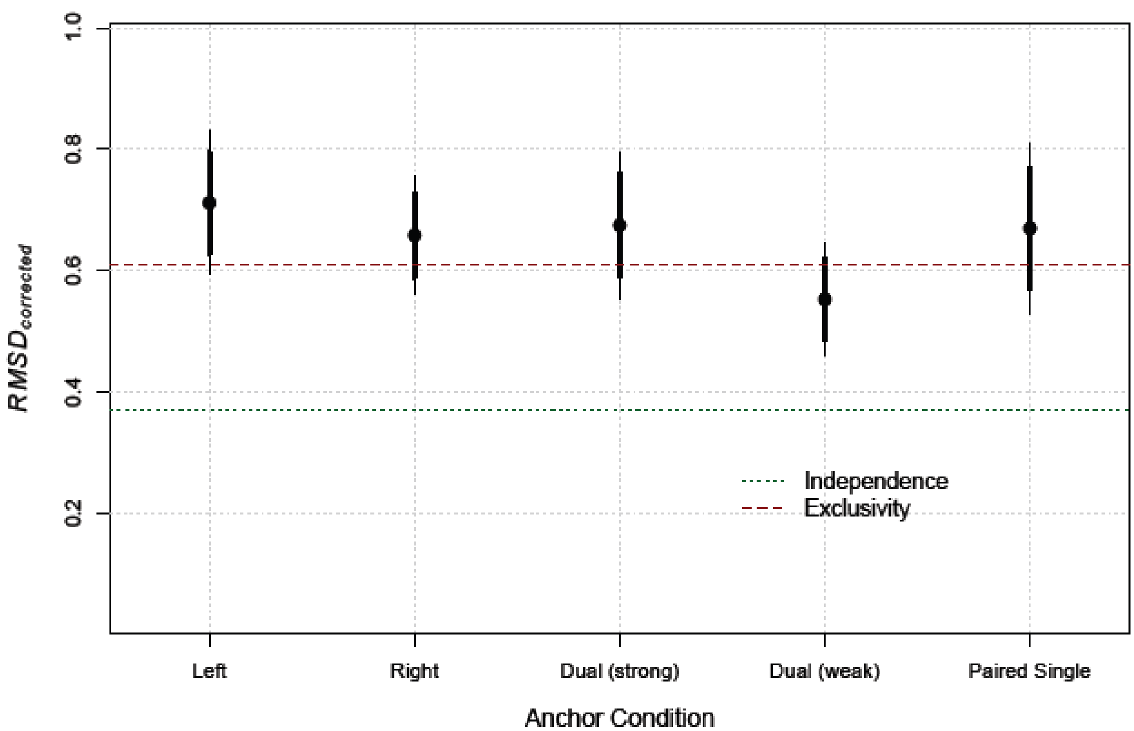


Figure 3. The mean RMSDcorrected scores for each condition compared to predictions from an independence or exclusivity model. All means are plotted with two-tiered CIs. The outer tier (thin lines) depict 95% CIs for the condition means. The inner tier (thick lines) are adjusted so that means that are different at the 95% confidence level have non-overlapping error bars.

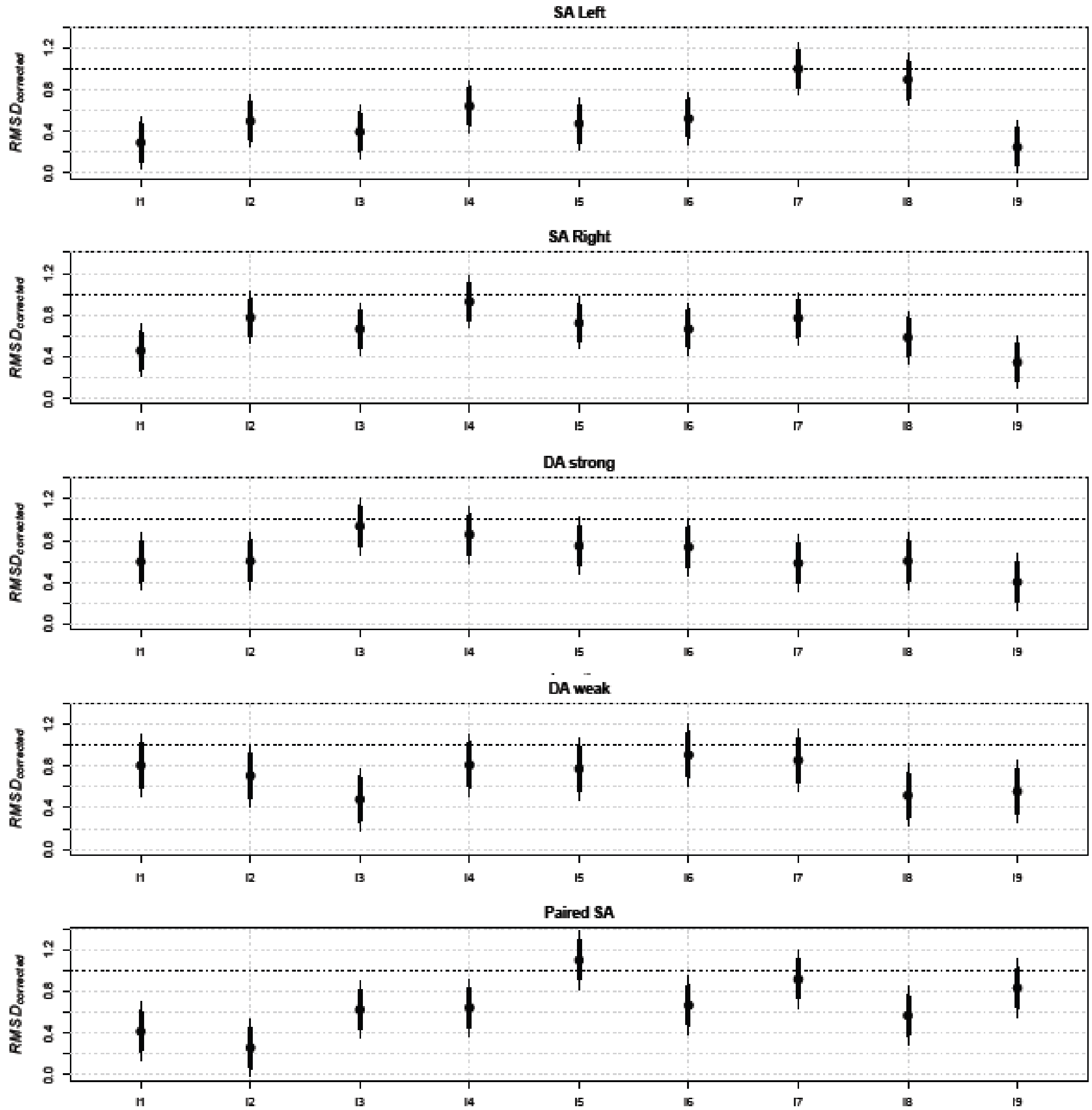


Figure 4. The mean RMSD$_{corrected}$ scores by location for each anchor condition. All means are plotted with two-tiered 95% CIs. The outer tier (thin lines) depict 95% CIs for the location means. The inner tier (thick lines) are adjusted so that means that are different at the 95% confidence level have non-overlapping error bars.

Figure 3 suggests that the targets appear to have been recalled with the greatest accuracy when there was only a left anchor present (indicated by non-overlapping inner tiers). A formal analysis was conducted using a mixed ANOVA with two factors, anchor condition (with 5 levels left anchor, right anchor, dual strongly associated anchor, dual weakly associated anchor and paired single anchor) and location (with 9 levels, locations 1 to 9). This revealed a significant effect of location, $F_{8,680} = 4.219$, $MSE = 0.315$, $p < .05$, but no significant effect of anchor condition, $F_{4,85} = 1.199$, $MSE = 0.483$, $p > .05$, and a significant anchor condition × location interaction, $F_{32,680} = 1.970$, $MSE = 0.315$, $p < .05$. The significant effect of location was further explored using post hoc pairwise comparisons. Post hoc analysis (using a Bonferroni correction) of the main effect of location revealed a significant difference between location 1 and 7 ($p < .05$), between locations 4 and 9 ($p < .05$) and between locations 7 and 9 ($p < .05$). The right and left anchor conditions show different patterns of recall across locations – with evidence of better recall close to anchor points and close to the central location (a 'virtual' anchor), though this is more marked for the left anchor than the right anchor presentations. The dual anchor and paired single anchor conditions show patterns broadly consistent with responses sampled exclusively from memories of left and right anchor presentations; levels of recall tend to fall between those of the respective single anchor presentation.

Detecting an exclusivity effect

Analyses thus far have failed to detect an advantage for dual anchor or paired single anchor presentation over single anchors. This is consistent with exclusivity, but cannot – on its own – be taken as evidence of the null effect expected if exclusivity holds. Evidence for a finding of exclusivity would be strengthened by demonstrating sufficient statistical power to detect independence. Using the average single anchor performance to predict performance under independence it is possible to estimate the expected $\text{RMSD}_{\text{corrected}}$ under independence as 0.37. When compared with single anchor performance, this corresponds to a standardized mean difference of $d = (0.611 - 0.371)/0.217 \approx 1.1$. The paired single anchor and the dual anchor conditions (n = 18) each have one-sided statistical power of .98 to detect an advantage of this magnitude, relative to the pooled single anchor conditions (n = 36). Thus, the key comparisons do not appear to be underpowered.

Evidence for a null effect can be assessed more directly by Bayesian methods. One relatively simple approach suitable for experimental tests is to use Bayes factors (Rouder, Speckman, Sun, Morey & Iverson, 2009). In the present case it is instructive to compare three different hypotheses: the null hypothesis (H_0) that all conditions produce equal levels of recall (as expected under exclusivity), the alternative hypothesis (H_1) that only strongly associated dual anchors produce independence, and the alternative hypothesis (H_2) that independence holds in paired single anchor and both dual anchor conditions. The expected pattern of $\text{RMSD}_{\text{corrected}}$ scores under each hypothesis can therefore be set out as

$$\begin{array}{ll} H_0 & \mu_{sa} = \mu_{psa} = \mu_{dw} = \mu_{ds} \\ H_1 & \mu_{sa} = \mu_{psa} = \mu_{dw} > \mu_{ds} \\ H_2 & \mu_{sa} > \mu_{psa} = \mu_{dw} = \mu_{ds} \end{array}$$

where the subscripts refer to single anchor, paired single anchor, dual weakly associated and dual strongly associated means. The alternative hypotheses H_1 and H_2 are order-restricted and therefore slightly trickier to work with than the case of a two-sided t test.

However, Rossell, Baladandayuthapani and Johnson (2008) describe Bayes factors for order-restricted inference in ANOVA. This method is implemented in R (R Core Development Team, 2012) via their *isoregbf* library. Bayes factors are a measure of the extent to which the observed data change the posterior odds relative to the prior odds of one hypothesis relative to another. To compute these it is necessary to know or to assume the prior probability of the hypotheses. The approach advocated by Rouder *et al*. (2009) is to set objective priors based on a range of effect sizes common to a research field. A scale factor makes it possible to adjust the anticipated effect size. In addition to incorporating order restrictions, Rossell *et al*.'s approach uses a prior that more strongly favours the alternative hypothesis over the null hypothesis when the observed effects are relatively small (as is the case here). A natural scale factor to plug into the analysis is expected standardized effect size for the difference in conditions under independence (d = 1.1). With this scale factor, the Bayes factor (computed from 10^6 Monte Carlo samples) of H_0 relative to H_1 is 7.4. The corresponding Bayes factor for H_0 relative to H_2 is 16.3. [1] Thus an exclusivity account is considerably more plausible than either of the alternative accounts.

Assuming that all three hypotheses are equally plausible *a priori*, the Bayes factors can be transformed into posterior probabilities for each hypothesis (where the Bayes factor is

[1] A common convention, adopted here is to express Bayes factors as odds in favour of the null hypothesis. Large Bayes factors thus indicate evidence in favour of H_0 – the pattern of means predicted by exclusivity. These odds can also be transformed into a posterior probability (as in Figure 5). Assuming a scale factor of d = .1.1 and that only two hypothesis are under consideration (rather than the three in Figure 5) the posterior probably of H_0 is .88 (relative to H_1) and .94 (relative to H_2).

the ratio of the posterior probabilities). Figure 5 plots the posterior probabilities of each hypothesis as a function of the scale parameter (or expected standardized mean difference) with *d* = 1.1 indicated by a dashed line. The hypothesis H_1 (exclusivity) dominates across a range of plausible prior effect sizes, its probability diminishing markedly only when *d* approaches zero.

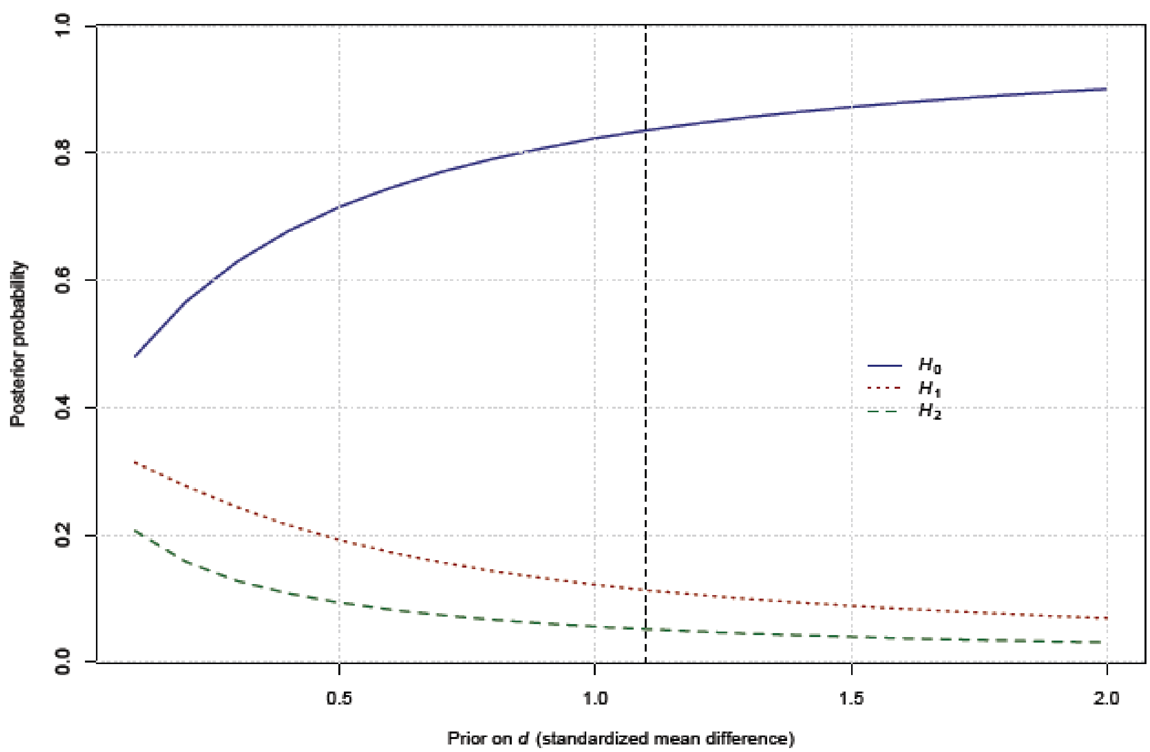


Figure 5. Posterior model probabilities for a null hypothesis corresponding to exclusivity and two alternative hypotheses as a function the expected standardized mean difference for the effect if exclusivity does not hold.

Discussion

Our results demonstrate and add further support for the exclusivity effect (Baguley *et al*., 2006), suggesting there was no significant increase in recall accuracy when the participants were able to recall the target location in relation to multiple anchors as opposed to a single anchor. Our results also suggest that the possibility of combining the anchor labels into a strongly associated combination (dual anchor condition) produced no improvement in recall accuracy when compared to the dual weakly associated anchor condition. This in turn suggests that the opportunity to combine the anchors does not lead to a greater level of recall accuracy in location memory judgements in the current paradigm. These findings are consistent with the current literature surrounding parallel retrieval in location memory in respect to both retrieval accuracy (Baguley *et al.*, 2006) and the speed of retrieving multiple representations (Brockmole & Wang, 2002), suggesting that even when time is not a limiting factor (fast processing is not required), participants still process location memory information in an exclusive fashion.

The post hoc analysis of the effect of location revealed three significant differences in location. These were between locations 1 and 7, locations 7 and 9 and also locations 4 and 9. Similar findings have been seen elsewhere in the literature (e.g., Baguley *et al*., 2006) and are most likely caused by a combination of the overuse of a central virtual anchor (location 5) and a left/right anchor bias (Chockron, Bartolomeo, Perenin, Heft & Ingbert, 1998).

A further interesting finding was that there was no significant difference between the paired single anchor condition and the dual anchor condition, which further strengthens the exclusivity hypothesis. In the paired single anchor condition, the two different representations for the targets' location are displayed at different times. This means that the participants have potentially two completely separate representations for a target object's location, which could both be accessed at retrieval. The findings here suggest that exclusivity cannot be solely the result of the participants encoding the dual anchor scene as a single large representation (comprising two anchors and the target object), instead of two distinctly separate smaller representations (left anchor to target and right anchor to target). If this were the case, it would be expected that the paired single anchor condition would yield higher levels of recall than the dual anchor condition (which would contain only a single representation). This was not observed in the current experiment.

Baguley *et al*. (2006) suggested two explanations for the effect of exclusivity. These were polarity and potential processing effort. The issue of polarity is related to the way in which the stimuli were designed. In this instance, when there are two representations of the same target's location, they are directional opposites. Thus, location 3 from the left is always location 7 when observed from the right and that estimation of the target's location is always made with the target being directly between the two anchors. Therefore it is possible that the conflict in polarity generated from the simultaneous processing of the two separate directions leads to exclusivity at retrieval. To the best of our knowledge, there is no empirical evidence to support this claim and the effect could be caused by the representations being exclusive. Indeed evidence from Baguley *et al*. (2006) contrasts the polarity explanation, since some of their participants encoded target locations with two anchors and then retrieved them with only a single anchor present. If there was conflict in polarity brought about by the concurrent processing of two directions, the removal of a single anchor at test should remove that conflict and hence increase retrieval accuracy.

Baguley *et al*. (2006) demonstrated no such increase in recall accuracy after the removal of a single anchor at retrieval, subsequently offering no empirical support for the polarity explanation; the memory traces remained exclusive and apparently without conflict.

The other explanation posited by Baguley *et al*. (2006) was that the effect of exclusivity occurs because of the effort involved in combining the representations. That is to say combining multiple representations is likely to be an effortful process, using up valuable cognitive resources (Baguley *et al*., 2006). Consequently there are two (potentially related) reasons why object location memory might be exclusive by default. First the abstract nature of the stimuli makes the consolidation of the two representations both extremely difficult and unnecessary (Baguley *et al*., 2006). Second, since (a) combining multiple representations places increased demands on limited cognitive resources, and (b) that the accuracy of the judgements appears high without increasing demand, then such a process also appears unnecessary. Of course this does not rule out the possibility that participants could still combine location information under some as yet undefined situations (potentially demonstrating non-exclusive recall). Indeed parallel retrieval of memory information has been shown in other areas of the memory literature (such as concurrent retrieval of words from same category word lists (Logan & Delheimer, 2001; Logan & Schulkind, 2000)). However, we did not observe this in the current experiment where the combination of anchor information was encouraged using strongly associated word combinations.

Finally, it is worth considering the role of the anchors within the paradigm used here. Baguley *et al*. (2006) demonstrated exclusivity using the anchors as a recall cue for both the target objects' identity and location. This assumes that the participants used the anchors for both of these functions. Certainly the anchors can be used to recall the identity of the target (see Baguley *et al*., 2006). However, it is not clear that the specified anchors are actually used to locate a target object and it is possible that the participants could have used either screen-based anchors or an egocentric frame of reference to locate the target objects. Another plausible explanation of our data would be that the participants encoded the target object's location egocentrically. If this is the case, the participants would only form a single representation of the target object's location and thus memory retrieval could only be exclusive. If recall was solely dependent on egocentric representations of space, the anchors themselves should not influence recall accuracy. However, our data does not appear to be consistent with this explanation. If all memory judgements were completed using an egocentric frame of reference, recall accuracy should be similar for each location and insensitive to in-scene anchors. The statistical analysis indicated a significant difference in recall accuracy between locations 1 + 7 and 7 + 9, suggesting that recall accuracy was higher in the locations adjacent to the anchor positions. This is further supported by Figure 4, which suggest greater recall accuracy for the locations adjacent to the anchors, especially in the conditions where only a single anchor was present at retrieval (namely the Left and Right anchor conditions). Thus, it appears that the anchors can impact on recall accuracy and subsequently the exclusivity effect cannot be simply explained by a reliance on egocentric frames of reference alone. This is also consistent with Xiao, Mou and McNamara, (2009), who suggested that allocentric frames of reference are more likely to be employed in a regular array, such as the one used in the current experiment (9 distinct locations along the horizontal axis, flanked by one or two anchors).

Finally, the interplay of allocentric and egocentric representations of space has been previously explored using the "Milner paradigm" (Milner, Johnsrude & Crane, 1997; Wang, Johnson, Sun & Zhang, 2005), which has been shown to limit the influence of other factors, such as screen-based representations and egocentric representations. It would therefore be interesting to explore the exclusivity hypothesis under such circumstances.

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