THE ROLE OF WORKING MEMORY IN BISTABLE FIGURE-GROUND PERCEPTION

By

MAUREEN CASSIDY TURNER

A Thesis Submitted to The Honors College

In Partial Fulfillment of the Bachelors Degree

With Honors in

Psychology

THE UNIVERSITY OF ARIZONA

May 2010

Approved by:

Mary

Dr. Mary Peterson
Department of Psychology

The University of Arizona Electronic Theses and Dissertations Reproduction and Distribution Rights Form

Name: Turner, Maureen Cassidy	
Degree title: BA	
Honors area: Psychology	
Date thesis submitted to Honors College:	
Title of Honors thesis: The Role of working memory in bistable figure-ground perception	
:The University of Arizona Library Release	I hereby grant to the University of Arizona Library the nonexclusive worldwide right to reproduce and distribute my dissertation or thesis and abstract (herein, the "licensed materials"), in whole or in part, in any and all media of distribution and in any format in existence now or developed in the future. I represent and warrant to the University of Arizona that the licensed materials are my original work, that I am the sole owner of all rights in and to the licensed materials, and that none of the licensed materials infringe or violate the rights of others. I further represent that I have obtained all necessary rights to permit the University of Arizona Library to reproduce and distribute any nonpublic third party software necessary to access, display, run or print my dissertation or thesis. I acknowledge that University of Arizona Library may elect not to distribute my dissertation or thesis in digital format if, in its reasonable judgment, it believes all such rights have not been secured. Signed: Date: 5 May 2010

I would like to dedicate this thesis to my beautiful mother, without whom I would undoubtedly not have been able to come so far, in science or in life.

Also, I would like to thank Dr. Mary Peterson who has been both an inspiration and an intellectual guide to me these past few years.

Abstract

There is a question of what cognitive resources underlie bistable figure-ground alternation. Figure-ground alternation is accomplished via inhibition. Research highlighting the role of inhibition in working memory processes point to the possible involvement of working memory in figure-ground alternation. We examined this issue by asking participants to simultaneously maintain a working memory load and indicate their perceptual reversals of figure-ground stimuli. Two separate types of working memory tasks were used, a verbal (multi-modal) task and a visual task. Concurrent visual working memory load caused perceptual alteration to speed, while verbal working memory load had no significant effect. This implies that working memory space is needed to maintain the current percept, while inhibition keeps the alternate interpretation from coming to dominance.

Introduction

Our rich daily experience, our broad field of vision, our unified knowledge about the way the world is are all actually elaborate puzzles fitted together by the brain out of complex, intricately processed sense data. The perception of an object, while it seems instantaneous, is accomplished through a series of neurological processes that we are totally unaware of as separate processes. Among the most basic and earliest (neurologically speaking) of these processes is the separation of the visual field into figures and ground, into objects and background to those objects. While the process seems straightforward – we have all seen the classic Rubin Vase, a picture that can be seen as a vase or as two faces – it has been revealed in recent research to be remarkably complex.

Figure-ground perception is the process by which we parse visual scenes into objects and background. When presented with an ambiguous display, the brain alternates between possible interpretations. Through the use of black and white computer displays, very much like the Rubin Vase, modern researchers have shown that figure-ground perception is hugely influenced by the familiarity of objects (Peterson, Harvey & Weidenbacher, 1991). This is logical, considering that the figure-ground distinctions we make in our everyday life are used to identify objects, generally objects very much like ones we have seen before, so that we can navigate the spatial world. When we see a silhouette of an object, we are able to tell where the object is by neural suppression (reduction in the firing rate in neurons) of the object that might have been perceived on the ground side of the object we do see (Peterson & Gibson, 1994). This inhibition extends to the high-level shape properties on the ground side (Peterson & Skow, 2008). That is to say, when we perceive one region as the figure in a bistable figure-ground display, we do so in virtue of the fact that our brain is inhibiting the other region. When our perception switches so that we see a different region as figure, we do so because that region has ‘won’ and overcome the inhibition. Figure-ground perceptual alternation can be understood as ongoing competition against inhibition, with the brain trying out various interpretations by inhibiting the alternatives.

If a figure-ground display is removed from view during alternation, the next time that the same display is seen, then the switching will start again by resuming the most recent interpretation if the display was removed for a short period of time, or, by seeing the interpretation that has been most ‘favored’ in the past if it has been a longer time (Kanai, Knapen, van Ee & Verstraten, 2007; Leopold, Wilke, Maier, & Logothetis, 2002). This, in combination with research demonstrating a variety of high-level influences on figure-ground organization, suggests that there is a memorial contribution involved in figure-ground alternation. While it is clear that figure-ground perception is intricately tied to memory processes, this link is very far from well understood.

There are several different types of memory at work in the human brain. It seems, given the rapid rate at which we are able to make many different figure-ground distinctions, that the memory involved in the process must be both readily accessible and likely extremely short term. Brascamp, Knapen, Kanai, Noest, VanEe & Van den Berg, (2008) have proposed a model of the memory involved in perceptions that switch back and forth that is very close in timing to our most current understanding and modeling of working memory more generally, although they did not explicitly mention the similarity. There are several reasons to think that the memory at work in bistable paradigms is working memory. Working memory has been understood as a central resource, highly interconnected to different modal areas. Areas of the brain that are highly interconnected across modalities have also been shown to be at work bistable perceptual paradigms. Right inferior frontal activation is observed in spontaneous perceptual reversals compared to stimulus driven switches, which has been traditionally understood as playing a role in inhibition of non-preferred responses (Aron, Robbins & Poldrack , 2004 also Sterzer & Kleinschmidt, 2007). The inferior frontal cortex has been demonstrated to be interconnected to various modality-specific brain regions (Greenlee, Oya, Kawasaki, Volkov, Severson, Howard & Brugge, 2007). So, the interconnectedness implicated in working memory is very similar to the interconnectedness that we expect during bistable alternation.

Further, there is evidence that manipulating the need for inhibitory power in tasks relates directly to changes in the working memory capacity required (Hasher & Zacks, 1988, also Healey, Zacks, Hasher & Helder, (in press). Working memory capacity and ability to inhibit a variety of distractors are closely linked (Engle, Laughlin, Tuholski & Conway, 1999). Healey et al (in press) have proposed that the construct that we now call working memory actually refers to inhibitory processes in the brain. For example, the degree to which you can hold a certain set of items in memory is just the degree to which you can inhibit competing distractors. This understanding of working memory lends itself readily to an explanation of bistable perceptual alternation in terms of working memory. Bistable figure-ground alternation occurs via inhibition of the ground region. Because this process uses inhibitory power, it seems plausible that the figural region might ‘enter’ working memory space, while the ground region is inhibited and kept out of working memory.

Working memory has recently come to be understood as a central resource as opposed to a collection of modality-specific memory stores (Morey & Cowan, 2005). There are differences between young and older adults on working memory tasks, which suggests localization of the function in the frontal regions of the brain that typically degenerate with age, rather than in more posterior modality specific areas (Rowe, Turcotte & Hasher, 2008 also Rypma, Berger & D'Espositio, 2002). Patients with right frontal lesions were significantly impaired at perceptual reversal with bistable stimuli (Meenan & Miller, 1994 also Ricci & Blundo, 1990). While there is ample evidence indicating that working memory is a central resource, there is also evidence to the contrary. For example, the contents of working memory can be decoded from modality specific areas (Harrison & Tong, 2009). In addition the memory of a stimulus that has been removed depends primarily on the spatial location of the stimulus in the field of view (Chen & He, 2004); this sort of spatial mapping of stimuli is a feature of posterior visual areas. To reconcile the conflicting evidence, it has been suggested that working memory is a central capacity that calls on modality specific storage areas (Saults & Cowan, 2007). The present experiment was able to examine which side of the conceptual divide regarding working memory bistable perception falls on.

In this paper, we report evidence for the influence of visual working memory load on figure-ground bistable perceptual reversals. We tested whether various working memory loads caused an increase in the rate of reversals reported by observers while viewing figure-ground bistable stimuli. We predicted that an increase in working memory load would lead to and increase in reversal rate. Because working memory operates by inhibiting various competing distractors, then filling working memory uses up inhibitory power. In order to maintain one interpretation during bistable viewing, inhibitory power is needed to suppress the competing percept. If a working memory load sufficiently fills working memory, then it uses all available inhibitory power, leaving none to maintain the current bistable interpretation. So, under working memory load, we expect more bistable reversals to occur. In Experiment 1, we tested the effect of a verbal working memory load. If working memory is a modality independent central resource, then verbal working memory load should increase reversal rate. However, it did not. In Experiment 2, we tested the effect of a visual working memory load. If working memory in modality specific we should find an effect of verbal working memory load. In Experiment 2, we found that adding visual working memory load speeds bistable reversals.

The influence that we found was modality specific. Verbal working memory load had no influence on perceptual reversals. This evidence was obtained using two different working memory paradigms. The first was a verbal working memory load administered during perceptual reversal (verbal working memory task, Conway, Kane, Bunting, Hambrick, Wilhelm & Engle, 2004). The second was a visual working memory load administered during perceptual reversal (visual working memory task devised by Luck, 2007).

Experiment 1

In Experiment 1, we examined the effect of a verbal, cross-modal, working memory load on bistable figure-ground reversals.

The verbal working memory task used in Experiment 1was adapted from Conway, et al.’s (2004) operation span task. Observers were presented with a sequence of target words and distractors to be remembered for later recall. While they maintained the words in working memory, they viewed ambiguous figure-ground displays, which were two region black and white novel displays (Figure 1). Their tasks were to indicate their perceptual reversals and, subsequently, recall the target words that they had learned. They reported about figure-ground reversals for 5000 milliseconds (ms). We predicted that bistable reversal rate would increase with increasing numbers of words in memory.

Method

Participants

Twenty-nine students at the University of Arizona participated in this experiment for credit in an introductory level psychology course. All had normal or corrected-to-normal vision. Nine of the students were unable to use or reported confusion about the use of the response button box. Their data were not included in the analysis. The data from twenty students were used for the final analysis.

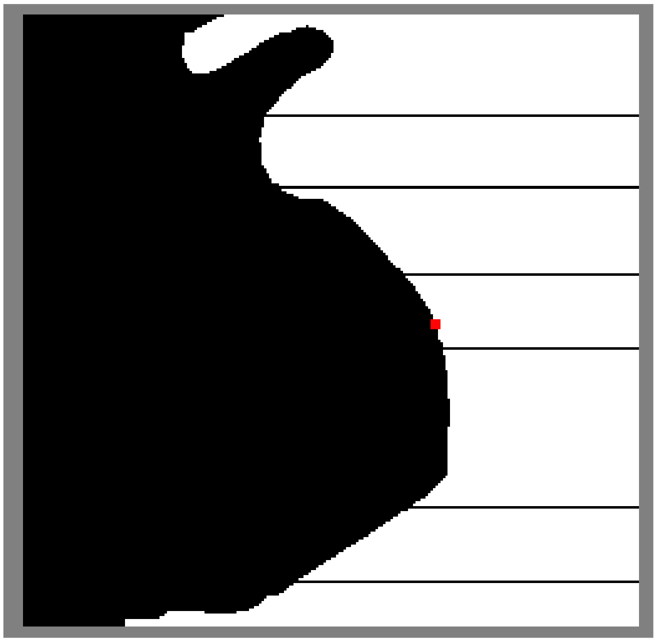

Figure 1. One of the bistable figure-ground displays used in this study.

Stimuli

Each trial consisted of a number of displays. Participants viewed between two and four displays for the verbal portion of the trial (verbal working memory task, Conway et al, 2004). Each verbal display consisted of a basic arithmetic problem followed by a target word. The arithmetic problems used numbers between one and ten. The only mathematical operations to be performed were multiplication, division, addition and subtraction. Half of the arithmetic problems were correct; the remainder were incorrect. The words were all common three, four or five letter nouns that were all unrelated semantically to the extent that it was possible. None of the words rhymed or were linguistically similar. Seventy-eight arithmetic problem and word pairs were made. These arithmetic word pairs were displayed centrally on a neutral grey background in the font Times New Roman.

The visual, figure-ground portion of the task consisted of 44 black and white figures presented on a neutral grey background at a viewing distance of 96cm. Each display was vertically divided into half black and half white with a tiny red fixation point located along the border at a height halfway between the top and the bottom of the display. The two colors met along a central border that was designed so that the black half and the white half were not symmetrical, but were balanced for overall surface area and approximate number of protrusions (see Figure 2). While all regions of all displays were completely novel, to the extent that it was possible, displays were designed so that neither the black nor the white region even resembled a recognizable, familiar object. The displays were intended to be ambiguous, and hence, reversible. Each display subtended a vertical visual angle of 7.72° and a horizontal visual angle of 1.58°. In half of the displays, the left side was black and in half of the displays the left side was white.

Procedure

Each trial consisted of a succession of displays (see Figure 2). First, participants viewed and responded to between two and five of the verbal displays. The order and timing of an example trial where participants had to remember two target words is shown in Figure 2. Each trial started with a verbal task display. When a verbal display appeared onscreen the participant responded by reading the arithmetic problem out loud, then said “yes” or “no” depending on whether they thought the math was correct or incorrect and then read the target word out loud. Immediately when the participant finished saying the target word out loud, the experimenter pressed a button to switch the display to show the next screen. No feedback was given. Participants completed between two and five verbal displays on any given trial. After the last verbal display was read, the experimenter pressed a button to switch the screen to show the visual display. The visual display was shown for 5000milliseconds. Participants indicated their subjective perceptual reversals by pressing the buttons on a two-button response box. Participants pressed the left button during the time that they perceived the left region as figure and the right button during the time that they perceived the right region as figure. After the visual display, a screen with a question mark in the center was shown as the cue for subjects to say out loud to the experimenter all of the target words that they remembered. The experimenter recorded these words.

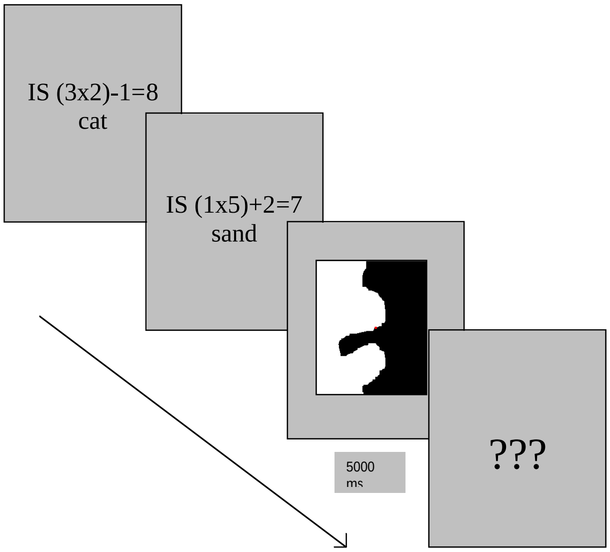

Fig. 2. Sequence of events in a trial in Experiment 1. The illustration shows an example of a trial sequence where participants would have to hold two target words in memory during bistable alternation.

The participants completed sixteen experimental trials, in two blocks of eight trials each. These experimental trials were preceded by, in order, one block of three verbal practice trials, one block of five visual practice trials and one block of three verbal/visual combination trials. Each subject was tested at all levels of working memory load, including a baseline measure of reversal rate without memory load. The experiment was a within-subjects design. Neither verbal stimuli nor visual stimuli were ever repeated. Participants completed the baseline measure first. Then, the order of the trials within and across each block was randomized such that subjects completed trials with the different degrees of working memory load in a mixed order.

Results and Discussion

Performance on the working memory task

Table 1 presents the mean percentage of target words that were correctly recalled at test for each level of working memory load. Overall, participants remembered a higher percentage of the target words at lower levels of verbal working memory load. Participants were able to remember, on average, 2.08 words per trial. This is in keeping with past literature showing that average working memory capacity on this type of task is generally only two to three items (Engle, Laughlin, Tuholski & Conway, 1999). With no concurrent task, participants remembered a mean of 2.37 words correctly during the same verbal working memory task that we present here (Arnell, Stokes, MacLean & Gicante, 2010). Participants’ performance was consistent with the performance that would be expected if they put forth full effort on the task (Conway et al, 2005).

Table 1.

Mean number of words correctly recalled on verbal WM task in Experiment 1

WM load	2 words	3 words	4 words	5 words
Percent correct	1.69	2.12	2.40	2.12

Performance on the figure-ground stimuli

Figure 3 presents the mean number of perceptual alternations that subjects reported under working memory loads of zero (baseline), two, three, four and five words. The number of perceptual reversals was determined by the number of times participants pressed the buttons to indicate their reversals during the 5000 milliseconds that they viewed the figure-ground display. A one way within subjects analysis of variance (ANOVA) showed no significant differences between the various conditions of working memory load., (F = 1.493; p = .237). Under verbal memory loads of two, three, four and five words, subjects reported perceptual reversals at essentially the same rate as reversals in the baseline condition, with no working memory load.

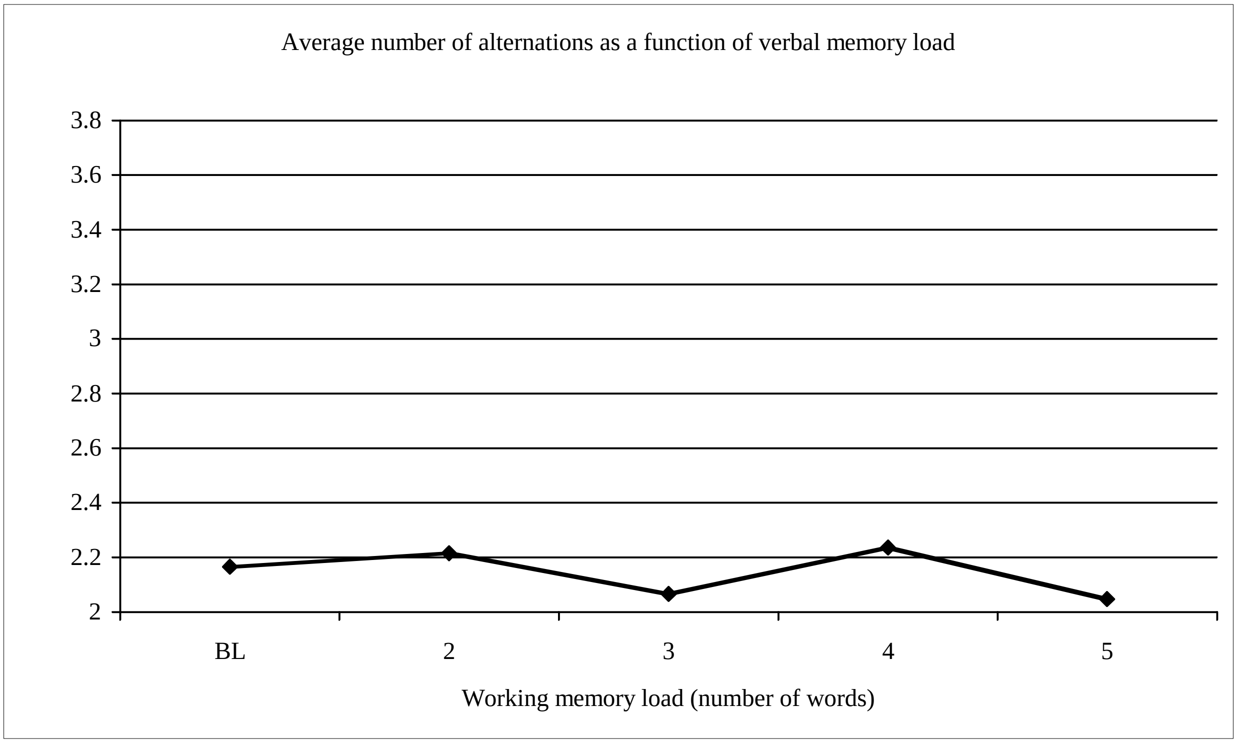

Figure 3. Results from Experiment 1: Average number of reversals of a bistable stimulus as a function of verbal working memory load.

Discussion

There was no effect of verbal working memory load on the number of reversals of a bistable dsiplay. Therefore, the results of Experiment 1 show no evidence that verbal working memory load affects perceptual reversals of bistable figures.

While working memory has been understood as a 'central' storage capacity, susceptible to multi-modal interference (Stevanovski & Jolicoeur, 2007), it is possible that there are also modality specific working memory stores (Barsalou, Simmons, Barbey & Wilson, 2003). In the next experiment, we examined whether visual working memory load had an effect on the visual task of reporting perceptual reversals of bistable figures.

Experiment 2

In Experiment 2, we examined the effect of a visual working memory load on bistable figure-ground reversals. During the visual working memory task, observers were presented with an array of colored squares to be remembered for later change detection. While they maintained the squares in working memory, they viewed ambiguous figure-ground displays. Their tasks were to indicate their perceptual reversals and, subsequently, to decide if a second array of squares was the same as or different from the first array of colored squares. We hypothesized that, if visual working memory capacity was required to maintain one interpretation of an ambiguous stimulus, then perceptual reversals would speed under greater working memory loads, in this case, a larger numbers of colored squares to keep in mind.

Method

Participants

Twenty-nine new students at the University of Arizona (10 females and 19 males) participated in this experiment for credit in an introductory level psychology course. All had normal or corrected-to-normal vision. Two of the students performed at chance on the WM task. Their data were not included in the analysis. The data from twenty-seven students were used for the final analysis.

Stimuli

Each trial consisted of three displays. Participants viewed two arrays of squares for the visual working memory portion of the trial. The two arrays seen on each trial were always identical with respect to the spatial layout of the squares. Each array consisted of between two and five squares, each of which was one of seven different colors. Colors were never repeated within an array. On half of the trials the first array, which was shown before the figure-ground display, was identical to the second array, which was shown following the figure-ground display. On the other half of the trials, the color of one of the squares was changed at the second viewing. There were 31 different pairs of arrays of squares. The arrays of squares were displayed on a neutral grey background.

The visual, figure-ground portion of the task was identical to the visual portion of the task in Experiment 1. The same set of 44 visual stimuli was used in Experiment 2.

Procedure

The order and timing of an example trial where participants had to remember two target squares is shown in Figure 4. Each trial started with a visual working memory square array display. A visual working memory square array was shown for 150 milliseconds. Participants were instructed to memorize, silently, the colors of each of the squares in the array during this time. Then a figure-ground display was shown for 5000 ms. Participants indicated their subjective perceptual reversals by pressing the buttons on a two-button response box. Participants pressed the buttons whenever they felt that their subjective impression of the figure-ground organization had switched. After the figure-ground display, a second array of squares was shown. This second array was either identical to the first array or else the color of one of the squares had been changed. Participants simply had to say out lout to the experimenter whether the second array of squares was the “same” or “different” from the previous array. The experimenter recorded these verbal responses. The second array of squares was shown until participants made their verbal response.

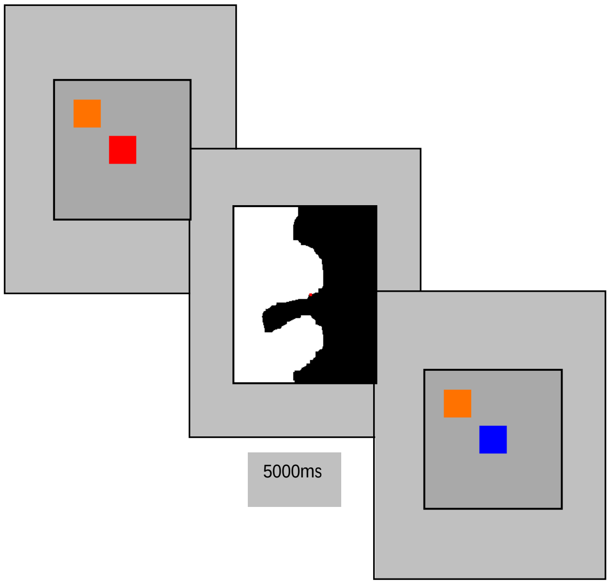

Fig. 4. Sequence of events in a trial in Experiment 2. The illustration shows an example of a trial sequence where participants would have to hold two squares in memory during bistable alternation.

The participants completed 24 trials, in two blocks of 12 trials each. This was preceded by one block of 4 visual working memory practice trials, one block of 7 figure-ground practice trials and one block of 3 visual working memory/figure-ground display combination trials. The experiment was a within-subjects design. Neither visual working memory stimuli nor figure-ground stimuli were ever repeated. The order of the trials within and across each block was randomized.

Results and Discussion

Performance on the WM task

Table 2 presents the mean percentage of correct same/different judgments at each level of working memory load during the squares task. Overall, participants were most accurate at detecting changes when there were fewer squares in the display. At five squares, the highest working memory load, participants were only slightly above chance in their change detection. This is in keeping with past literature showing that average working memory capacity on this type of task is generally only three to four items total (Luck, 2007). Participants' performance was consistent with the performance that would be expected if they put forth full effort on the task.

Table 2.

Change Detection Accuracy and Calculated Number of Remembered Squares

WM Load	2 squares	3 squares	4 squares	5 squares
Percent Accuracy	88.89	83.33	73.61	56.94
Calculated Mean Number of Items Remembered	1.78	2.5	2.94	2.84

Note. When participants remembered the colors of squares in an array, they also had to hold the figure-ground percept in visual working memory. Thus, at a memory load of two squares (for example), there were three items total in visual working memory.

Note. Mean number of items remembered is an estimate that was calculated as a function of accuracy per number of squares possible. In fact, our visual working memory task is not directly comparable to our verbal working memory task. This measure should give some idea of how performance on the two tasks compare.

Considering that the number of items in working memory was quite taxing (see 'note' to Table 2), performance was actually better than might be expected on a purely visual working memory task with memory loads of three, four and five squares. In an effort to explain this effect, participants were asked during post-experiment questioning what strategies they had used during the task. Participants reported resorting to verbal strategies, such as repeating the names of the colors, to remember the squares at high working memory loads. Importantly, at low working memory loads, participants completed the task by using only visual strategies. At high working memory loads, participants completed the task by using verbal strategies. This alters the nature of the task at higher working memory loads, making it more like the task used in Experiment 1.

Performance on the figure-ground stimuli

Figure 5 presents the mean number of perceptual alternations that subjects reported under working memory loads of zero (baseline), two, three, four and five squares. The number of perceptual reversals was determined by the number of times participants pressed a button during the 5000 ms exposure of the figure-ground display. Participants reported experiencing more perceptual reversals when they held two squares in working memory than when they tried to hold zero, squares in memory. An ANOVA comparing only the baseline and two item WM load conditions showed that this difference was statistically significant, (F = 2.575; p = .043). Holding two squares in working memory during bistable alternation significantly increased the rate of alternation. At working memory loads of three, four and five squares, there was no significant difference between the rate of alternation and the rate at baseline or the rate with two squares in memory. This finding is consistent with the hypothesis that working memory load speeds perceptual switching.

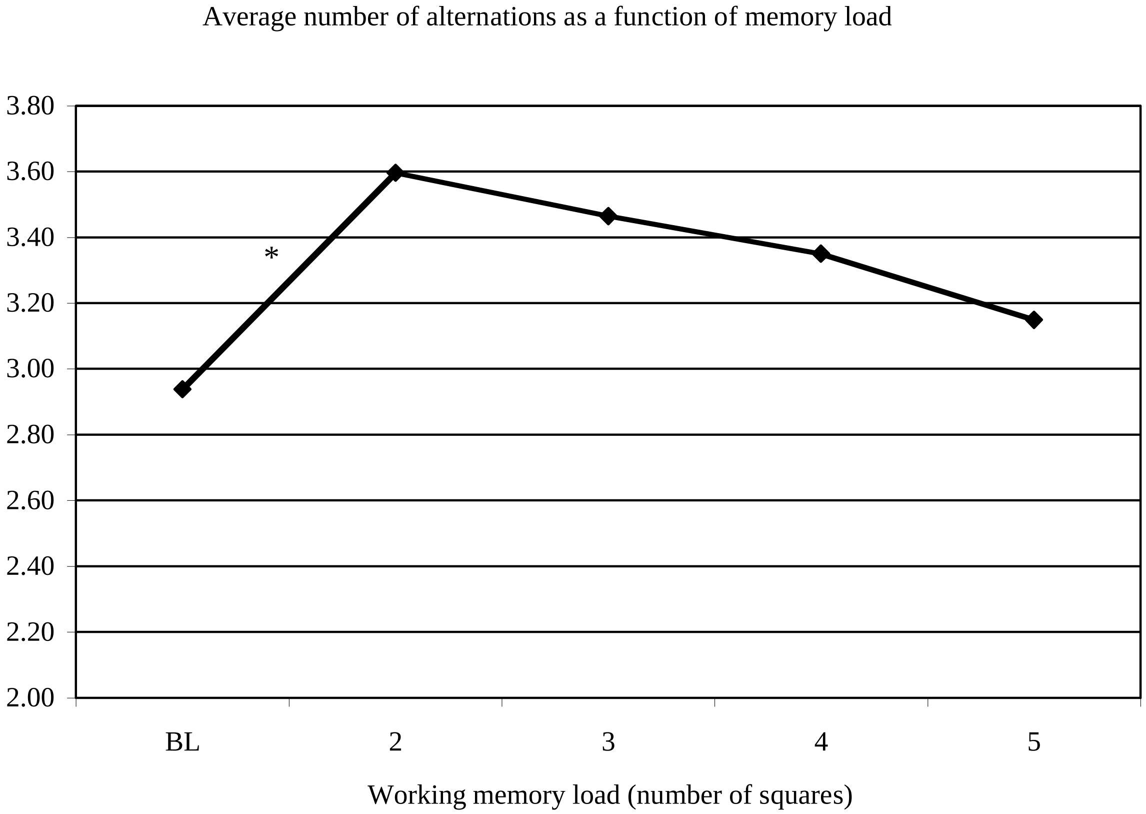

Figure 5. Results from Experiment 2: Mean number of reversals of a bistable figure-ground display as a function of visual working memory load.

Discussion

It is interesting that, with the visual working memory task, perceptual reversal was not significantly speeded at working memory loads of three, four and five squares. This can be explained by the difference in strategies used by participants at different levels of the working memory squares task. When subjects are using their visual memorial resources to maintain the squares in working memory, which they reported doing at low working memory loads, there is an effect of working memory load on bistable alternation. However, when subjects used verbal strategies to maintain the squares in memory, they effectively made the task into a verbal working memory task. We have shown in Experiment 1 that there is no effect of verbal working memory load on bistable alternation. Thus, the result in Experiment 2 is both confirm the finding in Experiment 1 that there is no cross-modal working memory interference on bistable alternation and provides the positive result that a visual working memory load of 2 items does interfere with bistable alternation.

General Discussion

Our results provide evidence that visual working memory load speeds viewers' reversals of bistable figure-ground stimuli. When observers maintained a visual working memory load consisting of two colored squares while they viewed black and white figure-ground bistable stimuli, their alternation rate was faster than baseline, when they held no square in visual working memory. This effect was not observed when participants maintained a verbal working memory load of several target words while viewing bistable stimuli.

The finding that visual working memory load speeds bistable alternation, together with the understanding of working memory as inhibitory functions (Engle, Laughlin, Tuholski & Conway, 1999; Hasher & Zacks, 1988 also Healey et al, in press) supports an interpretation of the data where the figural region of a bistable figure-ground stimulus is held in working memory by the inhibition of the ground region. When working memory is filled to capacity with other items to be remembered, inhibition is overwhelmed by the large number of items and is no longer able to suppress the interpretation on the ground side. This allows the bistable figure to reverse, and the former ground-region (now the figure) enters working memory.

The effect of visual working memory load on bistable alternation was observed only for a memory load of two squares, and not for memory loads of three, four and five squares. Our original hypothesis was that alternations would speed linearly as working memory load was increased. It is somewhat surprising that higher working memory loads resulted in alternations that were no different from baseline speeds. However, as was noted earlier, participants reported utilizing a different strategy to remember the colors of the squares at memory loads higher than two squares. We can conclude that the speeding effect observed at a memory load of two squares disappears at three, four and five squares because the task has become a verbal working memory task, or a mixture of visual and verbal working memory tasks, in virtue of strategy use. Future research should address this fault by examining the effect of a visual working memory task that cannot be completed via verbal methods on bistable switching. Based on the proposed explanation of the current results in terms of inhibitory power, it is reasonable to expect that at higher working memory loads, using a purely visual task, the speeding of alternation already observed at two items of working memory load should hold constant.

In this experiment, we have utilized only one class out of many possible types of bistable figures. There is a question of whether the results reported here would generalize to these other types of stimuli. Considering that suppression during figure-ground perception extends neurally well beyond the low-level edge properties of the stimulus into the higher level shape and object properties, we should expect that findings obtained with figure-ground stimuli will have a great deal in common with other types of bistable stimuli (Peterson & Skow, 2008). Also, there is evidence to suggest that executive functions and control are even more involved with more semantically complex bistable stimuli, for instance the bistable Necker cube. (Struber & Stadler, 1999). It is highly likely that the results reported here would generalize to other classes of bistable stimuli.

It might be argued that the effect we are seeing might have more to do with attentional allocation than working memory proper. Attention, as it is modulated by the prefrontal cortex, is needed to maintain the dominant percept (Windmann, Werhmann, Calabrese & Gunturkun, 2006). Temporo-parietal junction (TPJ) is important for stimulus driven attention. A visual short-term memory load increases, activity in TPJ is increasingly suppressed (Todd, Fougnie, & Marois, 2005). Memory load is importantly tied to attention, which is turn is used to maintain the dominant percept. So, conceivably, adding the concurrent working memory load during perceptual alternation might cause attention to be divided, thereby leaving less attentional strength to maintain the dominant percept. This would lead to a speeding in reversal rate. However, there is good reason to believe that this is not the case. Namely, the effect demonstrated in this paper is modality specific.It is unlikely that there are prefrontal resources that subserve only one modality.

Our results differ from past findings. When subjects were given a verbal counting distractor task, bistable reversals were slowed (Reisberg & O’Shaugnessy, 1984). However, these results should be interpreted as stemming from an attentional task, whereas, the effect we are reporting is caused by a working memory task. Essentially, when subjects engage in a counting task, they are performing an automatic task that is a distraction, but does not require memory storage. In the present experiment, participants had to maintain a heavy memory load while indicating alternations, so the tasks are actually quite different. Again, working memory and attention appear to be very closely related, but do not entirely supervene on one another.

In sum, the present results provide evidence that filling visual working memory results in the speeding of perceptual alternation because of the role of inhibitory capacity in both working memory and bistable perception.

References

Arnell, K., Stokes,K., MacLean, M. & Gicante, C. (2010). Executive control processes of working memory predict attentional blink magnitude over and above storage capacity. *Psychological Research, 74*, 1-11.

Aron A., Robbins T. & Poldrack R. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Science, 8,* 170–177.

Barsalou, L., Simmons, W., Barbey, A. & Wison, C. (2003). Grounding conceptual knowledge in modality-specific systems*. Trends in Cognitive Science, 7*(2), 84-91.

Brascamp, J. W., Knapen, T. H., Kanai, R., Noest, A. J., VanEe, R. & Van den Berg, A. V. (2008). Multi-timescale perceptual history resolves visual ambiguity. *PLoS ONE, 3*(1): e1497.

Chen, X. & He, S. (2004). Local factors determine the stabilization of monocular ambiguous and binocular rivalry stimuli. *Current Biology*, 14, 1013-1017.

Conway, A., Cowan, N. & Bunting M. F. (2001). The cocktail party phenomenon revisited: The importance of working memory capacity. *Psychonomic Bulletin & Review*, *8*(2), 331-335.

Conway, A., Kane, M., Bunting, M., Hambrick, D., Wilhelm, O. & Engle, R. (2005). Working memory span tasks: a methodological review and user's guide. *Psychonomic Bulletin & Review*, 12(5), 769-786.

Cowan, N., Elliot, E. M., Saults, J. S., Morey, C. C., Mattox, S., Hismjatullina & Conway, A. R. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology, 51*, 42-100.

Engle, R., Laughlin, J., Tuholski, S. & Conway, A. (1999). Working memory, short term memory, and general fluid intelligence: a latent-variable approach. *Journal of Experimental Psychology*, 128(3), 309-331.

Greenlee, J., Oya, H., Kawasaki, H., Volkov, I., Severson, M., Howard, M. & Brugge, J. (2007). Functional connections within the human inferior frontal gyrus. *The Journal of Comparative Neurology, 503*, 550–559.

Harrison, S. A., & Tong, F. (2009). Decoding reveals the contents of visual working memory in early visual areas. *Nature*, 458, 632-635.

Hasher, L & Zacks, R. (1988). Working memory, comprehension, and aging: a review and new view. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory, 22, 193-225. New York: Academic Press.*

Healey, M., Zacks, R., Hasher, L. & Helder, E. (*in press*).

Kanai, R., Knapen T. H., van Ee, R. & Verstraten, F. A. (2007). Disruption of implicit perceptual memory by intervening neutral stimuli. *Vision Research, 47*, 2675-2683.

Leopold, D. A., Wilke, M., Maier, A. & Logothetis, N. K. (2002). Stable perception of visually ambiguous patterns. *Nature Publishing Group: Neuroscience, 5*(6), 605-609.

Luck, S. (2007). *Scholarpedia*, 2(6), 3328.

Meenan, J. & Miller, L. (1994). Perceptual flexibility after frontal or temporal lobectomy. *Neuropsychologia*, 32(9), 1145-1149.

Morey, C. & Cowan, N. (2005) When do visual memories conflict? The importance of working-memory load and retrieval. *Journal of Experimental Psychology*, 31(4), 703-713.

Peterson, M. A., Harvey, E. M. & Weidenbacher, H. J. (1991). Shape recognition contributions to figure-ground reversal: Which route counts? *Journal of Experimental Psychology: Human Perception and Performance, 17*(4), 1075-1089.

Peterson, M. A. & Gibson, B. S. (1994). Object recognition contributions to figure-ground organization: Operations on outlines and subjective contours. *Perception & Psychophysics, 56*(5), 551-564.

Peterson, M. A. & Skow, E. (2008). Inhibitory competition between shape properties in figure-ground perception. *Journal of Experimental Psychology: Human Perception and Performance*, 34(2), 251-267.

Reisberg, D. & O'Shaugnessy, M. (1984). Diverting subjects' concentration slows figural reversals. *Perception*, 13, 461-468.

Ricci, C. & Blundo, C. (1990). Perception of ambiguous figures after focal brain lesions. *Neuropsychologia*, 28(11), 1163-1173.

Rowe, G., Turcotte, J. & Hasher, L. (2008). Age differences in visuospatial working memory. *Psychology and Aging*, 23(1), 79-84.

Rypma, B., Berger, J. & D'Espositio, M. (2002). The influence of working memory demand and subject performance on prefrontal cortical activity. *Journal of Cognitive Neuroscience*, 14(5), 721-731.

Saults, J. & Cowan, N. (2007). A central capacity limit to the simultaneous storage of visual and auditory arrays in working memory. *Journal of Experimental Psychology*, 136(4), 663-684.

Sterzer, P. & Kleinschmidt, A. (2007) A neural basis for inference in perceptual ambiguity. *Proceedings of the National Academy of Sciences*, 104(1), 323-328.

Stevanovski, B. & Jolicoeur, P. (2007) Visual short-term memory: central capacity limitations in short-term consolidation. *Visual Cognition*, 15(5), 532-563.

Struber, D. & Stadler, M. (1999). Differences in top-down influences on the reversal rate of different categories of reversible figures. *Perception*, 28, 1185-1196.

Todd, J. J., Fougnie, D., & Marois, R. (2005). Visual short-term memory load suppresses temporo-parietal junction activity and induces inattentional blindness. *Psychological Science, 16,* 965-972.

Windmann, S., Werhmann, M., Calabrese, P. & Gunturkun, O. (2006). Role of the prefrontal cortex in attentional control over bistable vision. *Journal of Cognitive Neuroscience*, 18(3), 456-471.