University of Nevada, Reno

The Mental Wormhole: Internal Attention Shifts Without Regard for Distance

A thesis submitted in partial fulfillment of the

requirements for the degree of Master of Arts in

Psychology

by

Ryan T. Tanoue

Dr. Marian E. Berryhill/Thesis Advisor

August, 2011

University of Nevada, Reno
Statewide • Worldwide

THE GRADUATE SCHOOL

We recommend that the thesis
prepared under our supervision by

RYAN T. TANOUE

entitled

The Mental Wormhole: Internal Attention Shifts Without Regard For Distance

be accepted in partial fulfillment of the
requirements for the degree of

MASTER OF ARTS

Marian E. Berryhill, Ph.D., Advisor

Gideon P. Caplovitz, Ph.D., Committee Member

Thomas J. Nickles, Ph.D., Graduate School Representative

Marsha H. Read, Ph. D., Associate Dean, Graduate School

August, 2011

Abstract

Attention operates perceptually on items in the environment, and internally on objects already encoded in visuospatial working memory (VWM). We investigated whether spatial and temporal constraints affecting perceptual attention extend to internal attention. A retro-cue paradigm in which a valid or neutral cue is presented after stimulus encoding and maintenance phases was used to manipulate shifts of internal attention. Participants' memories were tested for colored circles (Experiments 1, 2a-d, & 3a), or novel objects (Experiment 3b) and their locations within an array. In these experiments the time to shift internal attention (Experiments 1 & 3) and the eccentricity of encoded objects (Experiments 2 & 3) were manipulated. Our data distinguish between perceptual and internal shifts of attention. Unlike perceptual attention, stimulus eccentricity did not affect the time required to shift internal attention. Across several timing parameters and stimuli we found that shifts of internal attention require a minimum quantal amount of time regardless of the object eccentricity at encoding. These results indicate that in VWM, relative item location is encoded as part of object representations. Our findings are consistent with the view that internal attention operates on objects whose spatial information is represented in relative terms. Thus, it seems that perceptual attention abides by the laws of space and time, while internal attention shifts across spatial representations without regard for physical distance.

Acknowledgments

I would like to thank Dr. Marian Berryhill, Dr. Gideon Caplovitz and Dr. Thomas Nickles for their help and advice while serving as members of my thesis committee. I would like to especially thank my advisor, Dr. Marian Berryhill for her guidance, support and encouragement over the course of this project. Thank you also to the members of the Memory and Brain Laboratory, without whom I would not have been able to complete this project: Dwight Peterson and Kevin Jones for their help throughout the project, also undergraduate assistants Bien Cornejo, Edward Elliott, Adrienne Lattin and Terina Metoyer for their help during data collection. I would also like to express my appreciation to others who have supported me throughout this process including: Ross, Joyce and Michael Tanoue, and Candace Nakanishi.

Table of Contents

List of Tables

List of Figures

Introduction

Imagine you are expecting friends to pick you up and you are looking for cars stopping in front of your house. Yet when your friends unexpectedly arrive across the street, it may require several honks before you redirect your attention to them. In experimental settings, cueing paradigms use spatial cues to direct perceptual attention toward the location where an item is likely to appear. A vast perceptual cueing literature demonstrates that allocating attention to a location prior to stimulus onset enhances the detection and processing of the cued item resulting in improved VWM for the cued item (reviews include: Kastner & Ungerleider, 2000; Posner & Petersen, 1990; Schmidt, Vogel, Woodman, & Luck, 2002; Woodman, Vecera, & Luck, 2003). In short, spatial cues improve the likelihood that you will perceive and remember an item appearing at an attended location.

The cueing literature has recently expanded following reports that spatial cues presented after encoding and maintenance phases improve VWM performance even though no new information is provided. The term 'perceptual attention' refers to attentional effects on items in the environment and 'internal attention' refers to attentional effects on items in VWM. Experiments testing internal attention use retroactive cues (retro-cues) presented after encoding and maintenance phases of VWM, but before the retrieval phase. It is essential to note that these paradigms and associated attentional cueing effects are distinct from Sperling's classic research because the timing is well beyond the limits of iconic memory (>500 ms) (e.g. Sperling, 1960). Across a variety of stimuli, timing and design parameters a small literature reports robust VWM performance improvements (~5-16%) provided by retro-cueing (Berryhill, Richmond, Shay, & Olson, In Press; Dell'Acqua, Sessa, Toffanin, Luria, & Jolicoeur, 2010; Delvenne, Cleeremans, & Laloyaux, 2010; Griffin & Nobre, 2003; Landman, Spekreijse, & Lamme, 2003; Lepsien & Nobre, 2006; Lepsien & Nobre, 2007; Makovski & Jiang, 2007; Makovski, Sussman, & Jiang, 2008; Matsukura, Luck, & Vecera, 2007; Nobre, 2008; Nobre, Rao, & Chelazzi, 2006).

Since spatial cueing influences both perceptual and internal attention, researchers have investigated whether they are a single or distinct attentional mechanism(s). Evidence supporting a single underlying mechanism comes from several neuroimaging and behavioral studies. Event-related potentials and functional magnetic resonance imaging studies comparing activations associated with internal and perceptual attention have found considerable overlap in parietal, frontal and visual regions (Griffin & Nobre, 2003; Lepsien & Nobre, 2006; Nobre et al., 2004). Behavioral research has found similar effects in direct comparisons of the pre- and retro- cueing benefits associated with orienting perceptual and internal attention (Griffin & Nobre, 2003; Nobre et al., 2004). The parsimonious interpretation of such data is that perceptual and internal attention share a common neural mechanism that benefits VWM by enhancing the quality of the object representation and inhibiting the effect of distractors (Griffin & Nobre, 2003; Lepsien, Griffin, Devlin, & Nobre, 2005; Matsukura et al., 2007). Not all of the behavioral data is consistent with this perspective. Makovski and Jiang (2007) used single or multiple retro-cues to indicate one or more locations. They found that unlike perceptual attention, where multiple pre-cues provide performance benefits (Kramer & Hahn, 1995; Makovski & Jiang, 2007), there was no retro-cueing benefit when multiple retro-cues were presented. They concluded that internal attention is less flexible than perceptual attention and that there may be separable or partially overlapping mechanisms (Makovski & Jiang, 2007).

One aspect of attention that may contribute to the discussion of single or multiple mechanisms and to our understanding of internal attention is the rate of attentional shifting in perception and in VWM. Seminal research conducted by Tsal (1983) established that perceptual attention travels at a velocity of ~8 ms per degree of visual angle (Tsal, 1983). Tsal demonstrated that as the distance between fixation and the test location lengthened, the amount of time needed to reach the target also increased in a linear manner. In other words, items closer to fixation require less travel time and reveal attention-based benefits faster than items that are farther away. Thus, performance benefits provided by perceptual attention are not instantaneous and rise to asymptote by approximately 400 ms after cue presentation (reviewed in: Egeth & Yantis, 1997; Posner, 1980). To our knowledge, there are no studies examining how quickly internal attention can shift among representations held in VWM. This contrasts with the well-developed long-term memory literature in which recollections involving greater distances take longer amounts of time than those involving shorter distances (reviewed in: Kosslyn, 1981).

Here, we investigate whether internal attention is subject to the time and distance constraints imposed on perceptual attention. If internal and perceptual attention reflect a common mechanism, retro-cueing effects should grow when more time to switch attention is available. Secondly, as object eccentricity increases, we predict that more time will be required for internal shifts of attention. If internal attention is a separate mechanism, the effects of time and distance may be reduced.

General Methods

Experimental Design and Trial Sequence

Two randomly interleaved retro-cue conditions were tested: neutral and valid. The neutral retro-cue was uninformative and served as a control condition; the valid retro-cue was 100% predictive of the test location. Neutral and valid retro-cues were equally likely.

Participants were instructed to remember the color and location conjunction of each stimulus presented in the memory display; see Figure 1. They were informed that the neutral (X) retro-cues were not informative but that the valid (arrow) retro-cues would indicate the to-be-probed location. Each trial began with a fixation cross (1500 ms), followed by the memory display (300 ms). The memory display consisted of four equiluminant color patches out of a set of 10 possible colors. The stimuli were 3° x 3° degrees of visual angle and located at 6° from fixation. This was followed by a first delay period (1000 ms). Next, either the neutral or valid retro-cue (100 ms) appeared at central fixation so that it did not overwrite any of the stimulus or probe positions. The neutral cue was a capital ‘X’ (2.2°W x 2.0°H) and the valid cue was an arrow (3°L x 2.1°W) of visual angle. The stimuli and cues were not presented at the same physical location to avoid the possibility of overwriting. A second delay period of variable duration (100, 200, 300, 400, 500, 600, 700 ms) followed the retro-cue. The second delay durations were randomized and equally probable. Next, a probe screen appeared. The probe screen preserved the spatial arrangement of the memory display by indicating stimulus locations with empty annuli as placeholders, while the probe location was filled with a stimulus from the memory array. The task was to decide whether the probe stimulus matched the object shown during encoding. Participants responded by pressing the ‘Y’ key if the color-location conjunction matched (50%) the original memory display and by pressing the ‘N’ key if it did not match (50%). Responses were unspeeded. Participants completed 250 trials in five 50-trial blocks separated by rest breaks. Prior to the experiment, participants conducted a 10 trial practice block.

Articulatory suppression

During all experiments, participants were instructed to repeat a single syllable three-letter word out loud throughout the experiment to avoid verbal encoding of the colors. A different word was specified at the beginning of each block.

Equipment

Participants were tested individually in a room with dimmed lighting. They sat approximately 57 cm from a 17” LCD computer monitor (Dell 1707 FPc, Samsung SyncMaster 172N). The experiment was programmed in ePrime (Psychology Software Tools, PA, USA).

Experiment 1: Second Delay Effects on the Retro-Cue Benefit

We used a retro-cue paradigm to investigate the time course over which the retro-cue benefit developed. If shifts of internal attention are time-consuming, as they are in perceptual attention, the magnitude of the retro-cue benefit should grow as the post retro-cue delay duration increases.

Participants

25 volunteers from the University of Nevada psychology subject pool participated (ages 18 - 23, M = 20.2, 10 male) in exchange for course extra credit. The Internal Review Board of the University of Nevada approved all experimental protocols.

Results

Across experiments, an alpha level of .05 was used, and VWM raw accuracy was the primary dependent measure. Parallel analyses examining d' and reaction time are not discussed because they were consistent with the accuracy data.

A repeated measures analysis of variance (ANOVA) with cue type (valid, neutral) and second delay duration (100, 200, 300, 400, 500, 600, 700 ms) as within-subjects factors revealed a main effect of cue type ($F_{1, 24} = 71.76$, $p < .001$); see Figure 2. As expected, performance was significantly better in the valid retro-cue condition. An interaction between cue type and delay duration was observed ($F_{6, 144} = 2.44$, $p = .03$). The interaction was due to significantly greater performance in the valid retro-cue condition than in the neutral cue condition for all second delay durations beyond 300 ms (p's < .02, Bonferroni corrected pairwise comparison). An ANOVA comparing just the 300-700 ms conditions confirmed that there was no interaction between cue type and delay duration ($F_{4, 96} = 1.56$, $p = .19$). There was no difference in the magnitude of the retro-cue effect for second delay durations greater than 300 ms.

Discussion

Experiment 1 tested the hypothesis that internal attention, like perceptual attention, takes time to shift to a cued item in VWM. We varied the duration between the offset of the retro-cue and the VWM retrieval stage. There was no retro-cue benefit when the second delay was short. A significant retro-cue benefit emerged only at durations greater than 300 ms. These findings support the view that internal attention does require a measurable amount of time to shift. However, somewhat surprisingly, once this minimum amount of time was given, the magnitude of the retro-cue benefit did not continue to grow as the second delay duration increased.

Experiment 2: Object Eccentricity Effects on the Retro-Cue Benefit

In Experiment 1, we varied the second delay duration and maintained the eccentricity of the stimulus array and found that shifting internal attention takes time. In Experiment 2, we maintained the second delay duration and varied the eccentricity of the stimulus array. If internal attention is constrained by distance, placing stimuli farther from fixation will require longer times for attention to shift and the magnitude of the retro-cue benefit will diminish. If internal attention is not constrained by distance the magnitude of the retro-cue benefit will be constant across stimulus eccentricities. Our approach was to apply the briefest second delay duration that produced a significant retro-cue benefit (300 ms) and to assess the magnitude of the retro-cue benefit as a function of eccentricity. The robust nature of the retro-cue benefit forced us to run additional experiments with shorter second delay durations.

Method

Experimental Design and Trial Sequence

The procedure used in Experiment 1 was followed except that the second delay remained constant during each experiment: 300 ms (Experiment 2a), 200 ms (Experiment 2b), 150 ms (Experiment 2c), and 173.29 ms (Experiment 2d). These durations were determined by the refresh rates on monitors running at 60 Hz (300 ms, 200ms) and 75 Hz (150ms, 173.29ms). Object eccentricity varied: items were presented at 3°, 5°, 7° or 9° of visual angle from fixation. EPrime outputs were used to monitor the accuracy of the second delay duration length and any trials showing an unexpected delay were excluded from analysis.

Participants

New participants from the University of Nevada psychology subject pool were in each experiment in exchange for course extra credit: Exp. 2a: 20 volunteers (ages 18-33, M = 21.25, 6 male); Exp. 2b: 12 volunteers (ages 18-33, M = 22.75, 5 male); Exp. 2c: 5 volunteers (ages 19-24, M = 21.4, 0 Male); Exp. 2d: 22 volunteers (ages 18-49, M = 25.3, 9 male).

Results

In experiments 2a-2d, the factors of cue type (valid, neutral) and stimulus eccentricity (3°, 5°, 7°, 9°) were subjected to repeated measures ANOVA. In Exp. 2a and 2b, the first two second delay durations tested, 300 ms and 200 ms, revealed a retro-cue benefit (Exp. 2a: $F_{1, 19} = 73.20$, $p < .001$; Exp. 2b: $F_{1, 11} = 18.06$, $p = .001$), but no effect of stimulus eccentricity (Exp. 2a/b: $F < 1$, p = ns), and no interaction of cue type and eccentricity (Exp. 2a: $F_{3, 57} = 1.08$, $p = .37$; Exp. 2b: $F < 1$, p = ns; see Figure 4). Since there was a significant retro-cue benefit, but no interaction, it was possible the durations were too long and these data required us to shorten the second delay duration to 150 ms in Exp. 2c. This shorter second delay duration eliminated the retro-cue effect altogether across eccentricities ($F < 1$, p = ns). The second delay duration used in Exp. 2d split the difference between 150 ms (no retro-cue effect) and 200 ms (universal retro-cue effect): 173.29 ms. The results echoed Exp. 2a and Exp. 2b. The retro-cue benefit was present ($F_{1, 21} = 22.89$, $p < .001$), and yet again in spite of our best efforts there was no main effect of object eccentricity ($F_{3, 63} = 1.66$, $p = .19$) and no interaction between cue type and object eccentricity ($F_{3, 63} = 1.85$, $p = .15$).

Discussion

Experiment 2a-d tested whether internal attention is constrained by distance such that it takes longer to shift to items presented at greater eccentricity. We varied eccentricity and anticipated a gradient in the magnitude of the retro-cue effect in which items presented closer at encoding received a greater benefit than items presented farther away at encoding. Our data indicate that there was *no* significant difference in the magnitude of the retro-cue benefit across eccentricities. The retro-cue benefit was either present for stimuli encoded at all eccentricities (Exp. 2a, 2b, 2d) or at none of them (Exp. 2c). As long as sufficient time was given (≈173.29 ms) internal attention provided a benefit to VWM.

The present data suggest that the location of objects at encoding does not effect attentional shifting in VWM. This is a surprising difference from the well-documented relationship between attentional shifts and distance in perception where further distances require more time for attention to shift (Shulman, Remington, & Mclean, 1979; Shulman, Wilson, & Sheehy, 1985; Tsal, 1983).

Experiment 3: Manipulation of object distance and second delay duration

The purpose of Experiment 3 was to develop a stronger test of whether stimulus configuration really does not effect internal shifting of attention among items in VWM. The predictions were as follows: If internal attention shifts independently of stimulus eccentricity then the retro-cue benefit will remain constant across encoding eccentricities. If there is a relationship between object eccentricity and internal attention, there should be a gradient in the magnitude of the retro-cue benefit such that items presented closer benefit more and before items encoded farther away.

Method

The paradigm made several changes from that used in Experiment 2. First, two eccentricities were tested (3°, 12°). The 12° was used to magnify eccentricity effects. Second, the second delay durations in Experiment 3a were: 146.63, 159.96, 173.29, 186.62 and 200 ms (9-13 frames at a 75 Hz refresh rate). These were shortened by one frame in Experiment 3b: 133.3, 146.63, 159.96, 173.29 and 186.62 ms (8 - 12 frames). In Experiment 3b the color patches were replaced with an equal number of bilaterally symmetrical novel shape stimuli (10 total objects); see Figure 7.

Participants

Two groups of students from the University of Nevada psychology subject pool participated in exchange for course extra credit: Exp. 3a: 25 volunteers (ages: 18-29, M = 22.12, 10 male), Exp. 3b: 20 volunteers (ages: 18-33, M = 20.89, 3 male).

Results

In Experiments 3a and 3b, repeated measures ANOVA evaluated the factors of cue type (valid, neutral), object eccentricity (3°, 12°) and second delay duration (Exp. 3a: 146.63 – 200 ms; Exp. 3b: 133.3 – 186.62 ms). In Exp. 3a there was a main effect of cue type revealing the retro-cue benefit ($F_{1, 24} = 31.55$, $p < .001$; see Figure 6). No other main effects (eccentricity: $F_{1, 24} = 1.10$, $p = .30$; delay duration: $F_{4, 96} < 1$, p = ns) or any two-way or three-way interactions reached significance (all $p > .31$). The results from Exp. 3b were similar. There was a significant retro-cue benefit shown by the main effect of cue type ($F_{1, 19} = 18.92$, $p < .001$); see Figure 9. Here, however, there was a main effect of object eccentricity ($F_{1, 19} = 13.71$, $p = .002$). VWM performance was superior in the 3° condition (71.8%) compared to the 12° condition (67.1%). The key result here is that as in Exp. 3a, the main effect of second delay duration was not significant and neither were any of the interactions. Most importantly, there was no interaction between eccentricity and second delay duration.

Discussion

Experiment 3 rigorously tested whether spatiotemporal factors affect the velocity of internal shifts of attention. We varied both the eccentricity of objects at VWM encoding and the second delay duration. There was no evidence of a gradient in the magnitude of the effect across second delay durations. Experiment 3b replicated this finding using new stimuli. Our data confirmed that object eccentricity and second delay duration did not interact to modulate the retro-cue benefit.

One possible explanation is that internal attention shifts at a velocity greater than what we can detect. Experiment 3 presented stimuli at 3° and 12°, and used second delay durations limited by a 75 Hz refresh rate. Based on these constraints, internal attention would shift 9° in less than 13.33 ms (~1.5°/ms) to account for our observed lack of eccentricity effects on the retro-cue benefit. Therefore, if a relationship exists between internal attention and object eccentricity it shifts five times faster than the velocity of perceptual attention.

General Discussion

To gain leverage on whether perceptual and internal attention are controlled by a single mechanism we tested whether shifts of internal attention were subject to the spatiotemporal constraints that govern shifts of perceptual attention. Because perceptual shifts of attention require longer durations as distance increases it seemed reasonable to predict that internal shifts of attention would also need more time with increased spatial distance. However, there is also evidence suggesting that internal attention is less flexible than perceptual attention and therefore subject to control from a different mechanism. Our data yielded two main findings. First, similar to perceptual attention, internal attention takes a measurable, minimum amount of time to shift. Second, the eccentricity of objects at VWM encoding does not affect how quickly internal attention can shift among representations in VWM. Thus, once the minimal, quantal amount of time is allocated, internal attention appears to be impervious to the original spatial configuration of the stimuli. In other words shifts of internal attention are not constrained by spatial distance.

Experiment 1 showed that there was no retro-cue benefit at short delay durations. Thus, internal attention required time to shift and there were no significant differences in the magnitude of the retro-cue benefit once the shift was complete. These results demonstrate that a shift of internal attention is not instantaneous; it takes a small, but measurable, amount of time to produce the retro-cue benefit. However, increasing the time beyond this minimal value did not appear to improve the retro-cue benefit. Experiment 2 tested effects of object eccentricity during encoding on internal attention. Our results indicated that object eccentricity at encoding had no effect on the magnitude of the retro-cue benefit. These somewhat surprising results led to the conclusion that object eccentricity at the time of encoding had no effect on shifts of internal attention. To test this, Experiment 3 manipulated both object eccentricity and second delay duration in the same group of participants. Using two different stimulus sets, our results demonstrate that the retro-cue benefit is equivalent across encoding eccentricities and second delay durations. This confirms the idea that internal attention is not constrained by the eccentricity of objects during encoding. In sum, as long as the minimum amount of delay time after the retro-cue had passed, the retro-cue benefit remained constant regardless of whether the memory array was close or far apart at encoding.

The present results further previous research that suggests that late attentional selection is spatially invariant. Vecera and Farah (1994) suggested that there are two forms of object-based selection. They proposed that early attentional selection individuates object features but includes a spatial component whereas late stage attentional selection is object-based and independent of spatial location (Vecera, 1997; Vecera & Farah, 1994). Several groups have clearly demonstrated that spatial and object information remain separate during iconic memory (Awh & Jonides, 2001; Kramer, Weber, & Watson, 1997; Matsukura & Vecera, 2011; Vecera, 1997; Vecera & Farah, 1994) and VWM (Matsukura & Vecera, 2009). At this later stage, objects are thought to be an integrated whole rather than a lose assemblage of features (e.g., Duncan, 1984; Kahneman, Treisman, & Gibbs, 1992; Matsukura & Vecera, 2011; Vecera & Farah, 1994; Vogel, Woodman, & Luck, 2001). In support of this idea, research has demonstrated that object complexity has no effect on the capacity of VWM indicating that objects are stored whole, not as a list of features (e.g., Awh, Barton, & Vogel, 2007; Luck & Vogel, 1997; Vogel et al., 2001) (but see: Alvarez & Cavanagh, 2004).

Our data extend this literature by suggesting that internal attention operates on object-based representations that not entirely spatially invariant. These data support a spatial-invariance model that includes relative location as a component feature of object-based representations in VWM. Olson and Marshuetz (2005) demonstrated that relative location is encoded as part of object representations in VWM because relative but not absolute spatial information interfered with object VWM performance (Olson & Marshuetz, 2005). Our data are consistent with the idea that relative spatial information is included in object representations in VWM. The preservation of relative spatial information accounts for directional retro-cues' ability to shift internal attention toward object representations in VWM. The relative nature of the spatial information concurrently allows shifts of internal attention to be unaffected by the eccentricity of the objects at encoding.

In conclusion, the goal of these studies was to investigate how internal attention shifts among items represented in VWM. The broader goal was to seek evidence to determine whether perceptual and internal forms of attention reflect single or multiple underlying neural mechanisms. Previous neuroimaging investigations show extensive overlap between the neural mechanisms responsible for both forms of attention and similar behavioral cueing effects (Griffin & Nobre, 2003; Lepsien & Nobre, 2006; Nobre et al., 2004). Other behavioral data indicated that internal attention could not be divided in the way that perceptual attention can be split and is therefore more limited than perceptual attention (Makovski & Jiang, 2007). Importantly, the present data show that internal attention has advantages of its own. Our findings demonstrate that unlike perceptual attention, internal attention is not subject to the physical constraint of object distance at encoding. Whereas perceptual attention operates on objects in the real world and is constrained by physical distance (e.g., Tsal, 1983), internal attention operates on objects whose spatial information is represented in relative terms. Therefore, regardless of how far from fixation an item may be remembered, internal attention only requires a short, quantal amount of time to shift and provide a cueing benefit. In short, perceptual attention abides by the laws of space and time but internal attention can shift over a desk or a desert with equal alacrity.

References

Alvarez, G. A., & Cavanagh, P. (2004). The capacity of visual short-term memory is set both by visual information load and by number of objects. *Psychological Science, 15*(2), 106-111.

Awh, E., Barton, B., & Vogel, E. K. (2007). Visual working memory represents a fixed number of items regardless of complexity. *Psychological Science, 18*(7), 622-628. doi: PSCI1949 [pii] 10.1111/j.1467-9280.2007.01949.x

Awh, E., & Jonides, J. (2001). Overlapping mechanisms of attention and spatial working memory. *Trends in Cognitive Sciences, 5*(3), 119-126.

Berryhill, M. E., Richmond, L. L., Shay, C. S., & Olson, I. R. (In Press). Shifting attention among working memory representations: Testing cue type, awareness and strategic control. *Q J Exp Psychol*

Dell'Acqua, R., Sessa, P., Toffanin, P., Luria, R., & Jolicoeur, P. (2010). Orienting attention to objects in visual short-term memory. *Neuropsychologia, 48*(2), 419-428. doi: S0028-3932(09)00389-3 [pii] 10.1016/j.neuropsychologia.2009.09.033

Delvenne, J. F., Cleeremans, A., & Laloyaux, C. (2010). Feature Bindings Are Maintained in Visual Short-Term Memory Without Sustained Focused Attention. *Experimental Psychology, 57*(2), 108-116. doi: Doi 10.1027/1618-3169/A000014

Duncan, J. (1984). Selective attention and the organization of visual information. *J Exp Psychol Gen, 113*(4), 501-517.

Egeth, H. E., & Yantis, S. (1997). Visual attention: control, representation, and time course. *Annu Rev Psychol, 48*, 269-297. doi: 10.1146/annurev.psych.48.1.269

Griffin, I. C., & Nobre, A. C. (2003). Orienting attention to locations in internal representations. *J Cogn Neurosci, 15*(8), 1176-1194. doi: 10.1162/089892903322598139

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: object-specific integration of information. *Cogn Psychol, 24*(2), 175-219. doi: 0010-0285(92)90007-O [pii]

Kastner, S., & Ungerleider, L. G. (2000). Mechanisms of visual attention in the human cortex. *Annual Review of Neuroscience, 23*, 315-341.

Kosslyn, S. M. (1981). The medium and the message in mental imagery - a theory. *Psychological Review, 88*(1), 46-66.

Kramer, A. F., & Hahn, S. (1995). Splitting the beam: Distribution of attention over non contiguous regions of the visual field. *Psychological Science, 6*, 381-386.

Kramer, A. F., Weber, T. A., & Watson, S. E. (1997). Object-based attentional selection - Grouped arrays or spatially invariant representations?: Comment on Vecera and Farah (1994). *Journal of Experimental Psychology-General, 126*(1), 3-13.

Landman, R., Spekreijse, H., & Lamme, V. A. F. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research, 43*(2), 149-164. doi: Pii S0042-6989(02)00402-9

Lepsien, J., Griffin, I. C., Devlin, J. T., & Nobre, A. C. (2005). Directing spatial attention in mental representations: Interactions between attentional orienting and working-memory load. *NeuroImage, 26*(3), 733-743. doi: S1053-8119(05)00123-0 [pii] 10.1016/j.neuroimage.2005.02.026

Lepsien, J., & Nobre, A. C. (2006). Cognitive control of attention in the human brain: Insights from orienting attention to mental representations. *Brain Research, 1105*(1), 20-31. doi: 10.1016/j.brainres.2006.03.033

Lepsien, J., & Nobre, A. C. (2007). Attentional modulation of object representations in working memory. *Cereb Cortex, 17*(9), 2072-2083. doi: bhl116 [pii] 10.1093/cercor/bhl116

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature, 390*(6657), 279-281. doi: 10.1038/36846

Makovski, T., & Jiang, Y. V. (2007). Distributing versus focusing attention in visual short-term memory. *Psychon Bull Rev, 14*(6), 1072-1078.

Makovski, T., Sussman, R., & Jiang, Y. V. (2008). Orienting attention in visual working memory reduces interference from memory probes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*(2), 369-380. doi: 10.1037/0278-7393.34.2.369

Matsukura, M., Luck, S. J., & Vecera, S. P. (2007). Attention effects during visual short-term memory maintenance: protection or prioritization? *Perception & Psychophysics, 69*(8), 1422-1434.

Matsukura, M., & Vecera, S. P. (2009). Interference between object-based attention and object-based memory. *Psychonomic Bulletin & Review, 16*(3), 529-536. doi: Doi 10.3758/Pbr.16.3.529

Matsukura, M., & Vecera, S. P. (2011). Object-based selection from spatially-invariant representations: evidence from a feature-report task. *Atten Percept Psychophys, 73*(2), 447-457. doi: 10.3758/s13414-010-0039-9

Nobre, A. C. (2008). Spatial attention can bias search in visual short-term memory. *Frontiers in Human Neuroscience, 1*. doi: 10.3389/neuro.09.004.2007

Nobre, A. C., Coull, J. T., Maquet, P., Frith, C. D., Vandenberghe, R., & Mesulam, M. M. (2004). Orienting attention to locations in perceptual versus mental representations. *J Cogn Neurosci, 16*(3), 363-373. doi: 10.1162/089892904322926700

Nobre, A. C., Rao, A. L., & Chelazzi, L. (2006). Selective attention to specific features within objects: Behavioral and electrophysiological evidence. *Journal of Cognitive Neuroscience, 18*(4), 539-561.

Olson, I. R., & Marshuetz, C. (2005). Remembering "what" brings along "where" in visual working memory. *Perception & Psychophysics, 67*(2), 185-194.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*(1), 3-25.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annu Rev Neurosci, 13*, 25-42. doi: 10.1146/annurev.ne.13.030190.000325

Schmidt, B. K., Vogel, E. K., Woodman, G. F., & Luck, S. J. (2002). Voluntary and automatic attentional control of visual working memory. *Perception & Psychophysics, 64*(5), 754-763.

Shulman, G. L., Remington, R. W., & Mclean, J. P. (1979). Moving Attention through Visual Space. *Journal of Experimental Psychology-Human Perception and Performance, 5*(3), 522-526.

Shulman, G. L., Wilson, J., & Sheehy, J. B. (1985). Spatial Determinants of the Distribution of Attention. *Perception & Psychophysics, 37*(1), 59-65.

Sperling, G. (1960). *The information available in brief visual presentations*. Washington: American Psychological Association.

Tsal, Y. (1983). Movements of Attention across the Visual-Field. *Journal of Experimental Psychology-Human Perception and Performance, 9*(4), 523-530.

Vecera, S. P. (1997). Grouped arrays versus object-based representations: Reply to Kramer et al (1997). *Journal of Experimental Psychology-General, 126*(1), 14-18.

Vecera, S. P., & Farah, M. J. (1994). Does Visual-Attention Select Objects or Locations. *Journal of Experimental Psychology-General, 123*(2), 146-160.

Vogel, E. K., Woodman, G. F., & Luck, S. J. (2001). Storage of features, conjunctions, and objects in visual working memory. *Journal of Experimental Psychology-Human Perception and Performance, 27*(1), 92-114.

Woodman, G. F., Vecera, S. P., & Luck, S. J. (2003). Perceptual organization influences visual working memory. *Psychon Bull Rev, 10*(1), 80-87.

Appendix A

DIRECTIONS AND DEMOGRAPHIC QUESTIONS

Directions:
Experiments: 1, 2a-d, 3a

Verbal:
- Each trial will begin with a fixation cross.
- When the cross appears, please focus your attention on it.
- You will be shown an array of four colored circles.
- Your task is to remember the color and location of the circles
- After the array there will be a short delay followed by a cue.
- The cue will either be an arrow or an ‘X’.
- After the cue there will be another short delay and then your memory will be tested.
- A single colored circle will appear with three empty (colorless) circles.
- At this point, your task it to decide whether the single colored circle you see matches the color and location of the array that you remembered earlier.
- If it does, please press the ‘Y’ key. If it does not match, press the ‘N’ key.
- Do you have any questions?

Written:

You will see a display of four color dots organized as such:

1 2

3 4

After a pause, a cue will appear followed by a probe picture.

Your task is to judge whether the probe item shows the correct color in the correct location.

Press ‘Y’ if it does.
If it does not, press ‘N’

Press the Space Bar when ready.

Directions:
Experiment: 3b

Verbal:
- Each trial will begin with a fixation cross.
- When the cross appears, please focus your attention on it.
- You will be shown an array of four novel objects.
- Your task is to remember the shape and location of the objects.
- After the array there will be a short delay followed by a cue.
- The cue will either be an arrow or an ‘X’.
- After the cue there will be another short delay and then your memory will be tested.
- A single novel object will appear along with three empty locations.
- At this point, your task it to decide whether the single novel object you see matches the shape and location of the array that you remembered earlier.
- If it does, please press the ‘Y’ key. If it does not match, press the ‘N’ key.
- Do you have any questions?

Written:

You will see a display of novel objects organized as such:

1 2

3 4

After a pause, a cue will appear followed by a probe picture.

Your task is to judge whether the probe shows the correct item in the correct location.

Press ‘Y’ if it does.
If it does not, press ‘N’

Press the Space Bar when ready.

Demographic Questions:

____
Age

____
Gender

____
Number of Concussions

Appendix B

TABLES AND FIGURES

Experiment 1: Neutral Cue Accuracy

100 ms	200 ms	300 ms	400ms
.754 (.14)	.737 (.14)	.746 (.12)	.744 (.12)
1082 (165)	1095 (169)	1082 (154)	1042 (155)
500 ms	**600 ms**	**700 ms**	**Average**
.715 (.16)	.751 (.15)	.709 (.11)	.737 (.14)
1085 (154)	1065 (164)	1096 (217)	1079 (168)

Experiment 1: Valid Cue Accuracy

100 ms	200 ms	300 ms	400 ms
.767 (.13)	.808 (.15)	.857 (.1)	.845 (.11)
950 (129)	909 (134)	854 (131)	839 (130)
500 ms	**600 ms**	**700 ms**	**Average**
.841 (.12)	.893 (.08)	.864 (.1)	.839 (.12)
850 (161)	793 (146)	809 (140)	858 (146)

Table 1. Experiment 1 results: Mean scores (standard deviations) are shown for accuracy (top), reaction time (bottom) and condition averages (right).

Experiment 2a (300 ms Delay): Neutral Cue Accuracy

3°	5°	7°	9°	Average
.776 (.10)	.756 (.12)	.755 (.11)	.794 (.12)	.770 (.11)
1061 (172)	1076 (152)	1093 (178)	1123 (178)	1089 (169)

Experiment 2a (300 ms Delay): Valid Cue Accuracy

3°	5°	7°	9°	Average
.861 (.10)	.862 (.09)	.873 (.07)	.859 (.11)	.864 (.09)
869 (173)	874 (182)	868 (179)	873 (193)	871 (179)

Experiment 2b (200 ms Delay): Neutral Cue Accuracy

3°	5°	7°	9°	Average
.750 (.12)	.723 (.13)	.736 (.11)	.762 (.11)	.744 (.11)
1074 (214)	1081 (222)	1087 (238)	1135 (244)	1094 (224)

Experiment 2b (200 ms Delay): Valid Cue Accuracy

3°	5°	7°	9°	Average
.810 (.10)	.792 (.11)	.823 (.12)	.806 (.10)	.808 (.10)
955 (200)	960 (203)	944 (194)	936 (170)	949 (186)

Experiment 2c (150 ms Delay): Neutral Cue Accuracy

3°	5°	7°	9°	Average
.772 (.06)	.713 (.12)	.754 (.04)	.814 (.11)	.763 (.09)
1028 (98)	999 (114)	1004 (95)	990 (79)	1005 (90)

Experiment 2c (150 ms Delay): Valid Cue Accuracy

3°	5°	7°	9°	Average
.765 (.05)	.785 (.09)	.781 (.11)	.697 (.09)	.757 (.09)
938 (114)	934 (90)	947 (152)	953 (151)	943 (119)

Experiment 2d (173.29 ms Delay): Neutral Cue Accuracy

3°	5°	7°	9°	Average
.778 (.1)	.771 (.09)	.781 (.07)	.759 (.07)	.772 (.08)
1110 (216)	1099 (201)	1124 (183)	1113 (175)	1099 (199)

Experiment 2d (173.29 ms Delay): Valid Cue Accuracy

3°	5°	7°	9°	Average
.83 (.07)	.846 (.08)	.785 (.09)	.81 (.1)	.817 (.09)
1002 (186)	971 (192)	992 (169)	986 (181)	970 (187)

Table 2. Experiment 2a-d results: Mean scores (standard deviations) are shown for accuracy (top), reaction time (bottom) and condition averages (right).

Experiment 3a (Colored Discs): Neutral Cue Accuracy

	146.63 ms	159.96 ms	173.29 ms	186.62 ms	200 ms	Average
3°	.774 (.14)	.764 (.14)	.742 (.13)	.741 (.16)	.721 (.15)	.748 (.14)
	995 (169)	1033 (230)	1029 (225)	1012 (210)	999 (179)	1013 (203)
12°	.741 (.12)	.734 (.16)	.779 (.14)	.769 (13)	.757 (.13)	.756 (.14)
	1017 (196)	1026 (181)	1026 (193)	1035 (210)	1061(236)	1033 (169)

Experiment 3a (Colored Discs): Valid Cue Accuracy

	146.63 ms	159.96 ms	173.29 ms	186.62 ms	200 ms	Average
3°	.818 (.12)	.802 (.16)	.774 (.14)	.820 (.12)	.809 (.11)	.805 (.13)
	907 (215)	868 (169)	922 (217)	908 (208)	895 (201)	900 (202)
12°	.818 (.10)	.812 (.13)	.822 (.13).	.822 (.12)	.818 (.14)	.818 (.12)
	902 (206)	882 (211)	886 (158)	917 (188)	869 (159)	891 (184)

Experiment 3b (Novel Objects): Neutral Cue Accuracy

	133.3 ms	146.63 ms	159.96 ms	173.29 ms	186.62 ms	Average
3°	.684 (.16)	.707 (.18)	.709 (.14)	.702 (.12)	.665 (.13)	.693 (.15)
	1128 (197)	1101 (183)	1125 (288)	1106 (185)	1123 (176)	1117(205)
12°	.647 (.17)	.646 (.16)	.657 (13)	.670 (.18)	.621 (.16)	.648 (.16)
	1151 (200)	1202 (297)	1146 (240)	1152 (226)	1148 (256)	1160(244)

Experiment 3b (Novel Objects): Valid Cue Accuracy

	133.3 ms	146.63 ms	159.96 ms	173.29 ms	186.62 ms	Average
3°	.710 (.16)	.741 (.16)	.735 (.14)	.760 (.13)	.766 (.11)	.742 (.14)
	1045 (161)	969 (161)	1035 (204)	1014 (241)	1028(199)	1018(190)
12°	.687 (.15)	.692 (.15)	.680 (.13)	.694 (.15)	.714 (.12)	.693 (.14)
	1064 (262)	1046 (171)	1045 (194)	1048 (222)	1083(187)	1057(207)

Table 3. Experiment 3a-b results: Mean scores (standard deviations) are shown for accuracy (top), reaction time (bottom) and condition averages (right).

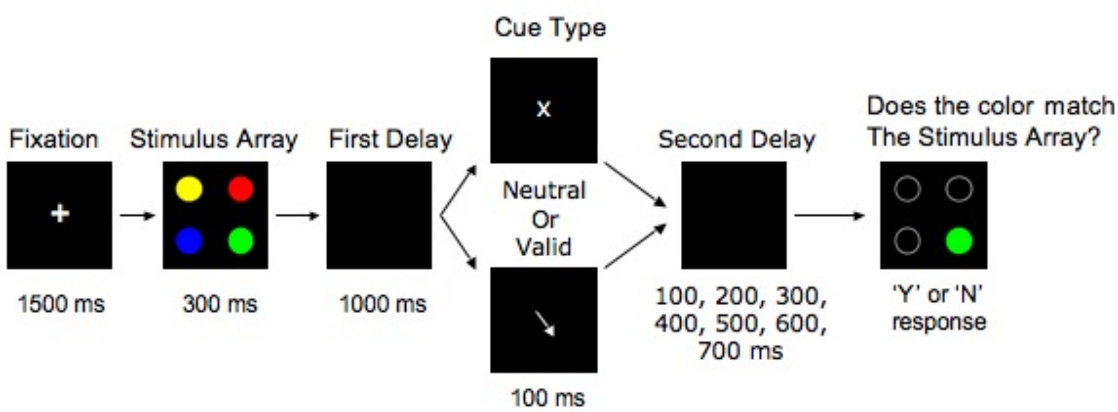


Figure 1. Trial Sequence Experiment 1: After a fixation cross (1500 ms), the four-item stimulus array appeared (All items presented at 6° eccentricity). Stimulus array was followed by the first delay period (1000 ms). Next, either a neutral or valid retro-cue flashed (100 ms) and was followed by a second delay (100, 200, 300, 400, 500, 600 700 ms). After the second delay period, a probe item appeared and participants judged whether it matched what had been shown in the stimulus array.

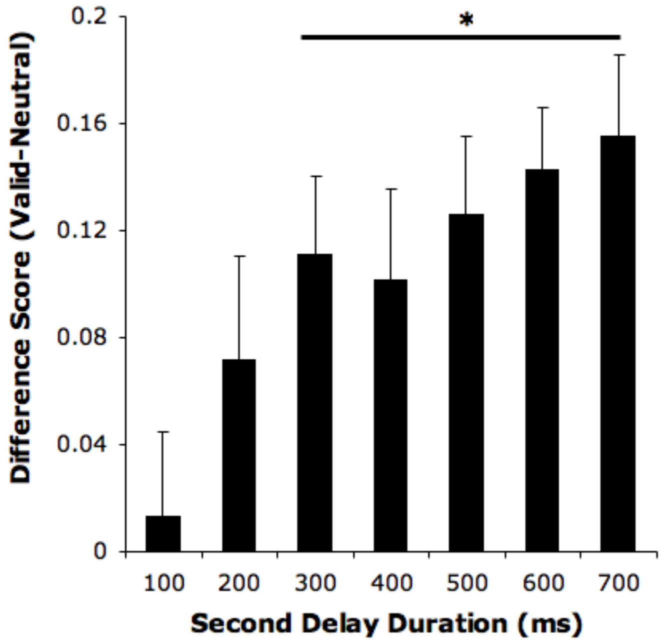


Figure 2. Experiment 1 results: Bars represent the difference in the proportion correct between the valid and neutral retro-cue conditions. Error bars reflect the standard error of the mean. Asterisk (*) signifies significance greater than $p < .05$.

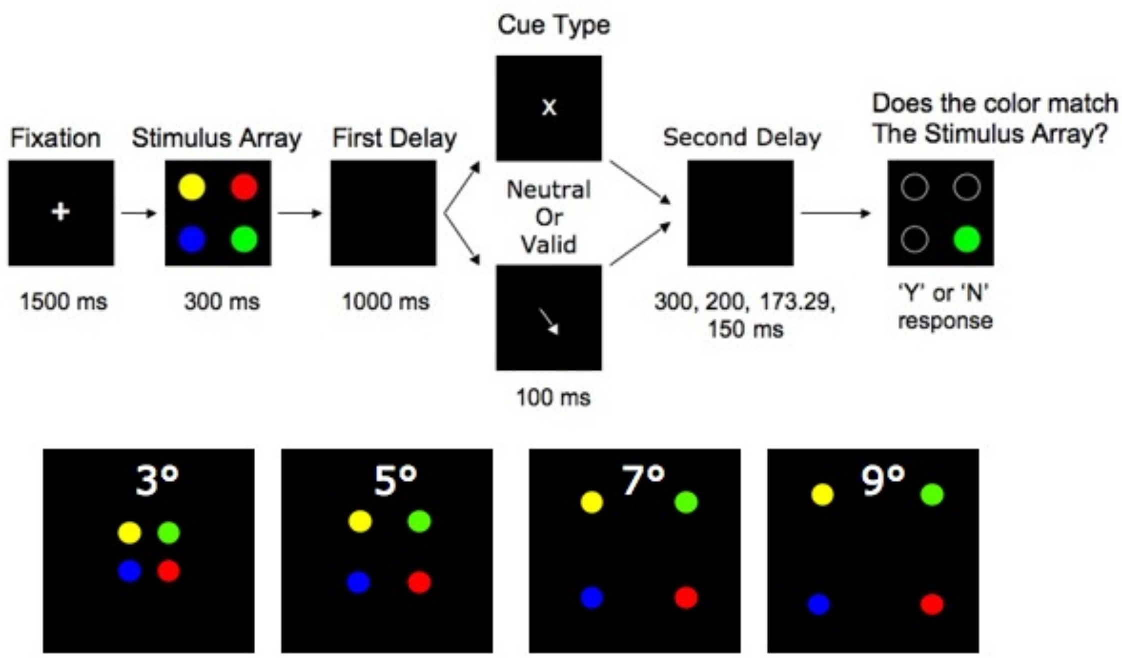
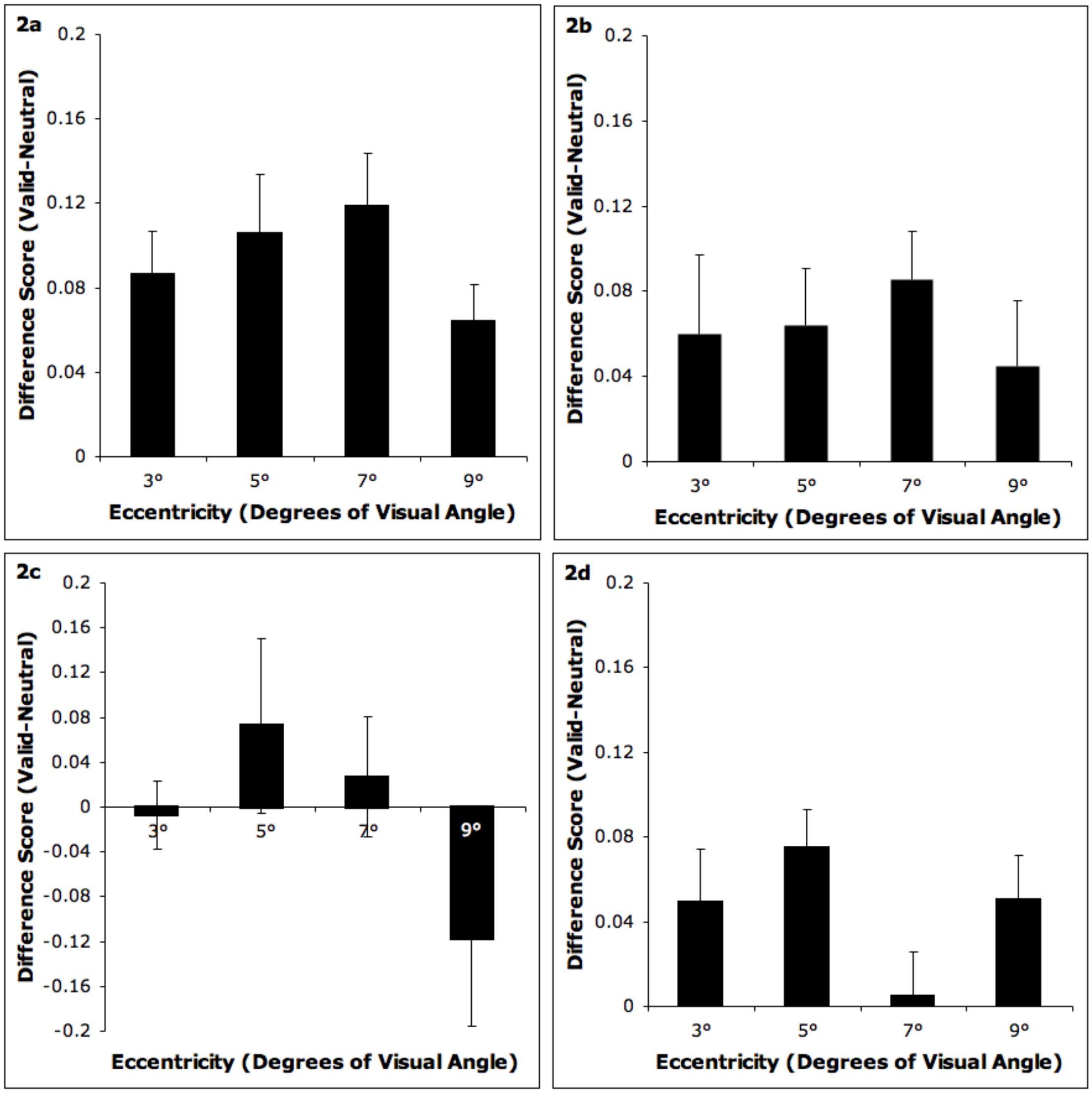


Figure 3. Trial Sequence Experiment 2a-d: After a fixation cross (1500 ms), the four-item stimulus array appeared (Items presented at 3°, 5°, 7°, 9° eccentricity). Stimulus array was followed by the first delay period (1000 ms). Next, either a neutral or valid retro-cue flashed (100 ms) and was followed by a second delay (Experiment 2a-d: 300, 200, 150, 173.29 ms). After the second delay period, a probe item appeared and participants judged whether it matched what had been shown in the stimulus array.



<u>Figure 4.</u> Experiment 2a-d results: Bars represent the difference in the proportion correct between the valid and neutral retro-cue conditions. Error bars reflect the standard error of the mean.

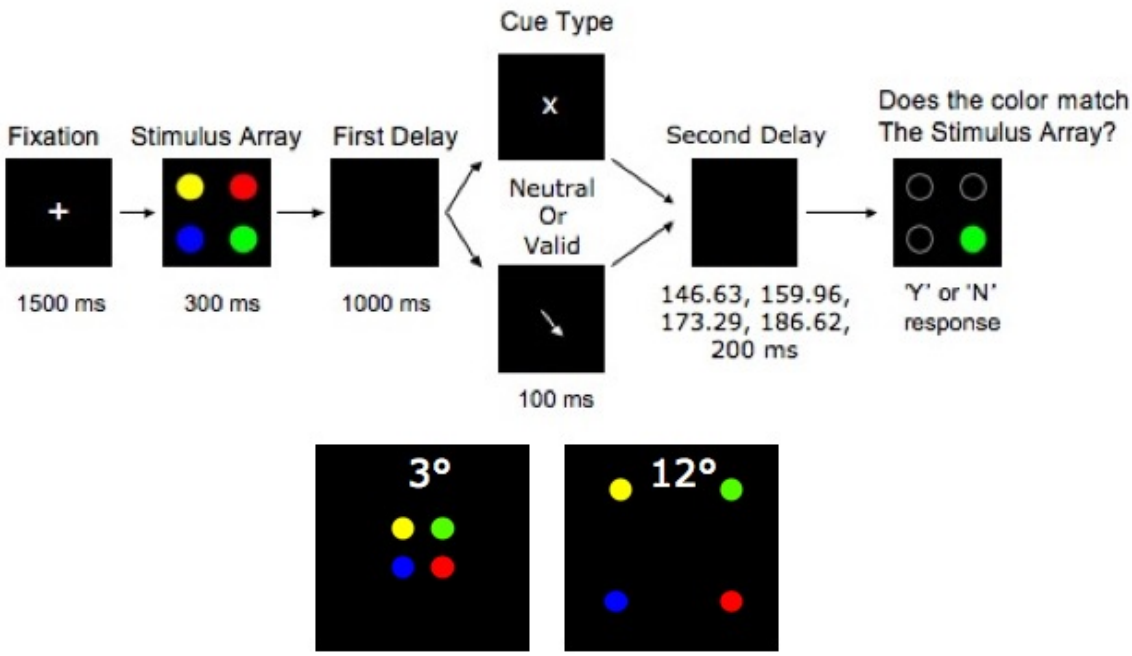


Figure 5. Trial Sequence Experiment 3a: After a fixation cross (1500 ms), the four-item stimulus array appeared (Items presented at 3° and 12° eccentricity). Stimulus array was followed by the first delay period (1000 ms). Next, either a neutral or valid retro-cue flashed (100 ms) and was followed by a second delay (146.63, 159.96, 173.29, 186.62, 200 ms). After the second delay period, a probe item appeared and participants judged whether it matched what had been shown in the stimulus array.

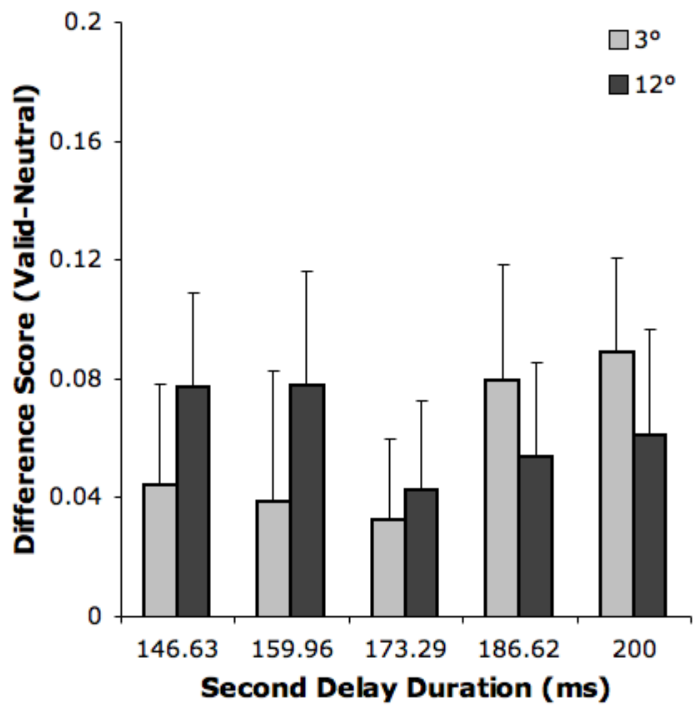


Figure 6. Experiment 3a accuracy results in difference in proportion correct (valid-neutral). Light grey bars indicate the 3° condition, dark grey bars the 12°. Difference scores facilitate comparison of the retro-cue benefit at both eccentricities. Error bars reflect the standard error of the mean.

Figure 7. Experiment 3b: sample of novel objects used as stimuli.

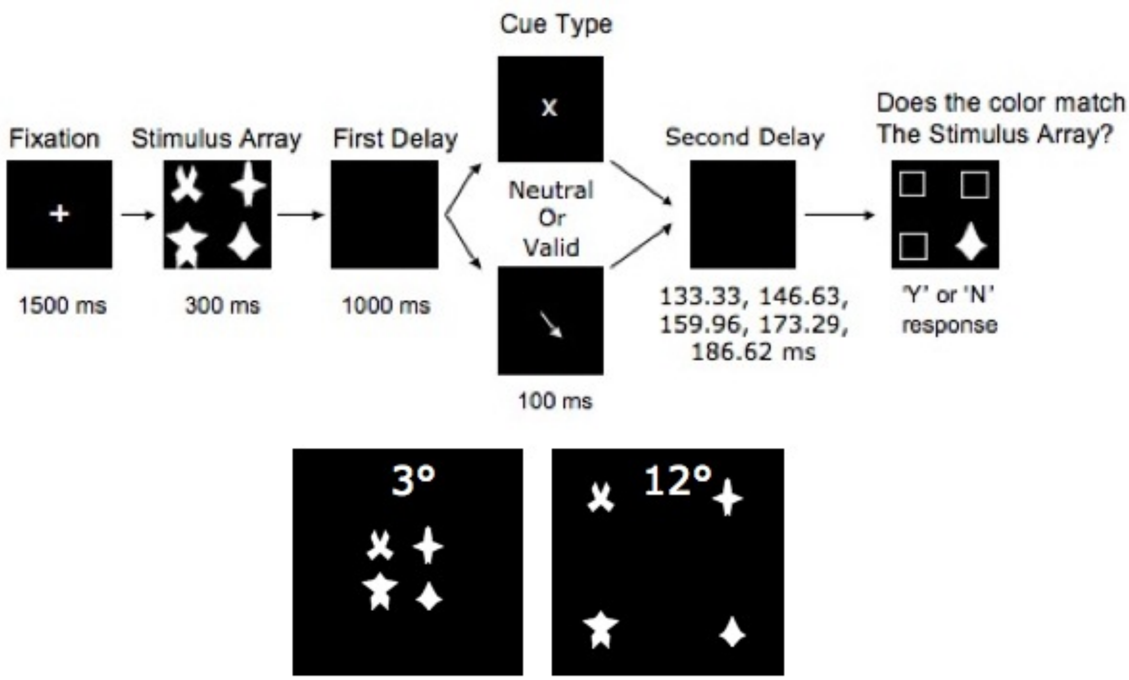


Figure 8. Trial Sequence Experiment 3b: After a fixation cross (1500 ms), the four-item stimulus array appeared (Items presented at 3° and 12° eccentricity). Stimulus array was followed by the first delay period (1000 ms). Next, either a neutral or valid retro-cue flashed (100 ms) and was followed by a second delay (133.33, 146.63, 159.96, 173.29, 186.62 ms). After the second delay period, a probe item appeared and participants judged whether it matched what had been shown in the stimulus array.

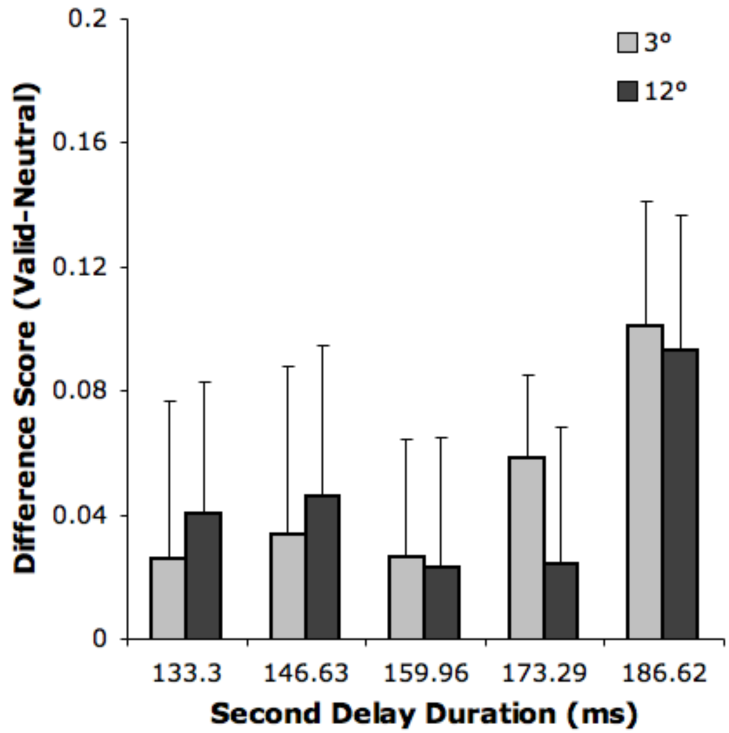


Figure 9. Experiment 3b accuracy results in difference in proportion correct (valid-neutral). Light grey bars indicate the 3° condition, dark grey bars the 12°. Difference scores facilitate comparison of the retro-cue benefit at both eccentricities. Error bars reflect the standard error of the mean.