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Perceptual Grouping by Closure in Visual Working Memory

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PERCEPTUAL GROUPING BY CLOSURE IN VISUAL WORKING MEMORY

by

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Abstract

Research on visual working memory (VWM) suggests a capacity limit of three to four objects (Luck & Vogel, 1997), but recent studies on the fidelity of VWM capacity for objects indicates that informational bandwidth, which can vary with factors like complexity and amenability to perceptual grouping, can interact with this capacity (Brady, Konkle & Alvarez, 2011). For example, individual features can be grouped into objects for an added benefit in VWM capacity (Xu, 2002). Along these lines, the Gestalt principles of proximity and connectedness have been shown to benefit VWM, although they do not influence capacity equally (Xu 2006; Woodman, Vecera & Luck, 2003). Closure, which has not been investigated for its influence in VWM capacity, is similar to connectedness and proximity as it promotes the perception of a coherent object without physical connections. In the current experiment, we evaluated whether closure produces similar or greater VWM capacity advantages compared to proximity by having participants engage in a change detection task. Four L-shaped features were grouped in tilted clusters to either form an object (closure condition) or not (no-object condition), with a set size of two (8 L features), four (16 L features), or six clusters (24 L features). Following a brief mask (1000 ms), the orientation of one cluster was changed (tilted 25 or -25 degrees) on half the trials. Our results indicate that there was no difference in accuracy or reaction time for the perceptual grouping conditions of closure/no-object, although we did find a main effect for set size and change conditions. Overall, it seems that grouping by closure provides no further advantages to VWM capacity than proximity; however, more experiments need to be conducted to solidify the findings of the current experiment.

Acknowledgments

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Abbreviations

1. Visual Working Memory (VWM)

2. Reaction Time (RT)

Introduction

Working memory has been of great interest to researchers due to its importance to perception and its use in everyday tasks. For instance, greater working memory capacity has been correlated with increased cognitive function (Carpenter, Just, & Shell, 1990; Gevins & Smith, 2000), fluid intelligence (Fukuda, Vogel, Mayr, & Awh, 2010), and has been shown to be a notable indicator of academic achievement (Alloway & Alloway, 2010). Baddeley and Hitch (1974) proposed the now classical model for working memory that differentiates loops depending on the type of information remembered. Verbal information is said to be stored in the phonological loop while visual and spatial information is kept in the visuospatial sketchpad. This model inspired research designed to test the capacity and limitations of the different loops within each type of working memory. Of particular interest, we aimed to evaluate the capacity of visual working memory (VWM) in the visuospatial sketchpad.

In regards to VWM, a change detection paradigm implemented with no letters or numbers that could be rehearsed and remembered through the phonological loop is the most widely used to evaluate VWM capacity. Early research using the change detection paradigm suggested that VWM was purely object-based; for example, Luck and Vogel (1997) determined that three to four simple objects could be fully retained in VWM. In a follow-up study, they accounted for input from other perceptual processes and errors made in the decision making process and found the same results when adding up to four features to each object, denoting that VWM is grounded in integrated object-based representations and not in the number of features in the objects (Vogel, Woodman, & Luck 2001).

Nonetheless, some recent studies that use a wider array of paradigms indicate that VWM capacity is not just based on objects, as feature display characteristics have been shown to influence VWM processes. Factors beyond object representation such as complexity, perceptual grouping, ensemble statistics, and top-down influences can affect how much information is stored in VWM (see Brady, Konkle & Alvarez, 2011 for a review). This led researchers to suggest that VWM capacity is not just object-based, but also contingent on the way visual information is presented. For example, adding features and complexity can decrease the number of objects retained (Xu 2002; Alvarez & Cavanagh, 2004) and the fidelity with which they are remembered (Zhang & Luck, 2008). There may also be a limit not just on the number of features within an object, but on the number of features in the overall display (Wheeler & Triesman, 2002).

Gestalt grouping principles allow people to perceive the world in a simpler way by creating meaningful groupings and connections between information. It is possible that Gestalt grouping could occur pre-attentively in VWM, leading to an easier and more unified image of the information presented. Previous research examined the effects to VWM capacity of having multiple features within an object; however, another approach is by using Gestalt principles to group independent objects and create the perception of one object with multiple parts. This could lead to more information being remembered in VWM, as objects are grouped and encoded together. Although only the principles of proximity, connectedness and similarity have been studied, Gestalt grouping does influence VWM. Woodman, Vecera, and Luck (2003) found that grouping objects by proximity benefits VWM, but when pitted against connectedness, the benefit was present for only connectedness. Connecting two objects increased the amount of information

held in visual working memory when it was overloaded (i.e., when more than 4 objects are in the display), suggesting that participants were encoding the objects as features of an object instead of as distinct objects. Similarly, there is an advantage in grouping by similarity, but spatial proximity was necessary for benefits to be seen (Peterson & Berryhill, 2013). Jiang, Chung, and Olson (2004) also suggest that connectedness can induce grouping automatically, even if it is not beneficial to the task. They found that connecting task irrelevant lines to dots obstruct a change detection task if the elongated axes of the lines change orientation, even when participants were prompted to ignore the lines. These findings suggest that gestalt principles can induce grouping automatically and affect how observers perceive scenes, and not all principles will elicit an equivalent object-based benefit in change detection performance.

The gestalt benefits seen in these studies can be explained by the commonly observed object benefit in VWM change detection paradigms. The object benefit can increase the amount of information held in VWM because participants are able to group distinct objects and features that are connected into one. There is a potential to hold more information from a display in VWM, as it is easier to encode features if they are grouped in objects. For instance, features of a display are best retained if they are in the same location in the object, second best if they are spatially segregated in the same object, and worse if they are not part of an object at all (Xu, 2002). Since many studies have features that are grouped by proximity and connected, there could be three mechanisms driving the object benefit: spatial proximity, connectedness or a hybrid account (Xu, 2006). Xu (2006) tested the effectiveness of connectedness and spatial proximity of features by analyzing the trade-off in monitoring one versus two feature changes in objects. In experiment one, she tested the effect of connectedness by having four displays with:

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(A) two objects connected, (B) two objects with a horizontal bar connecting them, (C) two objects slightly separated and (D) a control, two objects completely separated (see Figure 1). She found a significant cost in the control, but no effects for the other displays. Upon replication of the displays with two objects connected and two objects slightly separated (display A and C respectively), she found a significant cost of monitoring two features when they were slightly separated, suggesting that connection (display A) is best for the object benefit. A subsequent experiment tested proximity by keeping the object parts connected, but increasing the distance between the features that needed to be monitored, and found similar results. This led to the conclusion that both connectedness and proximity are important in the object-integrated benefit seen in VWM.

Previous research found a difference between connectedness and proximity for visual working memory capacity, suggesting that grouping principles do not work equally within VWM. As such, closure is somewhere in between connectedness and proximity, as this principle combines features into an object based on proximity, but the perception of closure arises. In this experiment, we tested the Gestalt principle of closure to determine if it affects VWM. We adapted stimuli from Kimchi, Yeshurun, and Cohen-Savransky (2007), who manipulated four disconnected segments to appear as an object (see Figure 2), and found that it attracts attention automatically, just for being an object. Using this type of stimuli, we organized four L-shaped features to either form an object (closure), or have random orientations that appeared near to each other (no-object). We used a change detection task to test for an effect of closure while controlling for proximity to determine if the perception of a closed object results in a significant advantage in VWM relative to unclosed features. Xu (2006) found that having two objects

slightly separated was less advantageous than having them connected, however, the two

separated objects were distinct from each other and it is possible that these were not encoded as

one object. We believe that having the features create that object representation will be more

beneficial to VWM capacity than just having them in close proximity.

Method

Participants

Sixteen undergraduate students (8 female, *M* age = 20.47, *SD* = 7.36) from the University of Central Florida were recruited and given class credit for one hour of participation in the study. Participants were screened for normal or corrected-to-normal visual acuity (Snellen chart) and normal color vision (Ishihara Plates).

Design and Stimuli

The experiment consisted of a change detection task with a within subjects repeated measures design of 3 (set size conditions = 2, 4, and 6) x 2 (perceptual grouping conditions = closure, no-object) x 2 (change conditions = change, no change). Each condition occurred at the same rate, with the frequency of each balanced per experimental block. The task was run on a Dell computer with a 1280 by 1024 pixel resolution monitor with a refresh rate of 100 hz and the distance from the monitor was controlled with the use of a chin rest.

To create the 2, 4, or 6 clusters for the closure/no-object condition, each of the four features (L-shapes) was created in Photoshop. Each feature had $1.8°$ x $1.8°$ of visual angle and the entire display had $12°$ of eccentricity. The four L-shapes were rotated 0, 90, 180, and 270 degrees in the closure condition to create the illusion of a diamond, and rotated randomly in another 255 potential layouts for the no-object condition (see Figure 3). The initial display for both the closure and no-object conditions had the clusters randomly oriented upright or 25° in either direction. The second display either had no change, or an orientation tilt of one of the clusters by 25° from the original display orientation (see Figure 3).

Procedure

Participants' gave informed consent and were prescreened for visual function. They were then taken to the computer, told to place their chin on the chin rest for the entire experiment, and prompted to read the instructions on the screen. The instructions informed participants to look for a change between two displays; if a change occurred they were instructed to press 1, and if a change did not occur they were to press 0. Participants were told that they would receive feedback after every trial and that the task was going to be difficult, but to try to respond as accurately as possible. The change consisted of a 25-degree tilt in the orientation of the features in one of the 2, 4, or 6 clusters.

The experiment took an hour to complete and included forty practice trials and three experimental blocks of 120 trials each (400 trials total), with breaks in between blocks. This allowed for thirty trials for each cell, with set size, change, and perceptual grouping conditions intermixed randomly within blocks, though equally controlled between blocks.

Each trial began with a fixation dot in the center of the screen (500 ms), followed by the initial display of an array of 8, 16 or 24 features (set size 2, 4, and 6) that lasted 250ms. A white screen, 1,000 ms mask, between change array presentations followed, with the test display presented last for 2,000 ms or until a response was selected (see figure 4). These timing parameters are consistent with other change detection tasks testing the capacity of VWM, as well as the 50 ms time of consolidation per object that was measured by Vogel, Woodman, & Luck (2006).

Results

Two participant's data were removed from analysis; one due to them not following the protocol, and another was removed due to reaction time (RT) data being above 2 standard deviations from the mean.

Accuracy for all set sizes was less than expected but still appear to be above chance (set size 2 *M = 0.74, SD = .12*; set size 4 *M = 0.60, SD = 0.06*; set size 6 *M = 0.57, SD = 0.06*). We analyzed the accuracy data using a repeated measures ANOVA with set size, change, and perceptual grouping as within-subjects factors. There was a main effect for set size ($F(2, 26) = 33.98$, $p = 0.00$, *partial* $\eta^2 = 0.72$) and change ($F(1, 13) = 27.91$, $p = 0.00$, *partial* $\eta^2 = 0.68$), but no main effect for the perceptual grouping condition $F(1, 13) = 1.28$, $p = .278$, *partial* $\eta^2 = 0.09$). An interaction between change and set size ($F(2, 26) = 11.12$, $p < 0.00$, *partial* $\eta^2 = 0.46$) (see graph 1) occurred; as set size increased, the decrease in accuracy was much greater for the change condition. The interaction for change x perceptual grouping ($F(1, 13) = 3.23$, $p = 0.10$, *partial* $\eta^2 = 0.20$) and set size x perceptual grouping interactions were not significant ($F(2, 26) = 3.55$, $p = 0.36$, *partial* $\eta^2 = 0.077$). Additionally, the three way interaction between set size, change and perceptual grouping was not significant ($F(2, 26) = 2.81$, $p = 0.08$, *partial* $\eta^2 = 0.18$). RT data was also collected, however, we found no significant results in any of the analyses (all *p* > .05).

Discussion

We predicted that closure would produce the perception of an object signal more effectively than proximity. Since VWM capacity has been tested with an emphasis on the memory capacity for objects (see Brady, Konkle & Alvarez, 2011 for a review), we believed closure would be more beneficial due to having a stronger signal as an object. However, we found no difference between these two Gestalt principles in a change detection task in regards to accuracy or RT.

Gestalt principles are believed to influence how people perceptually group the components of a display. Since these principles can help create the perception of an object (e.g. connectedness and closure), or a more cohesive display (e.g. similarity and continuity), researchers have applied them in change detection tasks to determine if they have any impact on VWM capacity. Some studies found a general benefit in VWM capacity when they used the principles of connectedness, proximity, or similarity to group the features of a display, although their benefits were not equivalent (Woodman, Vecera & Luck, 2003; Peterson & Berryhill, 2013). This implies that Gestalt grouping principles have a significant effect on what is remembered in VWM. The goal of this experiment was to determine if closure produced any effects on VWM capacity like those seen with other Gestalt principles.

As expected, accuracy for change detection decreased with increasing set sizes. However, based on the Luck and Vogel (1997) study that found a capacity of 3 to 4 objects, as well as other change detection experiments on VWM capacity, we expected accuracy for change detection to be nearly at ceiling for the smaller set sizes. Woodman, Vecera and Luck (2003) found that Gestalt principles benefitted VWM when the system was overloaded, with the lowest

accuracy being 70% for set size 6. Our findings were not as expected, with set size 2 accuracy being 74%. This indicates that our experimental task may have been too difficult for participants, and they may have been overloaded in both the no-object and closure conditions. This could be due to several factors. It could be that each feature of the object was taken as a distinct object in both conditions, thereby leading to a set size of 8, 16, and 24, instead of 2, 4, and 6 objects. It is also possible that the stimuli did not induce a sense of closure as intended. However, to further support this claim, more studies need to be conducted with the features of the object being closer together. Since accuracy was similar in both conditions, there is the possibility that the clusters of features were too large and spread out across the display for participants to be able to track the entire display and detect a change. This could better explain how we still found effects, but with low overall accuracy. Changes to future experiments to control for these factors could lead to different results.

Most importantly, our main hypothesis was not supported. We found no significant difference between the closure and no-object conditions, and we found no significant interactions of the perceptual grouping conditions with the set size and change conditions. Although we expected closure to be beneficial when VWM was overloaded, we found there to be no significant interaction between set size and perceptual grouping.

Jiang, Chung, and Olson (2004) found an inability to inhibit perceptually connecting features despite its disadvantage to the task. Our lack of significant results regarding the grouping conditions could arise from an unanticipated effect from the closure condition. Instead of helping them with the task, the grouping of features could have decreased the noise in the display and led to the task actually being harder compared to when the objects in the display

were more salient. Additionally, out of the 255 potential orientations for the no-object clusters, a few led to the image of a very salient socially negative symbol, and some led the accidental invocation of other Gestalt principles such as continuity and similarity. Further experiments with more obvious changes in orientation for the change condition (e.g., increasing the orientation change by 20 degrees), more control of the features in the no-object condition, and an added condition of connectedness could help clarify the results.

Lastly, it is possible that closure does not create the perception of a closed object and induce the object benefit prevalent in VWM. Both proximity and connectedness are important for the object benefits seen in VWM, and having two features spatially segregated induces a cost for monitoring two features of an object (Xu, 2006). Our findings suggest that the object benefit does not arise when the features are grouped to induce a sense of closure. It is possible that the features of an object rely on actual physical connections between the objects, and features of an object need to be physically connected and not just perceptually connected to induce a VWM capacity benefit. However, since this is the first experiment looking at the effects of closure on VWM, further studies need to be conducted to solidify these findings.

Overall, our findings are consistent with other studies on VWM capacity regarding change detection and set size, but they do not support our hypothesis that closure would be beneficial to VWM capacity. It is also somewhat surprising that we found no significant RT results. However, we did not stress participants to respond quickly, we only stressed accuracy. Further experiments with more particular conditions, a more significant change, and better-controlled factors, such as features and clusters that are smaller and closer together to make the

principle more salient, could help determine whether our results are definitive, or if closure could actually affect VWM capacity.

Appendix A: Figures
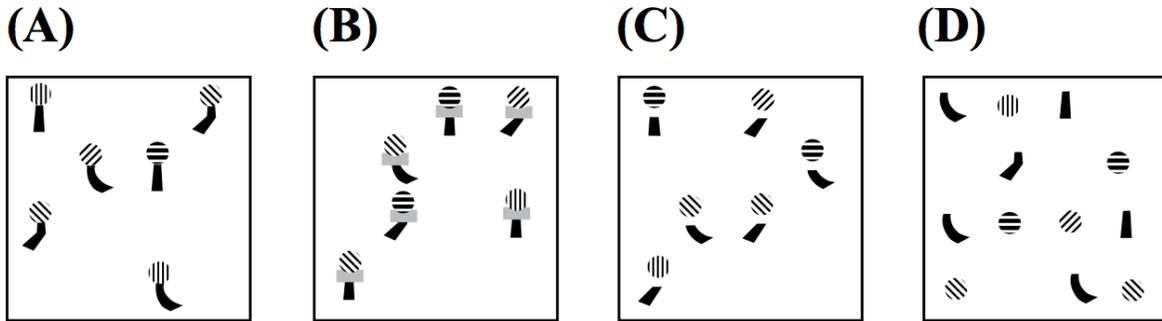
Figure 1: Stimuli from Xu (2006)

The two features that needed to be maintained were color and orientation. The different textures represent different colors in the display. (A.) Objects were connected (B.) Objects separated by horizontal bar (C.) Objects spatially segregated (D.) objects entirely separated.
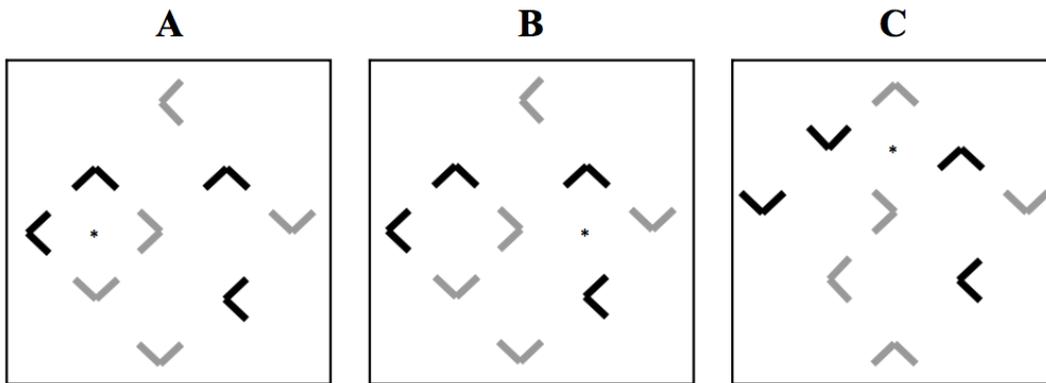

Figure 2: Stimuli from Kimchi, Yeshurun, and Cohen-Savransky (2007).

Stimuli from three conditions. (A.) Inside object condition (B.) Outside object condition (C.) No object condition.
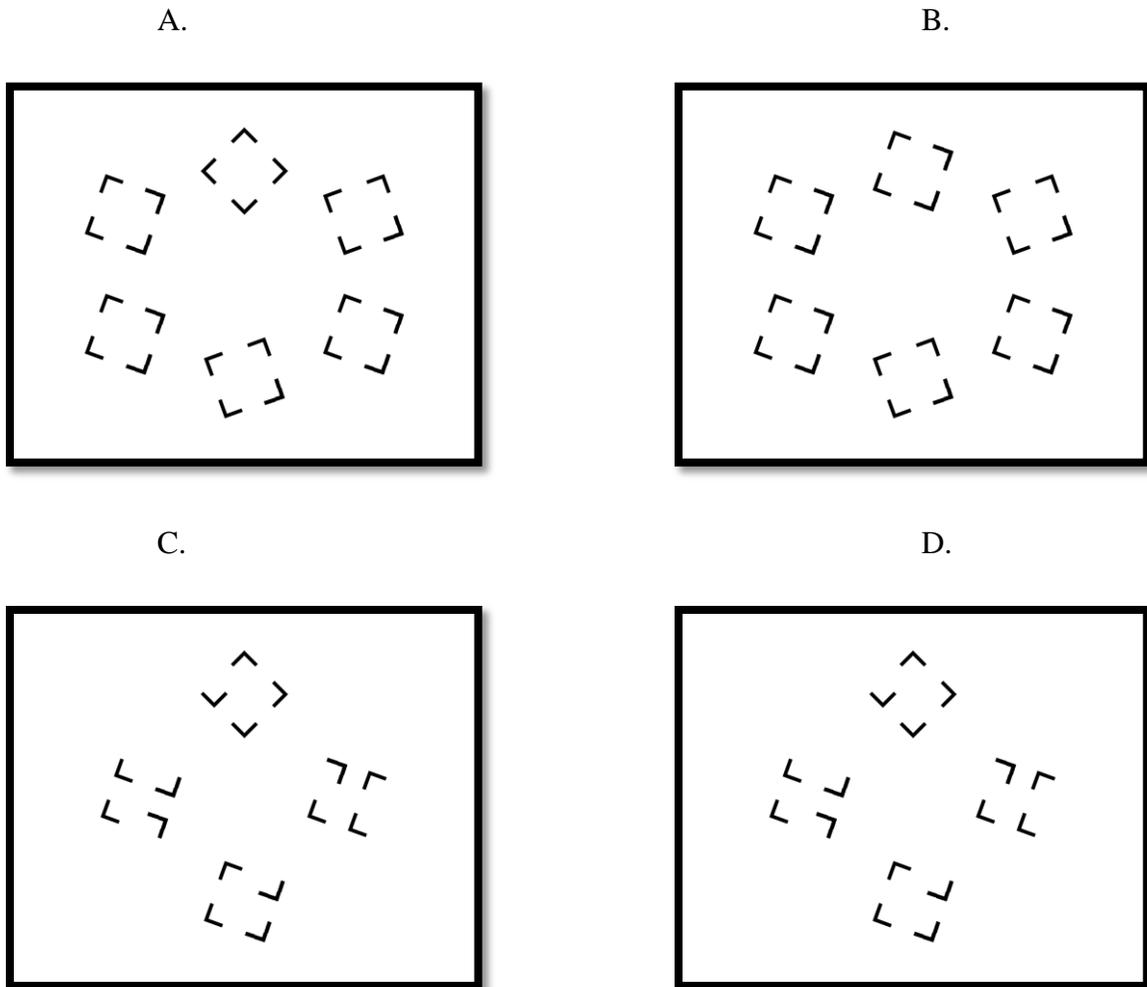
Figure 3: Sample Stimuli.

Mask between Initial and Second display of 1000ms. (A.) Initial display, set size 6, closure condition (top cluster is upright) (B.) Second display, change in 25° of one object (top cluster) (C.) Initial Display, set size 4, no-object condition (top cluster is upright) (D.) Second display, no change.
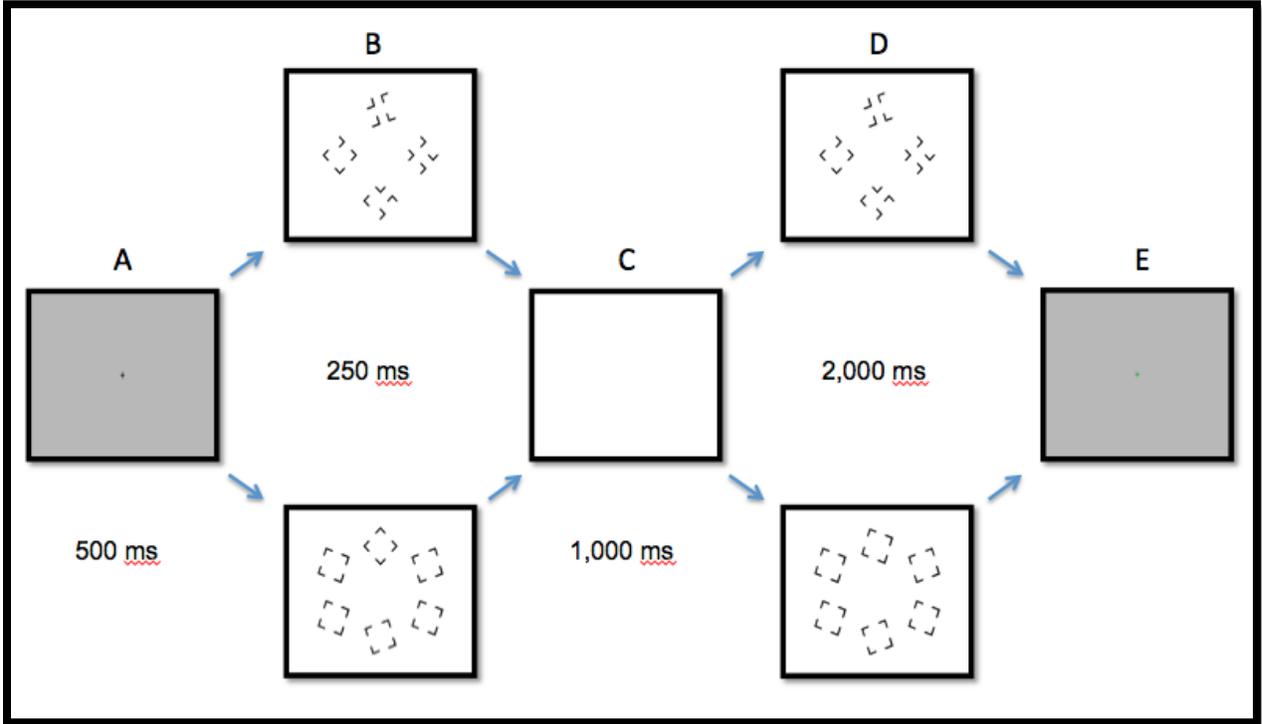
Figure 4: Change Detection Task

(A) Fixation screen followed by the (B) initial display. (C) White mask between displays. (D) Second display where the change could occur. (E) Feedback screen, green cross indicates correct response.
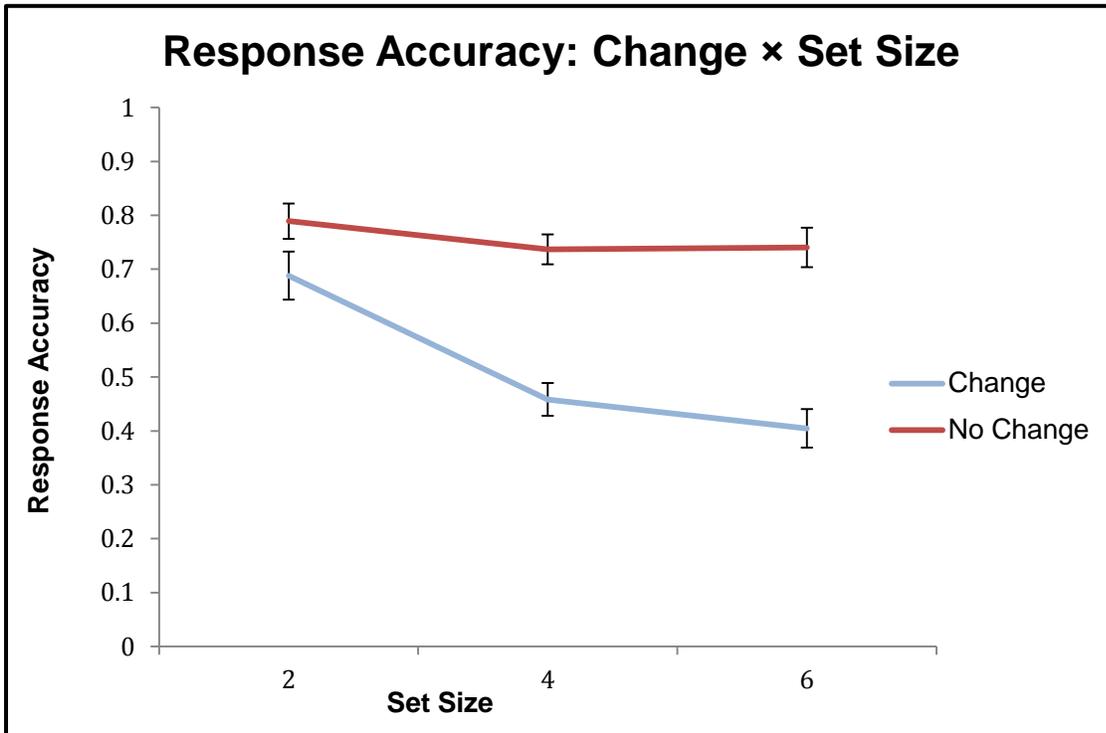
Figure 5: Response Accuracy. Interaction between change and set size

Appendix B: IRB Approval Letter

University of Central Florida Institutional Review Board Office of Research & Commercialization   12201 Research Parkway, Suite 501   Orlando, Florida 32826-3246

Telephone: 407-823-2901 or 407-882-2276 www.research.ucf.edu/compliance/irb.html

Approval of Human Research

UCF Institutional Review Board #1 FWA00000351, IRB00001138

To: Date: Dear Researcher: On 10/23/2015, the IRB approved the following human participant research until 10/22/2016 inclusive:

From:

Mark Neider and Co-PIs: Joanna E. Lewis, Sofia Neira October 23, 2015

Type of Review: Project Title: Investigator: IRB Number: Funding Agency: Grant Title:

Research ID:

UCF Initial Review Submission Form   Perceptual Grouping in Visual Working Memory Mark Neider   SBE-15-11698

n/a

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form cannot be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 10/22/2016,   approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be

accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual. On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 10/23/2015 09:18:07 AM EDT IRB Manager

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