EFFECTS OF SPATIAL CONFIGURATIONS ON THE RESOLUTION OF SPATIAL REPRESENTATIONS IN WORKING MEMORY

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Effects of Spatial Configurations on the Resolution of Spatial Representations in Working Memory

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Thesis Abstract

AysuMutlutürk, "Effects of Spatial Configurations on the Resolution of Spatial Representations in Working Memory"

Recent research has suggested that people represent spatial information configurally, and preservation of configural cues at retrieval helps memory for spatial locations (Jiang, Olson, & Chun, 2000; Simons, 1996). The aim of the present study is to specifically investigate the effects of configural cues on the resolution of spatial representations of objects. In an open-ended task, participants first studied a set of colored objects (Experiment 1 & 2A: 3 and 5 locations; Experiment 2B: 3 and 7 locations). Then in the test display, they were asked to determine the original location of a target object whose color was auditorially cued. The difference between the reported location and the original location was taken as a measure of spatial resolution. We manipulated available configural cues at retrieval. In all experiments, in one third of the trials non-target objects were presented in their original locations (same configuration condition) and in another third of the trials, objects were presented in random positions (different condition). In Experiment 1, in the remaining trials, the non-target objects were not presented at all (no configuration); in Experiment 2A & 2B, non-target objects swapped their colors (swap condition) resulting in the preservation of the spatial configural structure albeit a change in the test display. In three experiments, we consistently observed that the precision of reports was impaired by the configural disruption at retrieval; the effect of global configural disruption was significantly more than that of relative location change. We argue that participants may be using available cues in conjunction with the represented summary statistics of the original display in the precise computation of an individual location.

TezÖzeti

AysuMutlutürk,

“BütünselTemsillerinBireyselYerTemsillerininÇözünürlüğüÜzerindeEtkisi”

Literatürde bütünsel yapı (konfigürasyon) değiştirildiğinde mekansal bellek performansının düştüğünü gösteren çalışmalar bulunmaktadır (örn.;Jiang, Olson ve Chun, 2000; Boduroglu ve Shah, 2009). Bu çalışmanın amacı, bilgiyi geri getirme sürecindeki bir bütünsel değişikliğin, bireysel yer temsillerinin çözünürlüğü üzerindeki etkisini incelemektir. Deneylerde yer hatırlama görevi kullanılmıştır. Bu görevde katılımcılara bir grup renkli kare (Deney 1: 3 nesne, Deney 2 ve 3: 3 ve 5 nesne) gösterilmektedir. Ardından ekran yenilenir (test ekranı) ve katılımcılardan nesnelerden birinin en başta nerede gösterildiğinin fare aracılığıyla belirtilmesi istenir. Her bir denemede katılımcının verdiği yanıt ile nesnenin asıl yeri arasındaki mesafe hesaplanarak katılımcının hata miktarı ölçülür. Bu ölçüm, nesnenin yerinin ne kadar doğru temsil edildiğini göstermektedir. Denemelerin üçte birinde, test ekranında hedef nesne dışındaki diğer nesneler, ilk ekrandaki yerlerinde, diğer koşulda ise, farklı yerlerde gösterilmiştir. Son koşulda, test ekranında hiçbir nesne gösterilmemiştir.İkinci deneyde, test ekranında hiçbir nesnenin gösterilmediği koşul yerine, nesnelerin kendi aralarında renk değiştirdikleri ancak bütünsel yapının değişmediği, göreli konum değişikliği koşulu kullanılmıştır. Deneylerde elde edilen bulgular, belirli bir nesnenin yer bilgisini bellekten geri getirirken, bütünsel bir değişiklik olması halinde hata miktarının arttığını, yani çözünürlüğün azaldığını göstermektedir. Bu bulgular, bir nesnenin yer bilgisinin doğru olarak temsil edilmesi için gerekli hesaplama öğelerini (örn.; ağırlık merkezi ve diğer nesnelerin göreli konumları) sağlayabilecek grup temsilleri (ensemblerepresentations) bağlamında tartışılmaktadır.

CONTENTS

CHAPTER 1

INTRODUCTION

The representation ofvisuospatial information is necessary to act in space. In order to interact with space, one needs to keep track of the locations of objects.Such operationsare supported by visuospatial working memory (VSWM). VSWM is a limited capacity system that is responsible for maintaining, manipulating and reinterpreting information to support perception, long-term memory, and action (Baddeley, 1992).

It is widely suggested that VSWM can be divided into separate mechanisms for the storage of visual and spatial information (Logie, 1995). Interference studies (e.g. Hyun & Luck, 2007; Logie&Marchetti, 1991; Postle, D'esposito, &Corkin, 2005), selective object or spatial deficits in neuropsychological cases (e.g., Farah, Hammond David, Katherine, &Calvanio, 1988), as well as single-cell recordings highlighting different neural basis for spatial and visual storage of information (e.g., Monosov, Sheinberg, & Thompson, 2010; Rao, Rainer, & Miller, 1997), all support this dissociation.This has led to the independent investigations of representations in visual and spatial working memory.

Despite the abundance of findings that contribute to the investigation of encoding and maintaining visual objects (e.g., Luck & Vogel, 1997; Vogel, Woodman, & Luck, 2001) and integration of visual objects' features in space (e.g., Wheeler &Treisman, 2002; Treisman& Zhang, 2006), there are a few studies directly addressing the nature of spatial representations in working memory. The present study aims to explore the representation of spatial information in working memory. For that purpose, in the present study, we specifically focus on the relationship between configural representations of spatial information and the resolution of spatial representations.

Types of Spatial Representations

The main focus of the presentthesis is how multiple locations are represented in working memory, and whether there is an effect of spatial configurations on the resolution of location representations in working memory. In this regard, one important point is to what degree locations are coded independently or as a part of a configuration. There are two logical possibilities regarding how spatial information is maintained in memory: 1) Independent-absoluteand 2)configuration-based representations. In the case of independent-absoluterepresentations, the location of the object would be represented on the basis of its coordinates as it is in the earliest phases of spatial coding (e.g., retinotopic coding). On the other hand, in the configuration-based representations, location of an object would be represented in a relational form extracted from global layout, such as “X is next to Y”, “X is below Y”, and so on (Kosslyn et al., 1989).

In order to investigate the role of different mechanisms in spatial representations, Jiang and Wagner (2004) focused on whether individual locations or spatial configurations were learned in a contextual cuing paradigm. In a typical spatial contextual cueing paradigm, participants are asked to search for a target item among distractors. Half of the spatial contexts are repeated in the learning session. Thus, repeated context leads to a decrease in search time for the target item. Their study demonstrated that representations of spatial locations are based on both types of spatial information (individual target-distractor pairings and global configuration information) while looking for a target among distractors. Jiang and Wagner (2004) concluded that when one does not have a bird’s eye view of the overall spatial layout, one needs to search the visual environment serially, but the global configuration is also informative since it provides a frame of reference toreduce the amount of information from many locations to one global layout.

To sum up, different kinds of mechanisms of spatial representations are not mutually exclusive but they are highly interrelated. That is, other elements in a scene may be important sources of information, and this information about configuration may guide representations of individual locations. Then, how humans build these representations, and how configurationsimpact the detection and representation of the locations of each individual object should be further investigated.

Representation of Spatial Configurations

A line of research investigating representation of spatial configurations has focused on the effects of spatial configurations on VSWM performance.These studies have employed the change detection paradigm.In this paradigm,participants are initially presented with an array of objects in a study display. After a short interval during which participants maintain the representation of the display, they are shown the probe display that is either identical to or different from the study display. Participants are instructed to judge whether there is a difference between the study and test displays.

Using the change detection paradigm, Simons (1996) demonstrated that there was a fundamental difference between representations of spatial configurations and object properties. In the study, visual change detection performance was compared across three conditions: an old objectwas replaced with a new one, locations of two objectswere switched, or overall configuration of the array was changed. The results demonstrated that the performance for configuration changes was almost excellent compared to the performance for changes of object properties.

In another study, Jiang, Olson, and Chun (2000) suggested that visual information in memory was organized on the basis ofthe spatial configurations formed by the visual elements. Again, using change detection paradigm, they showed that performance for detecting color or location changes was impaired by disruption of the original configuration, or absence of configural cues in a display.Furthermore, Boduroglu and Shah (2009) examined the effects of task-irrelevant configuration changes on color change detection performance. They found that configuration changes biased participants to report a color change even when there was not one, suggesting that spatial configuration information is effortlessly encoded along with visual information.

These studies demonstrate that visual working memory is organized in a configural manner and that spatial configural cues help identify visual changes.However, no studies to date have provided direct information on whether spatial configuration information helps the memory for spatial locations of individual objects.

Jiang et al. (2000) found that when configuration in the probe display was consistent with the initial display, memoryfor location was much better than memory for location in inconsistent configuration at all set sizes. For instance, in set size 12, in the consistent configuration condition, spatial change detection accuracy was higher (~75%) than accuracy in the inconsistent configuration (~55%), and it was even higher compared to the accuracy in the set size three (~70%). This difference in memory performance that is highly influenced by the configural manipulation in addition to set size manipulation is striking. The higher accuracy in the consistent configuration condition compared to that in the inconsistent configuration conditionmaybe due to more than set size, orthe number of locations represented in working memory. In this regard, one possibility can be that higher performance in the consistent configurationcondition is a result of an increased resolution of spatial information about individual objects regardless of the set size.

The ensemble representations literature, which looks at how people use statistical averaging processes to extract gist can also offer insights into our understanding of configurations and their relationships with the memory for individual locations. Recent research has proposed that representation of a display may be encoded depending on statistical properties of the spatial layout rather than individual objects that compose this layout(Ariely, 2001; Alvarez &Oliva, 2008; Oliva&Torralba, 2006; 2007). These studies are important for the current research for two reasons: Firstly, the studies on statistical summary of a display highlight the role of global spatial representation in object recognition, and inevitably in object location. And more importantly, this line of research provides an explanatory mechanism of how spatial configuration information may be deduced from scenes.Finally, they may provide an additional perspective to enhance spatial cognition as representing multiple locations.

In a seminal study, Ariely (2001) found that participants were not good at judging the size of individual items in a display but they were able to make highly accurate judgments for the average size of the array. Similar conclusions were drawn based on other paradigms For instance, Alvarez and Oliva (2008) investigated whether information outside focused attention might be represented at an abstract level without specific local details. They used a multiple object tracking task in which participants tracked a set of target items moving continuously while ignoring another set of moving items (distractors) in the display. At a random moment, movement stopped, and one or some of the items disappeared. Participants either reported the location of an individual missing item or the centroid of four missing items (a group of targets or distractors). To report the location of an individual missing item, they clicked directly on the location of the item. To report the centroid of four missing objects, they clicked on the centroid of group. Results showed that participants accurately judged the centroid of distractors as well as the centroid of targets.Based on these results, Alvarez and Oliva (2008) argued that the robust representation of distractor centroid despite the lack of local details is due to representation of spatial layout on the basis of statistical summary of the display.

These studies from different lines of research present evidence for the organization of spatial representations in a configural manner. As previously outlined studies suggest, the mechanisms representing the individual location of an object and configuration are not mutually exclusive but they serve together (e.g., Jiang & Wagner, 2004). It is also argued that configural information constrains the analysis of individual features in the scene (Oliva&Torralba, 2006; 2007). If this is the case, it is reasonable to assume that an observer can extract the original location of a particular object with higher precision if the representation of overall configuration in the scene preserved. Therefore,it is possible that disrupting configuration-based representationsin scenes mightinfluence performance on spatial working memory tasks.

No research to date has directly investigated the effects of spatial configurations on the resolution of location representations in working memory. The present study aims at examiningthis question. Before outlining the experiments in the present study, addressing the issue of resolution in VSWM would be informative.

Resolution in Visuospatial Working Memory

In order to investigate the resolution of spatial representations and to determine the extent to which configurations help memory for individual locations, we should first address the relationship between capacity and resolution in VSWM. Recent studies have focused on measuring the capacity and resolution of visual working memory (VWM) in terms of representation of an object and its features.

In an influential study, Luck and Vogel (1997) explored visual WM capacity using a change detection paradigm. The results showed that visual WM capacity was fixed around 3-4 items. Even though subsequent research verified that visual WM has a limited capacity (e.g., Vogel, Woodman, & Luck, 2001; Wheeler &Treisman, 2002; Xu& Chun, 2006), capacity estimates of visual WM showed a remarkable variability. For instance, Todd and Marois (2005) reported individual differences invisual WM capacity, ranging approximately from 2 to 6 objects. Alvarez and Cavanagh (2004)demonstrated that there was an inverse relationship between memory capacity and complexity of items, suggesting thatresolution of objects representations in visual WM might influence capacity estimates.In an fMRI study, Xu and Chun (2006) provided evidence for the relationship between capacity and object complexity. Behavioral results indicated that capacity for simple and complex objects differed, about 4 and 2 respectively. They also presented neural evidence showing that activity in the inferior intraparietal sulcus (IPS) was linked to amemory for a fixed number of objects (up to 4) but activations in lateral occipital complex and superior IPS were varied by object complexity.

Awh, Barton, and Vogel (2007) presented evidence against the view that capacity and resolution may be dependent.They suggested that visual WM maintained a fixed number of items regardless of the complexity of those items, and difficulties in detecting changes of complex objects could be accounted for comparison errors. In the experiment, they replaced the target object with an object from either a different category (e.g., cube - Chinese character) or the same category (e.g., cube - cube). The results showed that as the sample-test similarity increased, memory performance decreased. Furthermore, they found that individual differences in the capacity estimates were independent of individual differences in the resolution of representations. Therefore, they introducedanother question arguing that number and resolution could be distinct facets of visual WM, and change detection tasks with simple and complex objects might measure the different aspects of visual WM.

These controversial results were addressed by Zhang and Luck (2008) employing a method that independently measured the capacity and resolution for objects in visual WM. They asked participants to report the color of the target item in the sample display by clicking on a color wheel in the probe display. The distance between the reported and the original color values indicated how well the color was represented. Their results supported that both capacity and resolution were fixed.

Bays and Husain (2008) criticized the assumptions of Zhang and Luck (2008) by arguing that visual WM resources were distributed among all itemsin an array and the distribution of resources could be predicted by a power law.In another study, Bays, Catalao, and Husain (2009) indicated that errors in memory for location in the Color Wheel Task might result in mistakenly reporting colors of non-probed items instead of the color of the probed item. They suggested that these errors in memory for location were actually interpreted as random guesses for colors in the study of Zhang and Luck (2008).

In the present study, we mainly focus on the resolution of spatial representations. Resolution of representations basically refers to the fidelity of representations[1], and in the *visual* WM literature, it has been operationalized in two ways: 1) Comparison of recognition errors in a change detection task that requires making fine or coarse discriminations between complex objects (Awh et al., 2007); or 2) Precision of responses measured by open-ended tasks requiring retrieval of exact features of studied objects (e.g., Bays & Husain, 2008; Bays et al., 2009; Zhang & Luck, 2008; Zhang & Luck, 2011). Given that the former approach provides a more indirect measure, in the current experiments, we chose to measure spatial resolution by using an open-ended task.

The Color Wheel Task that enables to independently measurethe capacity and resolution of visual WMdoes not refer to resolution in spatial WM. In a more recent study, Boduroglu, Shah, and Ng (2010) addressed this issue. They designed the Spatial Recall Task in which the distance between the reported location of the target object and its original location indicated how well the spatial location was represented. Their results showed that despite the presence of relationship between resolution and capacity, there was no relationship between visual and spatial resolution in working memory. They also demonstrated that both visual and spatial representation resolutions are reliable; that is, individuals do not show a lot of variation in this across hundreds of trials. These findings point out the need to independently explore the resolution of spatial representations in working memory.

Aim of the Present Study

Using change detection paradigm, previous studies highlight that the presence of consistent configural information at retrieval provides an advantage for the

[1] In the field of engineering and statistics, *accuracy* refers to how close a measured value is to its actual value. *Precision* refers to how close the measured values are to each other, and it is analogous to *reliability*. In the VWM literature, resolution is analogous to the concept of accuracy (LeBlanc, 2004).

representation of individual locations in working memory tasks (Jiang et al., 2000). However, it is not clear what type of advantage is provided by spatial configuration. The current study questions whether the advantage provided by configuration is due to an increase in resolution for individual locations. In order to investigate the effects of configuration on the resolution of spatial representations, we conducted three experiments. In these experiments, instead of the change detection paradigm, we employed a modified version of the Spatial Recall Task (Boduroglu et al., 2010). In the Spatial Recall Task, participants study a set of randomly placed colored objects. Then, one of the objects is presented at the center and participants are asked to drag this target object to its original position.

Since we plan to investigate the interaction between configuration-based and absolute location representations, in the current experiments, we manipulated the nature of configuration information presented to the participants at the retrieval stage. In our task, the target was not presented in the probe display in any of the conditions. Participants were presented with a study display including multiple colored objects randomly positioned. In the probe display, participants heard the color name of the target object over the headphones, and they are asked to click on the original position of the target object. The target object appeared at the position where the mouse was clicked. The distance between the reported location of the target object and its original location was taken as a measure of how well the spatial location was represented.

At retrieval, the location of non-target objects were manipulated which resultedin either the preservation or disruption of the initially studied configuration. In the same configuration condition, positions of non-targets in the probe display remained identical with their positions in the study display. In the different configuration condition, positions of the non-targets randomly changed. In the no configuration condition, none of the non-targets werepresented resulting in the absence of configural cues. As participants place the target in its original location, the original configuration is regenerated only in the same configuration condition. If congruency of spatial configurations between study and retrieval influence the resolution of individual location representations, then we would expect participants to report the location of targets more precisely in the same as opposed to different and no configuration conditions.

To assess whether configuration-based representations influence the spatial WM resolution when the number of to-be-recalled locations increased, we also manipulated set size (Experiment 1 and 2A: 3 and 5 spatial locations; Experiment 2B: 3 and 7 spatial locations). It is generally argued that visual WM capacity is limited (e.g. Alvarez & Cavanagh, 2004;Luck & Vogel, 1997). However, there is no consensus on the exact limit of visual WM. While some argue that people can only represent 3-4 objects, each at the same resolution (Zhang & Luck, 2008), others argue that people can represent a much higher number of objects, flexibly allocating their resources across these resulting in each object being at lower resolution (e.g. Bays et al., 2009). The current evidence does not allow us to specify whether capacity for spatial working memory is similarly limited and not much is known regarding the resolution of spatial representations. Furthermore, we do not know the impact of number of locations on the representation of configurations. It is possible that as the number of locations to be represented increase, people's reliance on configural representations also increase albeit at the cost of individual location representations. Or alternatively, these two types of representations may co-exist at all set sizes. It is likely that we would observe load effects, with resolution of representations being higher at smaller set sizes especially when configural information is congruent between study and retrieval. However, we cannot specifically predict what would happen at different and no configuration conditions.

CHAPTER 2

METHOD

Participants

Twenty-sixBoğaziçi University undergraduates with normal or corrected-to-normal vision participated in the experiment in return for course credit. Data from one participant was excluded because s/he reported that s/he had astigmatism, leaving 25 participants (21 female; mean age = 20.24 ± 2.35). All participants providedinformed consent and they weredebriefed at the end of the session.

Apparatus

The participants were tested in a well-lit room. A computer with an Intel Core 2 Duo processor, ATI Radeon X300/X550/X1050 Series graphics card, and a 17-inch CRT Philips 107S6 monitor was used to present stimuli. The screen resolution was set to 640 x 480,with a refresh rate of 75Hz (refresh duration = 13.33ms). The experiment was programmed in E-Prime (Psychology Tools, Inc.). Participants viewed the computer screen from approximately 57cm, where 1cm corresponds to 1° visual angle.

Design

The study involved 2 (Set Size) x 3 (Configuration) within subject design. Set Size included the *set size 3* and *set size 5* conditions. Configuration included the *same configuration, no configuration,* and *different configuration* conditions. Dependent variables were the amount of error (the Euclidean distance between the reported location and the original location) and reaction time (RT).

Materials

There were two within subject variables: Configuration (same – no – different) and Set Size (3 – 5). In the study display, participants were presented with either 3 or 5 randomly positioned colored squares (500ms). After a brief delay (900ms), they were presented with the probe display. In the probe display, participants had to determine the location of one of the colored squares; the target object's color was heard over headphones. The onset of the sound cue was simultaneous with that of the probe display. In one third of the trials, no other objects were presented in the probe display (no configuration condition). In the remaining trials, we manipulated the locations of non-target objects; they were presented either in their original locations (same configuration condition) or in randomly determined new positions (different configuration condition). The probe display was shown until participants responded, and instructions emphasized accuracy over speed. Participants responded by clicking on the location of the target object with a mouse. The target object appeared where the mouse click was done.

The stimuli consisted of a set of colored squares with sides of 1cm, subtending a visual angle of 1°. The squares colored in red (255, 0, 0), green (0, 255, 0), blue (0, 0, 255), purple (128, 0, 128), and yellow (255, 255, 0) were displayed on a gray (128, 128, 128) background (RGB values are in parentheses).[2] The target object was randomly chosen. The repetition of colors was not allowed in a particular display.

The peripheral region of the screen was not used since locations in the peripheral region may be represented with lower resolution. Therefore, in each trial, locations of the squares were pseudo-randomly generated within a 12 x 12° square

[2] The set size 3 condition consisted of colored squares in red, green, and blue.

region. In addition, squares were separated from the center of the screen by a minimum distance of 3°, and they were separated from each other by a minimum inter-item distance of 3°.

In the different configuration condition, non-targets were presented in a new set of locations in the probe display with the above-mentioned constraints. In addition, each new location in the probe display was separated from the original location of the target object by a minimum distance of 3°. Thus, an overlap between an object at a new location and the target location was prevented.

Each participant completed a total of 360 experimental trials. Trials were blocked by set size. Each block included 180 trials, and 60 trials for each condition were randomly intermixed within the blocks. After completing 60 trials, participants were required to take a 2-minute break. Before the beginning of the experimental trials, each participant received 15 practice trials (five practice trials for each condition in both set sizes). Half of the participants first received the set size 3, the other half first received the set size 5 condition.

Procedure

Participants signed a consent form before the experiment, and they answered the demographic information and strategy questions after the experiment. Before beginning the test, participants were given an overall instruction. In addition, before each block, they were given written and verbal instructions particular to that block.

Each trial began with a warning cross that stayed on the screen for 500ms signaling the appearance of the next study display. Participants were instructed to keep their eyes on the fixation cross while it was visible. The stimulus display with randomly located objectswere presented for 500ms followed by a 900ms-blank interval. After the blank interval, the probe displaywas presented. In the probedisplay, the target objectwas not visible, and participants heard the color name of target object over the headphones. Participants were instructed to recall the original location of the target object, and to respond by clicking on the location of that object with left mouse button. The target object appeared where the mouse was clicked. The probe display was shown until participants responded, and instructions emphasized the accuracy over the speed of responses. After each response, participants were asked whether they remembered or guessed the answer, they were instructed that the "guess" option was to be used only when they did not have any idea where the target was (Figure 1A).

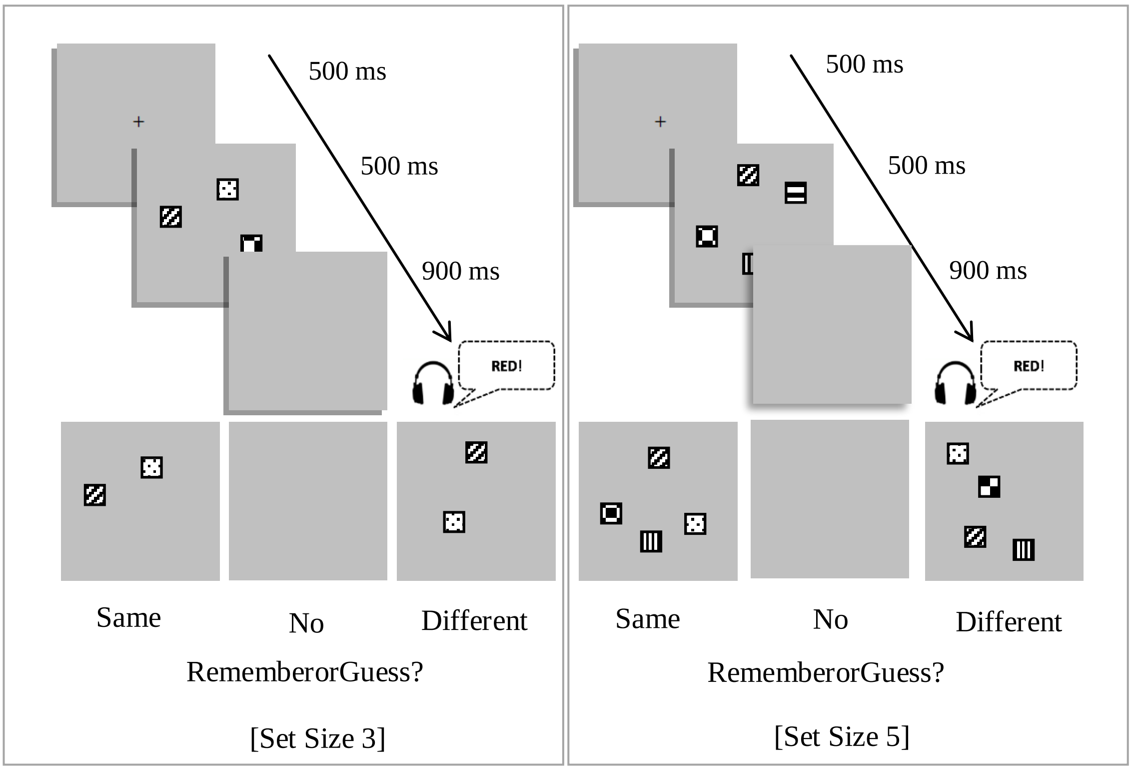

Fig. 1 Figure 1 illustrates probe types (same – no – different configuration) within the set size 3 and 5 in Experiment 1. Different shadings represent different colors.

CHAPTER 3

RESULTS

To determine how accurately each location was represented on each trial, we calculated the Euclidean distance between the target and reported location. For each participant, we calculated the median error across remember trials for each condition, per list length. We chose to report median errors because data was non-normally distributed; the results of the Kolmogorov-Smirnov test of normality revealed that the distributions deviated from a normal distribution (all *p*s< .001). We excluded "guess" responses from further analyses[3]; in all conditions, participants' errors were significantly higher in the "guess" (same configuration: *M* = 68.44, *SD* = 50.39; no configuration: *M*= 55.05, *SD* = 34.91; different configuration: *M* = 63.17, *SD* = 27.45) than "remember" (same configuration: *M* = 21.40, *SD* = 6.56; no configuration: *M* = 27.26, *SD* = 7.26; different configuration: *M* = 27.45, *SD* = 8.59) trials (all *p*s< .001).[4]

In order to assess whetherconfiguration had an effect on the precision of responses,2 (Set Size) x 3 (Probe Type) repeated measures ANOVA was conducted with Probe Type (same, different , no configuration) and Set Size (3 and 5) as within-subject factors. The results revealed that there was a main effect of Probe Type, $F(2,48) = 41.10$, $MSE = 14.42$, $p < .001$, $\eta^2_p = .63$. This main effect was driven by the larger amount of error in the different and no configuration conditions (*M* = 27.45,

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[3]The percentage of guess responses in each condition was as follows (*SD*s in parentheses): For set size 3, 3% (±5); 2% (±3); 8% (±10) in the same, no, and different configuration conditions, respectively. For set size 5, it was 13% (±16); 13% (±12); 29% (±17) in the same, no, and different configuration conditions, respectively.

[4]When we took an objective criterion to exclude as guess responses rather than their subjective indication of a "guess" (for each participant, trials with overall mean error + 3 SD were excluded), the pattern of results remained the same, (the amount of errors in remember trials as follows; same configuration: *M* = 21.26, *SD* = 6.47; no configuration: *M* = 27.14, *SD* = 7.28; different configuration: *M* = 26.92, *SD* = 8.59).

SD = 8.59 and *M* = 27.26, *SD* = 7.26, respectively) compared to that in the same configuration condition (*M* = 21.40, *SD* = 6.56, $p < .001$, Bonferroni corrected). Set size had a main effect, $F(1,24) = 9.11$, $MSE = 34.60$, $p = .006$, $\eta^2_p = .28$, as expected this was due to the higher amount of error in the set size 5 (*M* = 26.82, *SD* = 8.06) than the set size 3 (*M* = 23.92, *SD* = 6.88) condition. There was no interaction between Probe Type and Set Size, $F(2,48) = .31$, $MSE = 14.15$, $p = .69$, $\eta^2_p = .01$(Figure 2).

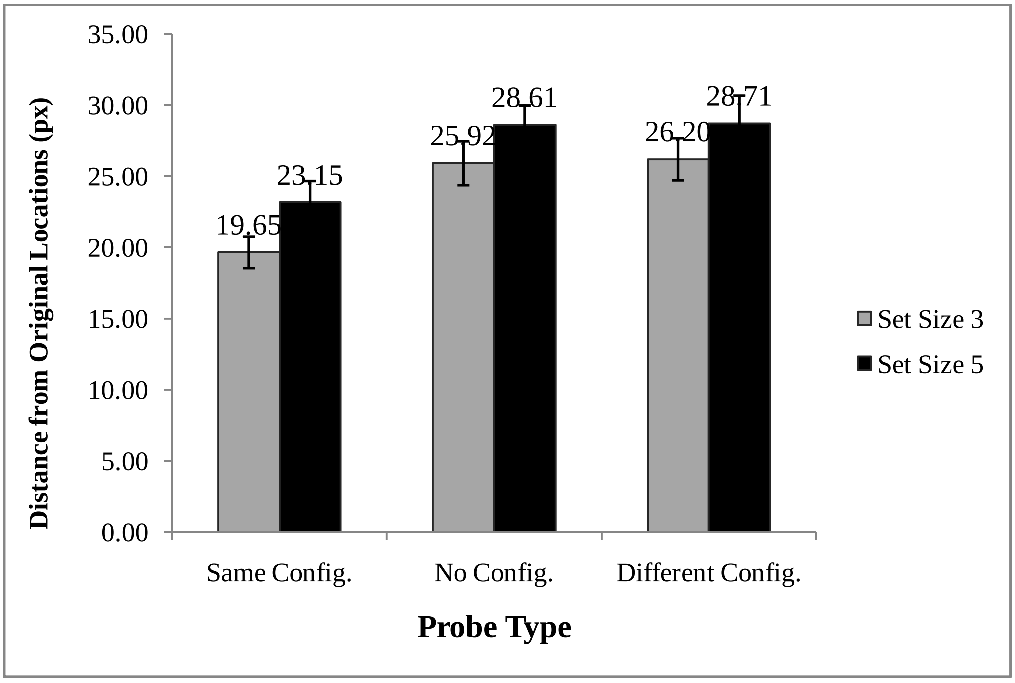

Fig. 2 Median errors as a function of Probe Type in Experiment 1.(Config. = Configuration).

Analyses of reaction time data also revealed that there was a main effect of Probe Type, $F(2,48) = 377.56$, $MSE = 10462.74$, $p < .001$, $\eta^2_p = .94$. Post-hoc comparisons showed thatthere was a significant RT difference between different and same configuration conditions, ($p = .02$, Bonferroni corrected). More interestingly, RTwas significantly longer in the no configuration condition (*M* = 2193.62, *SD* = 207.07) than in both the same and different configuration conditions (*M* = 1677.85, *SD* = 251.07, and *M* = 1742.07, *SD* = 263.34, respectively, all*p*s< .001, Bonferronicorrected).The RT pattern suggests that the absence of configurationcues brought an additional cost during the retrieval of individual object locations.There was also a main effect of Set Size; participants responded slowly in the set size 5 trials (M = 1947.1, SD = 236.68) than set size 3 trials (M = 1795.26, SD = 244.31),$F(1, 24) = 24.65$, MSE = 35072.38, $p < .001$, η^2_p= .51. There was no interaction between Probe Type and Set Size, $F(2,48)$ =1.24, MSE =5678.83, p = .30, η^2_p= .05 (Figure 3).

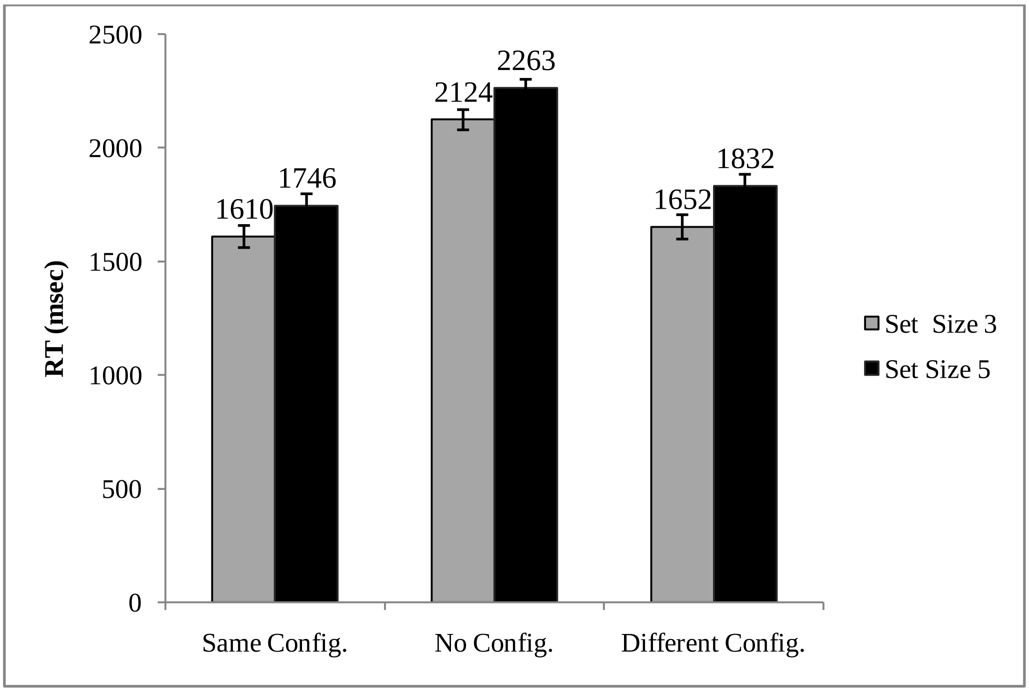

Fig. 3RTs as a function of Probe Type in Experiment 1.(Config. = Configuration).

Overall, these data indicate that changing configurations or absence of configural cues at retrieval reduced the precision of individual location representations. Consistent with findings of load effects on memory, the increase in set size resulted in higher amount of error in recalling the location of the target.

Color – Location Binding Error

In the no configuration condition, participants were not presented with any of the non-target objects at retrieval,which may have in turn misled them to report the location of a non-target object. This would have caused an artificial increase in error in the no-configuration condition in comparison to the same configuration condition.To assess thispossibility, we calculated the distance between each non-target and reported location, and compared it to the distance between the target and reported locations.

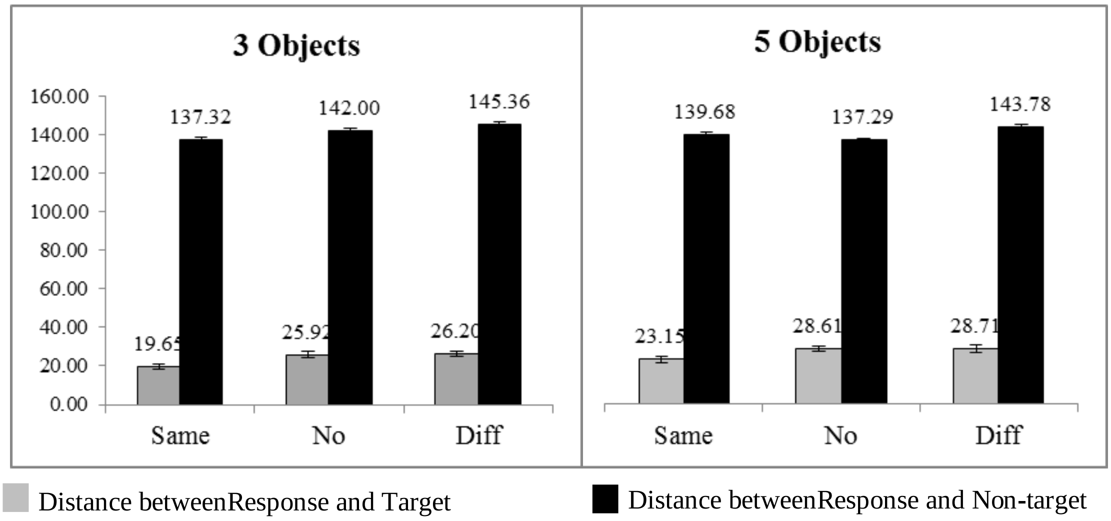

Fig. 4 The distance between target – reported locations and non-target – reported locations (Diff = Different).

As illustrated in Figure 4, the average distance between target location and response was minimumcompared to the distance between non-target locations and responses in all configuration conditions, including the no configuration condition (all *t*s>50, all *p*s< .001). This pattern of results wasthe same for all the participants. The large distance between responses and non-target locations suggests that in the no configuration condition, the participants were unlikely toreport a non-target instead of the target.

CHAPTER 4

DISCUSSION

In the present experiment, we demonstrated that configurations have an effect on the precision of individually reported targets. Specifically, we showed that disruption or absence of configuration cues at retrieval reduces the resolution of spatial WM for individual object locations. We also observed an increase in the amount of errors from set size 3 to 5, suggesting that such an increase in the set size may result in lower memory resolution.

The RT data was consistent with the accuracy data, indicating that consistency of configural cues at encoding and retrieval impact responses. Most critically, though, is the impact of the lack of configural cues at retrieval; RT was slowest when no configural cues were present at retrieval. It is possible that participants were trying to visualize the original configuration while trying to retrieve the target location and in the no configuration condition, the lack of configural cues may have interfered with the effective utilization of visual imagery in determining the particular location. Furthermore, the increase of errors between the same and no configuration conditions were not due tocolor-location binding errors. Responses were more distant from distractors than target locations.

These findings have two major implications for the study of spatial working memory representations. In a novel spatial recall based task, we replicated previous findings demonstrating that the absolute location of an individual object is represented along with the representation of spatial configuration (Boduroglu& Shah, 2009; Jiang et al., 2000; Simons, 1996). More importantly, we provided direct evidence for the fact that the inconsistency of configurations between encoding and retrieval reduced the resolution of individual location judgments. Even though previous studies have shown that inconsistent spatial configuration cues at encoding and retrieval impact*visual* change detection accuracy (Boduroglu& Shah, 2009; Jiang et al., 2000), our findings are novel in demonstrating that configural cues impact the quality of spatial representations.

CHAPTER 5

EXPERIMENT 2

Experiment 1 demonstrated that configural information impact the resolution of spatial responses for targets. However, it is possible that the results from Experiment 1 could be attributed to the existence of a change, not necessarily a global configural change, in the two critical conditions (no and different configuration conditions). In other words, a change at retrieval (e.g., a relative location change) that distracts participants may have reduced the reported representation precision.

In Experiment 2, we directly tested this alternative possibilityby using acolor swap condition instead of the no configuration condition. In the color swap condition, at the retrieval phase, non-target objects switched their colors allowing the overall spatial configuration to remain the same. The same and different configuration conditions were identical with those in Experiment 1. If the existence of a change in the probe display results in an increase in error, then we would expect the amount of error in the color swap condition to be close to the different condition, and significantly more than in the same condition.However, if participants were selectively responsive to global configuration changes,then we would expect the amount of error to be highest in the different configuration condition.

Experiment 2A

In this experiment, the study display contained 3 or 5 objects. The same and different conditions were similar to Experiment 1. In the color swap condition, the locations of the non-target objects were kept the same but the colors were swapped between them. This manipulation introduced a condition where the only change was that of the colors and the spatial configuration formed by the non-targets were the same with that of the study display (Figure 5).

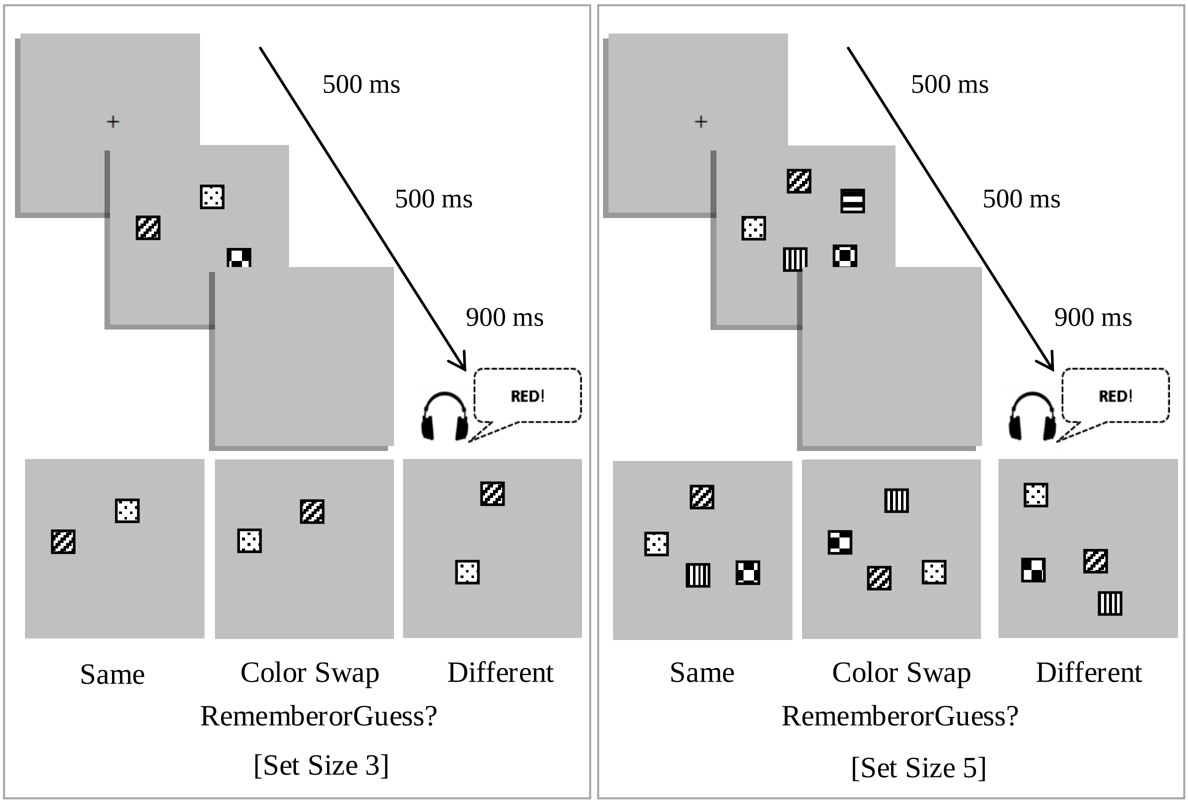

Fig. 5 In Experiment 2A, the no configuration condition replaced with color swap condition as shown in the figure. Different shadings represent different colors.

Method

Participants

Twenty-six Boğaziçi University undergraduates with normal or corrected-to-normal vision participated in the experiment in return for course credit (18 female; mean age = 19.85 ± 1.64). All participants provided informed consent and they were debriefed at the end of the session.

Materials and Procedure

Procedures were identical to Experiment 1 except for the following changes. In Experiment 2A, instead of the no configuration condition, we used the color swap condition to test whether any change at retrieval may equally decrease the precision of reports as configural changes. There were two within-subject variables: Probe Type (same – color – different) and the Set Size (3 and 5). In the color swap condition, in the probe display, non-target objects switched colors. The same and different conditions were identical with the same and different configuration conditions in Experiment 1.

Results

The data was analyzed similarly to Experiment 1. The K-S tests revealed that errors were non-normally distributed in each condition (all *p*s<. 001), Thus, for each participant we calculated the median error for each condition. As in Experiment 1, participants' errors were significantly higher for "guess" responses (same configuration: *M* = 49.12, *SD* = 31.55; color swap: *M* = 50.21, *SD* = 27.57; different configuration: *M* = 62.11, *SD* = 29.68) than "remember" trials (same configuration: *M* = 19.77, *SD* = 4.16; no configuration: *M* = 21.38, *SD* = 4.87; different configuration: *M* = 28.12, *SD* = 6.28; all *p*s< .001)[5].

Taking the amount of errors as the dependent variable, a 2 (Set Size)x 3 (Probe Type)repeated measures ANOVA was conducted. The results yielded a main effect of Probe Type, $F(2,50) = 87.22$, $MSE = 11.71$, $p < .001$, $\eta^2_p = .78$.Post-hoc comparisons revealed that the amount of errors in the different configuration condition (*M* = 28.12, *SD* = 6.28) was significantly higher than both the color swap(*M* = 21.38, *SD* = 4.87) and the same configuration (*M* = 19.77, *SD* = 4.16) conditions (all *p*s< .001, Bonferroni corrected)(Figure 6). The amount of errors in

[5] Percentage of guess responses in each condition was as follows: For the set size 3, 2% (±4); 6% (±6); and 10% (±13) in the same configuration, color swap, and different configuration conditions, respectively. For the set size 5, it was 12% (±11); 21% (±15); and 31% (±17) in the same configuration, color swap, and different configuration conditions, respectively.

the color swapcondition was significantly higher than that in the same configuration condition (p = .006, Bonferroni corrected).There was a marginal effect of set size on errors, $F(1,25) = 3.33$, $MSE = 35.19$, $p = .08$, $\eta^2_p = .12$, with greater error when 5 as opposed to 3 locations were studied (M = 22.22,SD = 5.04; M = 23.96, SD = 5.16 forthe set size 3 and 5, respectively). As in Experiment 1, there was no interaction between Probe Type and Set Size, $F(2,50) = 2.84$, $MSE = 18.54$, $p = .09$, $\eta^2_p = .10$.

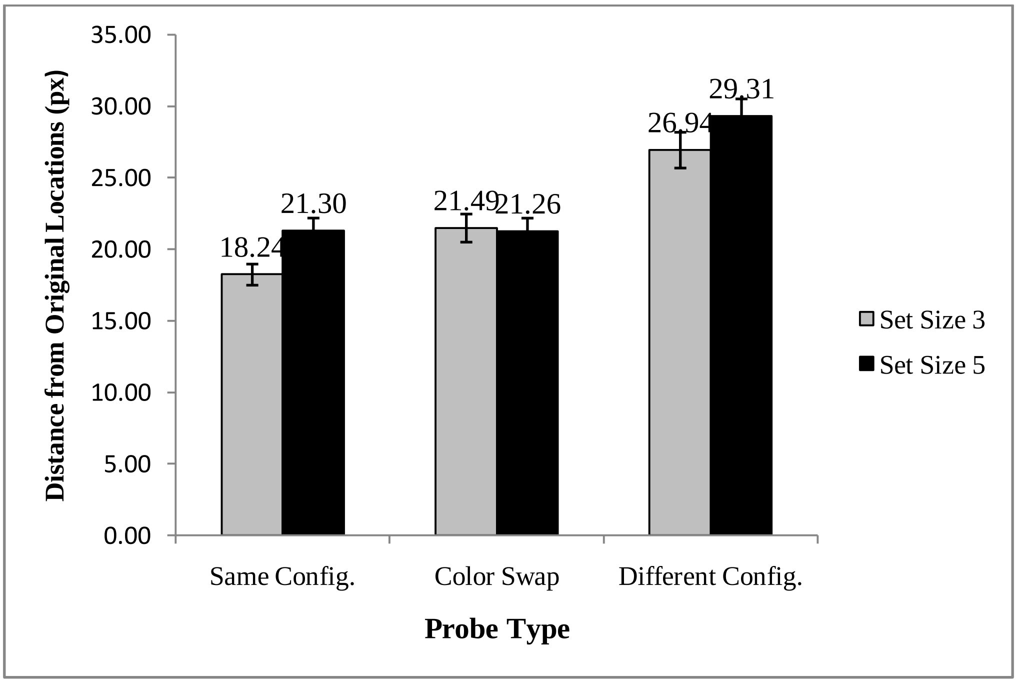

Fig. 6 Median errors as a function of probe type in Experiment 2A. (Config. = Configuration).

Analysis of the RT data showed thatProbe Type had a main effect on RT, $F(2,50) = 14.97$, $MSE = 5564.22$, $p < .001$, $\eta^2_p = .37$. Post-hoc comparisons revealed that this effect was due to the longer reaction times in the different configuration condition (M = 1724.58, SD = 226), that is RT in the different configuration condition was significantly longer than RT in the same configuration (M = 1644.83, SD = 212.64, p< .001, Bonferroni corrected) and color swap conditions (M = 1678.84, SD = 219, *p*= .002, Bonferroni corrected). RT difference between the same and swap conditions was marginal (*p* = .09) with slower RT in the color swap condition compared to RT in the same configuration condition.

There was also a main effect of Set Size on RT, $F(1, 25) = 4.56$, MSE = 80083.51, $p = .043$, $\eta^2_p = .15$. That is, RT in set size 5 was (M = 1731.14, SD = 238.13) longer than RT in set size 3 (M = 1634.36, SD = 200.28).The interaction between Probe Type and Set Size was not significant, $F(2,50) = 2.30$, MSE =3910.01, $p = .11$, $\eta^2_p = .08$.

Discussion

In Experiment 2A, we found that the errors were the highest in the different configuration condition. Critically, the amount of error in the swap condition was significantly less than in the different configuration condition. As in Experiment 1, the amount of error was least in the same configuration condition. This pattern of resultssupports our previous findings suggesting that configural congruency impacts resolution of representations. Moreover, the fact that there was a greater amount of error in the swap than in the same configuration condition suggests that any type of locationchange associated with configural cues influences resolution. The swap manipulation results in a relative location change. Each individual object, while part of a global configuration, has spatial properties relative to other objects. Swapping their colors impairs individual associations between the target and non-target objects. Most critically though is that the impact of swapping on spatial resolution is significantly less than that of the changes in global configuration. This pattern of findings is consistent with Jiang and Wagner's (2004) results who reported that people are more adversely affected by global configural changes as opposed to relative location changes in a visual search task.

Findings from this experimentsuggest that the resolution of spatial representations is severely impaired by a global configuration disruption. In the present experiment, we also observe some degree of influence exerted by relative locations; however, compared to the impact of global configuration change, this is minimal.In other words, the resolution of individual location representations is mainly affected by global configuration structure rather than relative locations of non-target objects. This provides further support to the idea that configural congruency influence the resolution of spatial representations.

Surprisingly, the amount of error was not worse in a larger set size. This may be due to the lack of memory load influenceon the color swap condition. To examine this possibility, we excluded swap condition trials from the data set, and reanalyzed the data for only the same and different configuration conditions. This reanalysis revealed a set size effect that is the amount of error was higher for the larger set size.[6]This may have occurred because when people have to represent more objects, they are more inclined to represent the overall configuration as an ensemble rather than focusing on individual locations. Hence, in a larger set size, they were less influenced by color swapping condition in which relative locations swapped but overall configuration remained the same. To further explore this idea, we conducted Experiment 2B.

Experiment 2B

In Experiment 2B, we further investigated whether the configural effects we reported on individual location representations would be observed in larger setsizes. Thus, in this experiment, we increased the set size from 5 to 7. All other aspects of

[6] Exclusion of the color swap trials from the data set revealed a significant set size effect. That is, the amount of error was significantly higher in the set size 5 (M = 25.30, SD = .97) compared to that in the set size 3 (M = 22.59, SD = .83), $F(1, 25) = 5.78$, MSE =33.11, $p = .024$, $\eta^2_p = .19$.

Experiment 2B were identical to Experiment 2A. It is possible that when people are presented with more targets than that they can possibly represent, they would be more inclined to only represent the overall configuration and not individual locations. The fact that for many visual properties viewers represent ensemble statistics is consistent with this idea (for a review, see Alvarez, 2011). If this is the case, then, we would expect the amount of error to be similar across set size 3 and 7. Alternatively, when people are given a larger set of objects above their capacity, they may either represent a subsample of the objects or represent everything at a lower resolution. Then, we would expect error rates to increase in the set size 7 as opposed to the set size 3 condition.

Method

Participants

Twenty-six Boğaziçi University undergraduates with normal or corrected-to-normal vision participated in the experiment in return for course credit. Data from one participant were excluded because s/he did not follow instructions, leaving 25 participants(17 female; mean age = 19.56 ± 1.16).

Materials and Procedure

The only difference between Experiment 2A and 2B was that the set size 7 was used in Experiment 2B instead of the set size 5 in Experiment 2A.

Results

Data were analyzed similar to previous experiments. The general pattern of descriptive results was similar to Experiment 2A. For the purpose of brevity, we focus on our main manipulations.To compare the amount of errors across the three probe type and two set size conditions, we again conducted 2 x 3 repeated measures ANOVA. The results showed a main effect of configuration, $F(2,48) = 41.62$, $MSE = 62.33$, $p < .001$, $\eta^2_p = .63$. The amount of error was significantly more in the different configuration condition (M = 28.83, SD = 10.32) than in the color swapcondition (M = 20.80, SD = 4.95, $p< .001$, Bonferroni corrected), and it was the least in the same configuration condition (M = 18.57, SD = 4.62). All ps<001, B. corrected)(Figure 7).

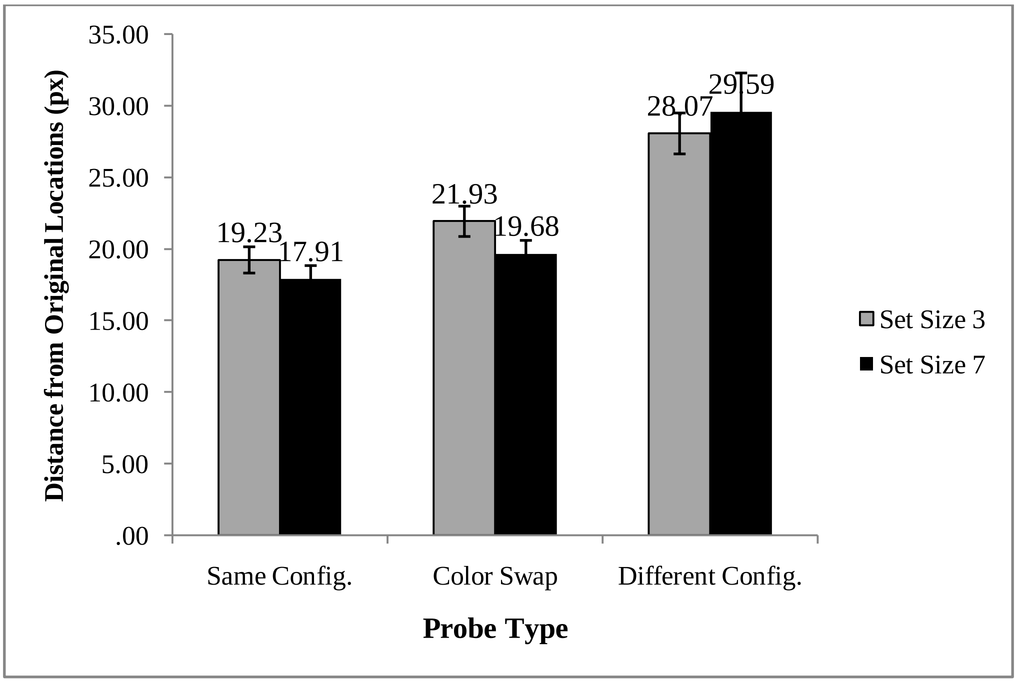

Fig.7Median errors as a function of probe type in Experiment 2B. (Config. = Configuration).

Interestingly, there was no main effect of the set size, $F(1,24) = .51$, $MSE = 34.21$, $p = .48$, $\eta^2_p = .02$. Interaction between the configuration and the set size was not significant, $F(2,48) = 1.78$, $MSE = 27.29$, $p = .18$, $\eta^2_p = .07$.

A 2 (Set Size) x 3 (Probe Type) repeated measures ANOVA was also conducted on RT data. Probe Type had a main effect on RT, $F(2,48) = 10.33$, $MSE = 12093.87$, $p = .001$, $\eta^2_p = .30$. This effect was driven by the longer reaction times in the different configuration and color swap conditions ($M = 1760.70$, $SD = 250.01$ and $M = 1729.02$, $SD = 238.15$, respectively) compared to the reaction times in the same configuration ($M = 1673.72$, $SD = 244.98$) (all ps< .01, Bonferroni corrected). There was no main effect of Set Size on RT, $F(1, 24) = 2.86$, $MSE = 62648.32$, $p = .10$, $\eta^2_p = .11$. The interaction between the configuration and the set size was not significant, $F(2,48) = .44$, $MSE = 5207.10$, $p = .65$, $\eta^2_p = .02$.

Discussion

Consistent with Experiment 2A, in Experiment 2B, we found that the amount of error was highest when spatial configurations changed at retrieval suggesting that participants indeed represent individual target objects within larger configurations.

Interestingly, the amount of error was not adversely affected by the set size increase from 5in Experiment 2A to 7 in Experiment 2B. Similarly, we did not observe an adverse effect of set size increase from 3 to 7 within Experiment 2B. In this regard, one possibility is that the constraints brought by the area in which we randomly arrange the objects for both set sizesmight confound the amount of error in high load condition. The lack of an adverse effect of set size increase to 7 may be due to the fact that participants could not flexibly move the mouse cursor in this area when it contained 6 non-target objects rather than 2 or 4 objects as it was in the set size 3 and 5 conditions. In other words, participants had to choose a location from the remaining (smaller) region. This may have increased the possibility of correctly guessing the target object's location when there are 6 non-target objects as opposed to 2 non-target objects in the same visual area in the test display.

If this had been the case, then in the different configuration condition the amount of error should have been similar to the same and color swap conditions when the set size was 7. Six non-target objects were present in the different configuration as well as in the same and color swap conditions; however, the errors were remarkably higher in the different configuration condition than other conditions. This means that participants could flexibly report target locations when the probe display contained 6 non-target objects. Therefore, the possibility of a– confoundingfactor on errors, which is due to the area constraints, is unlikely.

Another explanation for the lack of a load effect may be related to participants' bias in identifying responses as "guesses" in the high load conditions. The exclusion of a greater proportion of high-error trials as "guess" in the load 7 as opposed to load 3 condition may have artificially reduced the average of error in the load 7 condition. However, this possibility also seems to be unlikelysince when we took an objective criterion (for each participant,exclusion of trials above overall mean error + 3 SD) to exclude guess errors, the pattern of results remained the same[7]. This means that the absence of a load effect in this experiment is not due to participants' bias to report high-error trials as guess in the set size 7.

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[7]When we took an objective criterion to exclude guess responses, the pattern of results for remember responses remained the same. There was a main effect of the Probe Type, $F(2,48) = 39.12$, $MSE = 34.15$, $p < .001$, $\eta^2_p = .62$. The amount of error was significantly higher in the different configuration condition ($M = 28.07$, $SD = 10.05$) than that in the color swap condition ($M = 20.34$, $SD = 4.68$, $p < .001$, Bonferroni corrected). It was the lowest in the same configuration condition ($M = 18.26$, $SD = 4.38$) compared to both the different configuration ($p < .001$, Bonferroni corrected) and color swap conditions ($p < .001$, Bonferroni corrected). There was no main effect of the set size, $F(1,24) = 2.35$, $MSE = 25.41$, $p = .14$, $\eta^2_p = .09$. Interaction between the configuration and the set size was not significant, $F(2,48) = 1.27$, $MSE = 27.22$, $p = .29$, $\eta^2_p = .05$.

One final explanation for the lack of a load effect may have to do with strategic changes in representing objects when load increased from 3 to 7. Specifically, participants may have tried to focus more on individual locations when the number of objects to be remembered was below typical capacity limits. However, when load superseded capacity, participants may have relied more on global configurationrepresentations. Therefore, they may have gained greater benefit from the spatial configurations when the set size exceeded typical capacity limits.

When more objects are presented, it is unlikely that people represent each one of these objects independently. Rather, there is evidence to suggest that people represent summary information (such as ensemble statistics) when more information is presented (Ariely, 2001; Alvarez &Oliva, 2008; 2009; Brady & Alvarez, 2011; Chong &Treisman, 2005). In the present case, people may not have represented the absolute coordinates of each object but they may have effortlessly represented spatial configurations as an ensemble. Then, instead of recalling absolute coordinates of a missing target, they may just locate it as if they regenerate the spatial configuration that they initially encoded. In other words, they locate a missing object to complement the given configuration so that it could be same as the initial one. Briefly, when the set size is larger, people may not focus on the individual location of each object but they can still precisely locate a missing object in the spatial layout.

CHAPTER 6

GENERAL DISCUSSION

Findings from the three experiments presented here demonstrate that people rely on configuration information while recalling the exact position of a target. These findings are consistent with previous studies indicating that spatial configurations are encoded along with individual objects (Simons, 1996), and visuospatial WM is organized in a configural manner (Boduroglu& Shah, 2009; Jiang et al., 2000). More importantly, the evidence presented in this study is the first to show the effects of configuration information on the resolution of spatial locations. In our three experiments, we consistently demonstrated that the precision of reports was impaired both by the configural disruption, and by the absence of configural cues at retrieval. These results suggest that precision of absolute location representations may be bound to configuration information.

While the experiments presented here do not directly address the issue of why consistent configurations at retrieval positively impact the resolution of target locations, we believe that this may have to do with how the target locations are computed. One possible explanation for the effects of configuration on individual location representations may be that the knowledge of other locations and centroid inferred from configuration of the study display may make the computation of an individual location more precise. In other words, the available information (e.g., centroid and relative locations forming global pattern) may provide useful and necessary components for computation of the exact location of a missing target. Then, it is reasonable to assume that people report the location of a missing target, which they roughly remember, with a lower amount of error when configuration information is preserved. This possibility is consistent with the proposals suggesting that visual information may be represented depending on statistical summary of spatial layout rather than individual objects that compose this layout (Ariely, 2001; Alvarez &Oliva, 2008; Alvarez, 2011; Oliva&Torralba, 2006; 2007).

Similarly, in our study, people may rely on statistical summary of a display to represent a spatial layout with multiple object locations. If this is the case, then providing the same configuration cues that are consistent with the summary representation may allow people to compute exact location of a missing target that complements gist of the display previously encoded. However, when configuration cues change, visual display remains inconsistent with the summary representation wherever the missing target is located. This may result in a deviation in the computation of exact location. In the case that configuration cues are all absent, people have nothing to compare with summary representations. Thus, to report target locations, they have to rely only on a gist of the display without any local details related to configurations. This again makes it difficult to compute the target location precisely. To summarize, as opposed to preserved configurations, disruption or lack of configuration cues at retrieval decreases the resolution of spatial WM for individual locations.

One interesting finding in our study is that an increase in set size from 5 to 7 did not adversely influence the precision of reports. This result may seem to fit well with the fixed resource accounts of visual WM, suggesting that resolution reaches asymptote when capacity limits (3-4 objects) are exceeded (Zhang & Luck, 2008; Anderson, Vogel, &Awh, 2011). However, this account cannot fully explain the lack of any effect of the set size increase from 3 to 7 object locations. In this regard, our findings on spatial locations are also inconsistent with flexible resource models of visual WM, arguing that visual WM precision decreases as the number of objects to-be-remembered increases (Bays &Husain, 2008; Bays et al., 2009). The reason for this inconsistency may be that both fixed and flexible resources models of visual WM assume that individual objects are encoded independently, but not in relation to other objects and as a part of global configurations (Brady & Alvarez, 2011). Moreover, as previously emphasized, WM resolution for object features and spatial locations may be distinct dimensions of visuospatial WM (Boduroğlu et al. 2010).Since there are a few studies directly addressing the nature of representations in spatial WM, whether capacity for visual and spatial working memory is similarly limited is not thoroughly understood.

In the context of the present study, we argue that at larger set sizes, people tend to rely more on configuration information in a combination with absolute locations rather than depending only on absolute coordinates of individual objects. Such higher-order representations may be more beneficial to recall exact locations of individual objects when it is unlikely to represent each one of them independently. Thus, relying on configuration information may allow people to deal with capacity limitations of working memory when they have to process multiple objects (Alvarez, 2011). Consistent with this explanation, many studies have suggested that there is an interaction between higher-order representations and individual objects maintained in WM (Brady & Alvarez, 2011), and that statistical regularities in a set of objects allow people to recall larger number of individual objects from that set (Brady, Konkle, & Alvarez, 2009; Brady &Tenenbaum, 2010). In the present study, our goal is not specifically focus on the relationship between capacity and resolution of spatial WM; however, our findings offer strong clues for further investigation of the spatial WM capacity and resolution in relation to configuration information.

To conclude, in the present study, we have directly shown that inconsistent configurations at retrieval negatively affect the resolution of spatial WM for individual locations. Considering previous works, we propose that spatial configurations are represented as a summary of multiple locations at an abstract level. These summary representations provide a framework and one of the necessary components to precisely compute the absolute locations of a missing target. Underlying reason of the decline in spatial WM resolution in the case of inconsistent configurations may be indeed a deviation in those computations due to the distortion of configural cues. Further research needs to directly test these computations in spatial WM.

APPENDIX

Calculations for Locations

Locations were generated in the Cartesian coordinate system. E-Prime assigns (0, 0) to the left upper corner of the screen. At the resolution of 640 x 480 pixels, the center of the screen is (320, 240).

At 57 cm viewing distance, 1cm corresponds to 1° visual angle based on the formula, V = 2 arctan (S/2D), where V is visual angle, S is object size, and D is viewing distance. On a 17-inch monitor (32cm x 24cm), 1cm is equal to 20 pixels. This is based on the following formula:

$$\text{pixels} = \text{cm}*(\text{resolution}_{\text{width}}/\ \text{screen size}_{\text{width}}) \rightarrow \text{px} = 1*(640/32)$$

or

$$\text{pixels} = \text{cm}*(\text{resolution}_{\text{height}}/\ \text{screen size}_{\text{height}}) \rightarrow \text{px} = 1*(480/24)$$

Further calculation steps are based on the above-mentioned values.

All the locations were randomly generated in a 12 x 12° region. First, limits (corners) for 12 x 12° grid were identified by taking center of the screen as the center of the grid. These limits were (200, 120); (440, 120); (200, 360); (440, 360).

To prevent congestion in a certain region, the 12 x 12° grid was divided into quadrants (see Figure 8), and object locations were distributed in a balanced manner. For instance, in the set size 5, 1 location was generated from each of three quadrants, and 2 locations were generated from a fourth quadrant, which was randomly assigned. After minimum/maximum x and y coordinates of each quadrant(Q) were identified, coordinates of each location were generated within these limits by using excel RAND function.

Calculations for Locations

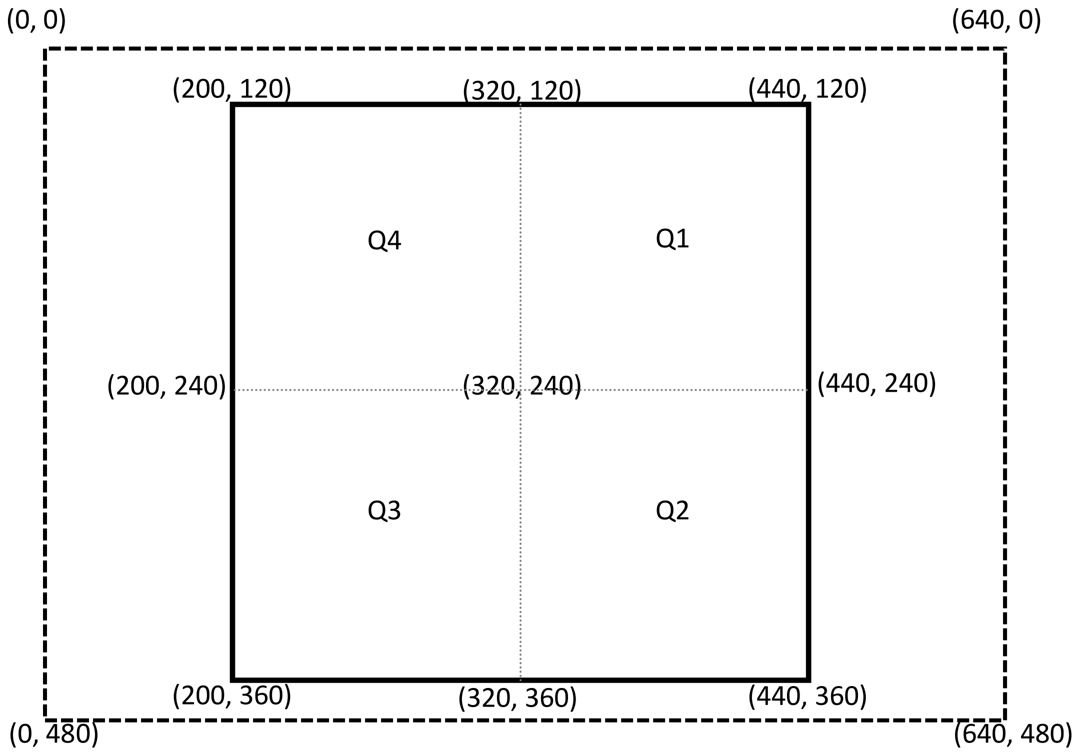

Fig. 8 Cartesian coordinates assigned to the screen(compatible with E-Prime).

That is to say, in one trial, if Q1, Q2, and Q3 each included 1 location, and Q4 included 2 locations, then coordinates for 1 location would be randomly generated within the limits of Q1 (x_{min} = 320; x_{max} = 440; y_{min} = 120; y_{max} = 240), for 1 location within Q2 (x_{min} = 320; x_{max} = 440; y_{min} = 240; y_{max} = 360), for 1 location within Q3 (x_{min} = 200; x_{max} = 320; y_{min} = 240; y_{max} = 360), and for 2 locations within Q4 (x_{min} = 200; x_{max} = 320; y_{min} = 120; y_{max} = 240).

After generating a number of trials for each set size, each location in each trial was tested for the following criteria:

a) Inter-item Distance: For each location, it was calculated by the following formula:

$$D_i = \sqrt{(x1 - x2)^2 + (y1 - y2)^2}$$

Calculations for Locations

b) Distance from the Center: Each location was separated from the center of the screen by a minimum distance of 3° using the formula below:

$$D_c = \sqrt{(320 - x)^2 + (240 - y)^2}$$

c) In the different configuration condition, to prevent an overlap between the target location and displaced non-target locations, inter-item distance was calculated for the probe locations (D_{ip}) as well as the locations in the study display.

If $D < 60$ pixels for one or more locations in one of these calculations, the trial including that location(s) was coded as 0 by using IF-THEN functions, and all the trials coded as 0 were excluded by using FILTER function.

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