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Spatial Proximity as a Determinant of Cognitive Control Context

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by

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Nathaniel Diede

Washington University in St. Louis

August 2015

For Emma, who is one year from starting her own education.

ABSTRACT OF THE THESIS

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Professor Julie Bugg, Chair

The speed and flexibility of cognitive control is exemplified by the context-specific proportion congruency (CSPC) effect. Two locations on a computer screen may be biased to present either mostly congruent (MC) stimuli or mostly incongruent (MI) stimuli, necessitating rapid shifts of cognitive control in order to maximize speed and accuracy of responding. The episodic retrieval account has posited that the speed and flexibility of control can be explained by attentional settings being bound with contextual cues (e.g. the location at which a stimulus appears) into an episodic representation—allowing for settings to be retrieved automatically. However, what determines which setting is bound with which location cue has not yet been investigated. The present study posited that relative spatial proximity determines which setting is applied to a given location. In Experiment 1, six locations were arranged to manipulate relative spatial proximity. A biased (e.g., MC) location was placed on the top edge of a screen and a biased (e.g., MI) location was placed at the bottom. At the middle of the screen two MC (above fixation) and two MI (below fixation) locations were placed within close proximity. A CSPC effect was found between outer locations at the edge, while the middle locations were treated as a single 50% congruent location. Experiment 2 separated the middle locations to be closer to the outer locations of their same congruency. A CSPC effect was then found between the middle locations.

Results are interpreted within the *relative proximity hypothesis* that posits multiple locations can influence the formation of an episodic representation when they are placed closer to one another relative to other locations.

Chapter 1: Introduction

Cognitive control, the ability to perform goal directed behavior in spite of distractors, appears to be fast and flexible. The speed and flexibility of cognitive control is exemplified by the context-specific proportion congruency (CSPC) effect (Crump, Gong, & Milliken, 2006). In a CSPC paradigm, a contextual cue (e.g., the location a stimulus is presented) signals the likelihood of response conflict for a given location. For instance, flanker stimuli (Eriksen & Eriksen, 1974) in one location may be biased to present mostly congruent (MC) stimuli (all arrows pointing in the same direction), while the other location may be biased to present mostly incongruent (MI) stimuli (central target arrow pointing in a direction different than the surrounding arrows). Since each location has a different history of conflict, or bias, control may be adapted to allow more (MC location) or less (MI location) processing of the distracting arrows. Such adaptation is seen when comparing the compatibility effects between the two locations. The compatibility effect is the difference in reaction time between congruent and incongruent stimuli. As would be expected from a shift in control, the compatibility effect in the MC location is larger than in the MI location. This difference is the CSPC effect. Because a participant cannot predict on any given trial in which context the next stimulus will appear, the shift in control is thought to occur very rapidly post-stimulus onset (see also Crump et al., 2006, for evidence that the CSPC effect does not reflect awareness of the proportion congruence manipulation).

The speed and flexibility of cognitive control may be explained by the formation of stimulus-attention representations that are retrieved automatically when cued by a context (see Bugg & Crump, 2012, for review). This is most clearly demonstrated by a study conducted by Crump and Milliken (2009). Context was cued by the location of a to-be-named color patch that followed a color word (in white ink) in a modified Stroop paradigm (e.g., green and white color patches presented above fixation were MC, while those presented below were MI). In addition, two unique color-word pairs (e.g., blue and yellow) were presented without bias, meaning they had a 50% chance of being congruent or incongruent regardless of the location the color patch was presented. Despite being unbiased, these color-word pairs still exhibited a CSPC effect (i.e., smaller congruency effect for blue/yellow color patches appearing below fixation in the MI location), implying that control was being used to shift reliance on distractors in response to the context (location) of the stimulus. Crump and Milliken proposed an episodic retrieval mechanism to explain their results. This *episodic retrieval account* argued that context cues and attentional settings from an experience were bound together to form an episodic representation. Therefore, when a context (such as the location of a stimulus) cued the retrieval of a particular episode, attentional settings for that context were retrieved automatically. This account received support from an fMRI study by King, Korb, and Egner (2012), who found greater BOLD response to context switches in an area of the brain associated with mediating cued shifts of attention (the medial superior parietal lobule; Serences, Schwarzbach, Courtney, Golay, & Yantis, 2004).

An open question is what causes a given contextual cue to be associated with a particular attentional setting. The present paper will argue that relative spatial proximity of locations can determine cognitive control context when location is used as a context cue. In other words, a mostly congruent location may not necessarily function like a mostly congruent location (i.e., triggering retrieval of an attentional setting associated with relatively more processing of distractors) if it is adjacent to a mostly incongruent location. The two locations may instead be represented in a single episode representing the average proportion congruence (i.e., 50% congruent) of the two locations, with both triggering a similar control setting. This is in contrast to a strong location-specific episodic retrieval account that would suggest each location is represented in a distinct episode, with the attentional setting associated with that episode reflecting only the history of conflict at that particular location. The concept of relative spatial proximity is reminiscent of the Gestalt principle of spatial proximity, whereby visual stimuli that are closer to one another are more likely to be grouped together (Pomerantz & Portillo, 2011). Though Gestalt principles typically refer to statically presented objects, spatial proximity has been shown to influence feature integration of temporally separated stimuli (Hermens, Scharnowski, & Herzog, 2009), as would be necessary for this principle to be applied to the CSPC paradigm.

Although two prior CSPC studies have used paradigms with more than two locations, these studies have not been able to ascertain the effect of spatial proximity on context-specific control. Corballis and Gratton (2003) placed an unbiased (50% congruent) location at the center of a screen with an MC location on the right and an MI location on the left (see Figure 1A). Different compatibility effects were found for each location—a smaller effect in the MI location compared to the MC location (i.e., a CSPC effect), with the unbiased location having a moderate compatibility effect. These results could be explained by a strong location-specific version of the episodic retrieval account, where each location is associated with its own representation. However, biased locations had equal relative distances to the unbiased location which allowed for the possibility that both biased locations were equally influencing the episodic representation (and associated attentional setting) of the middle location. This limitation also applies to the study of Wendt, Kluwe, and Vietze (2008). Four locations were presented equidistantly, landing on the points of an imaginary square at the middle of a computer screen (see Figure 1B). The two biases (MC and MI) occupied locations diagonal from one another (e.g., bottom-left MI; top-right MC), while the remaining two locations were unbiased (e.g., top-left and bottom-right locations). As in Corballis and Gratton, the two unbiased locations both had similar, moderate compatibility effects, while the MI location showed the smallest and the MC location the largest. Again, this may be consistent with the strong location-specific version of the episodic retrieval account, or, the moderate effects for the unbiased locations could be the result of equal relative proximity to biased locations. For example, the top-left unbiased location's effect may be the result of the upper portion of the screen being encoded as MC, combined with the left portion of the screen being encoded as MI. Without manipulating relative proximity, it is impossible to determine how each location was being represented.

The present study modified the CSPC paradigm in order to test the influence of relative spatial proximity on location-specific control. Instead of holding relative proximity of locations constant, two MC locations above fixation were placed close to two MI locations below fixation while holding the distance to more distal locations that shared their individual biases (MC and MI, respectively) constant. If each location independently cues an episodic representation, then the compatibility effect for each location should reflect the bias of that location regardless of nearby locations. However, if an alternative version of the episodic retrieval account holds, locations of opposing biases (MC versus MI) that are proximal to one another should both influence the attentional setting bound with the episodic representation (hereafter termed the *relative proximity hypothesis*). If both have equal influence, a single unbiased 50% congruent representation should form from the summation of the two biases, thus washing out the CSPC effect when the compatibility effect associated with each biased location is compared. Meanwhile, biased locations set off relatively distally should still exhibit a CSPC effect, due to the cueing of distinct episodic representations.

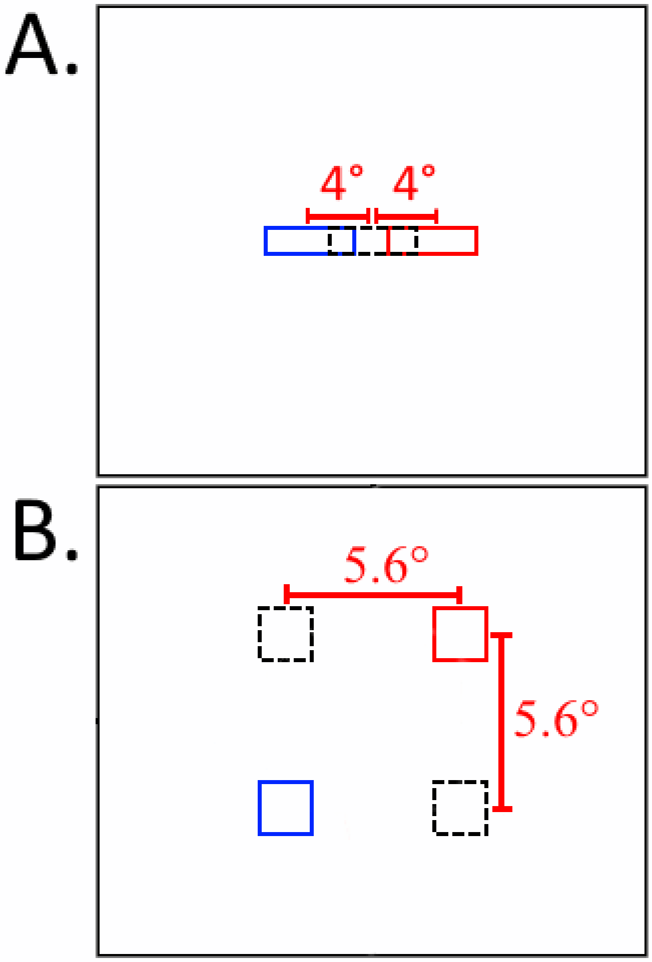

Figure 1. Schematic depiction of the relative locations in degrees of visual angle used in (A) Corballis and Gratton (2003) and (B) Wendt, Kluwe, and Vietze (2008). Blue squares denote mostly incongruent locations, red squares denote mostly congruent, and dashed lines denote unbiased locations.

Finally, a second question was concerned with how adding multiple locations on screen influenced the magnitude of the CSPC effect. Crump, et al. (2006) made an initial attempt to obtain a CSPC effect using shape cues presented centrally on a screen. Though they found location successfully cued control, shape did not (i.e., the compatibility effect was equivalent for mostly congruent shapes and mostly incongruent shapes; though see Crump, Vaquero, & Milliken, 2008, for conditions under which shape is an effective cue). They conjectured that location based CSPC effects may benefit from "spatial uncertainty", a property inherent of location cues but not shape cues. The present paradigm allowed us to test the effect of spatial uncertainty by having a second condition where only the two distal locations were presented on screen. If spatial uncertainty influences learning about context-specific proportion congruence or the application of cognitive control to different locations, a larger CSPC effect should be found in a condition with six biased stimulus locations compared to two.

Chapter 2: Experiment 1

2.1 Method

2.1.1 Participants

A sample of 48 participants was recruited from the Washington University student population (33 female, $M_{age} = 20.13$, $SD_{age} = 1.67$). Inclusion criteria were: aged 18 to 25 years, right-handed, and self-reported normal or corrected to normal vision. All participants were compensated for their time by receiving either $5 or course credit.

2.1.2 Procedure

Testing was conducted in a small room with a participant seated in front of a keyboard and a 1280 x 1024 LCD monitor running E-prime. An experimenter sat to the participant's right, initially gaining consent and administering a demographics questionnaire. Participants were instructed to respond to the central arrow of a seven-arrow line by using their right index finger to press the corresponding arrow buttons on a keyboard number pad (e.g., pressing '8' if the target arrow pointed up), resting their finger on the '5' key after each response. Instructions emphasized responding as quickly and accurately as possible. Once the instructions were read, participants initiated 12 randomly presented practice trials that displayed flanker stimuli at the center of the screen. After reading a screen saying how many blocks they would be completing along with a reminder to respond quickly and accurately, participants began the first of three experimental blocks with breaks allowed in between.

Participants were randomly assigned to one of two conditions that differed on the number of locations presented in a given half of the screen. The Single location condition presented only one location above fixation and one location below fixation. The Multiple condition presented three locations above and three below fixation (see Figure 2A). All participants completed three blocks of 96 randomly presented trials. Within each block in the Single condition, 48 trials were presented in both the upper and lower halves of the screen. The same was true for the Multiple condition, albeit the 48 trials in each half were evenly distributed across the three locations in each half (i.e., the one outer and two middle locations). The proportion of congruent items presented was held constant across the three locations. Stimuli were presented on screen until a response, after which a fixation cross was presented for 1000 ms. Both reaction time and error rate were recorded. Proportion congruency of each half of the screen was counterbalanced across participants. Once the task was complete, the experimenter provided the participant with a post-experiment questionnaire and debriefed them. The experiment lasted approximately 30 minutes.

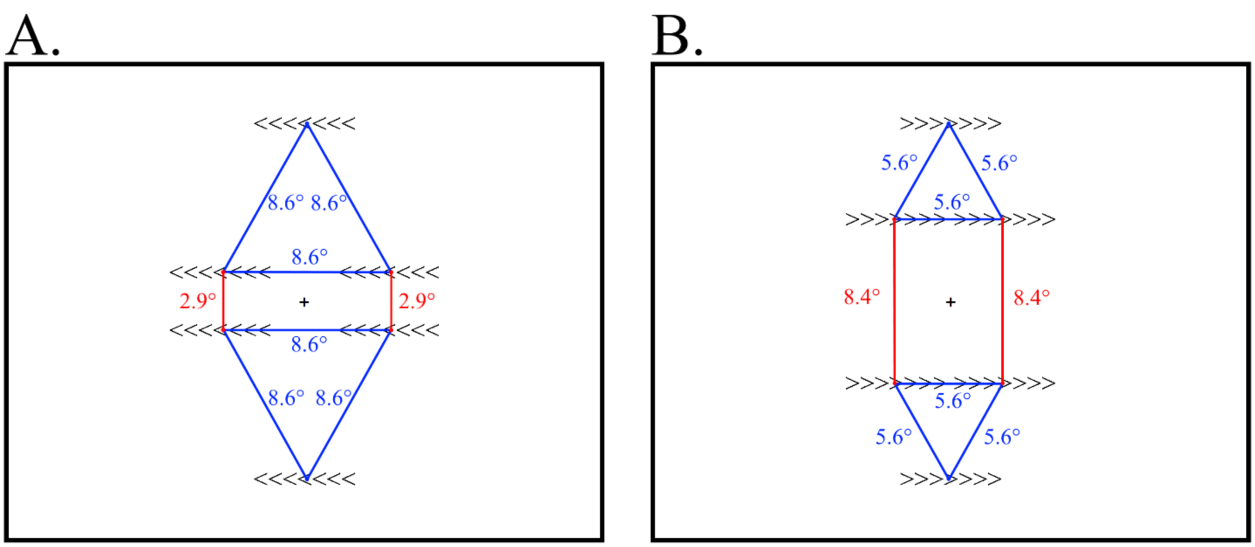

Figure 2. Relative distances of stimulus locations as measured by visual angles in Experiment 1 (A) and Experiment 2 (B). Uppermost and lowermost locations were also used in the Single condition. Visual angles calculated with a viewing distance of 70 cm. Note that only one flanker stimulus was presented per trial. Images are to scale.

2.1.3 Design

For both Experiments 1 and 2, a 2 x 2 x 2 mixed-design was used with Trial Type and proportion congruency (PC) as within-subjects factors and number of locations (NOL) as the between-subjects factor. Trial Type referred to whether a stimulus was congruent (all arrows pointing in the same direction) or incongruent (central target arrow facing a different direction than the flanking arrows). Proportion congruency was manipulated by varying the relative frequencies of congruent and incongruent trials that appeared on the top and bottom halves of the screen. In the MC half, 75% of trials were congruent trials whereas in the MI half 25% of trials were congruent.

To measure relative distance between each stimulus location, visual angle was calculated using a viewing distance of 70 cm, measuring from or to the center of either a centrally located fixation cross, or the center of the target arrow of a flanker stimulus. Stimuli in the Single condition appeared 9.1 degrees above and below the central fixation cross. The two locations used in the Single condition were also used in the Multiple condition, hereafter termed the *outer locations*. In addition, the Multiple condition included two *middle locations* in both the upper and lower halves. The middle locations were located 4.5 degrees from the central fixation cross, 8.6 degrees from all other stimuli in a given half of the screen, and 2.9 degrees from the nearest location in the opposite half of the screen (refer to Figure 2). The middle locations were chosen in order to form equilateral triangles when measured from target arrow to target arrow between the three locations presented in a given half. The flanker stimuli were 5.6 degrees wide by 0.7 degrees tall, and comprised of up, down, left, and/or right arrows. The central fixation cross was 0.5 degrees wide by 0.5 degrees tall.

2.2 Results

Reaction times (RT) less than 200 ms and greater than 2000 ms were eliminated from all analyses in order to control outliers, excluding less than 0.01% of trials. Additionally, trials on which an error was committed were excluded from RT analyses. In this and the subsequent experiment, an alpha level of .05 was set with partial eta squared used as the measure of amount variance explained. Besides those effects reported no other effects were significant.

2.2.1 Reaction Time Analyses

The first contrast compared upper versus lower halves of the screen in both NOL conditions to test if increasing uncertainty influenced the magnitude of the CSPC effect. A 2 (Trial Type: Congruent vs. Incongruent) x 2 (PC: MC vs. MI) x 2 (NOL: Single vs. Multiple) mixed-design ANOVA was conducted on RTs, indicating a main effect of Trial Type, $F(1, 46) = 746.52$, $MSE = 1405$, $p < .001$, $\eta^2_p = .942$, due to slower RT on incongruent ($M = 797$ ms) compared to congruent trials ($M = 649$). Two significant 2-way interactions were found: a Trial Type x NOL interaction, $F(1, 46) = 4.38$, $MSE = 1405$, $p = .042$, $\eta^2_p = .087$, due to a larger compatibility effect in the Multiple condition ($M = 159$) compared to the Single condition ($M = 136$). More importantly, a Trial Type x PC interaction was found, $F(1, 46) = 8.53$, $MSE = 324$, $p = .005$, $\eta^2_p = .156$, due to a 16 ms CSPC effect. Finally, the Trial Type x PC x NOL interaction was not significant, $F < 1$, due to similar CSPC effects in both Single ($M = 18$) and Multiple conditions ($M = 13$).

To test if proximal locations influenced one another, the middle locations were compared within the Multiple condition to test for the presence of a CSPC effect. A 2 (Trial Type) x 2 (PC) within-subjects ANOVA was used, finding only the main effect of Trial Type significant, $F(1, 23) = 443.96$, $MSE = 1638$, $p < .001$, $\eta^2_p = .951$, due to slower RT on incongruent trials ($M = 797$) compared to congruent trials ($M = 622$).The Trial Type x PC interaction was not significant, $F < 1$ (see Figure 3).

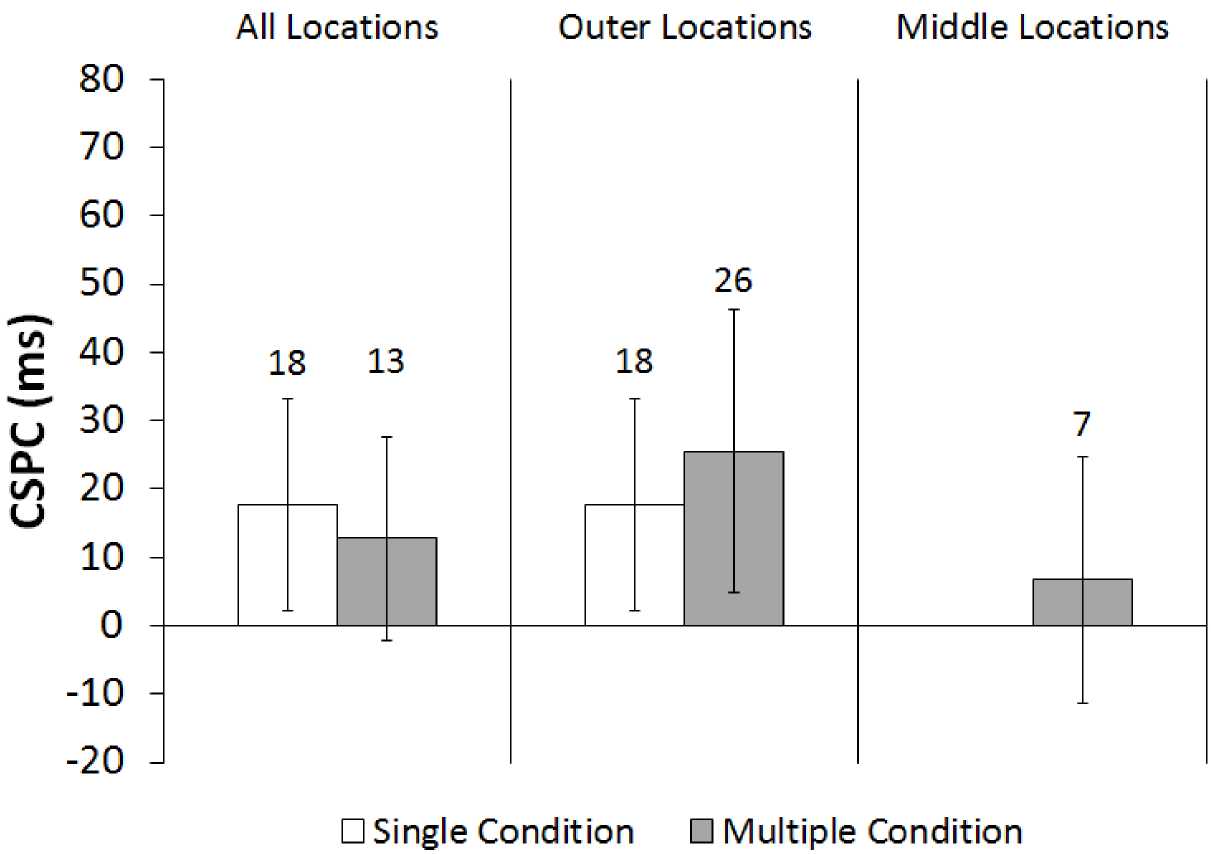

Figure 3. Average context-specific proportion congruency (CSPC) effects in Experiment 1. Outer locations are only those locations that are present in both Single and Multiple conditions. Middle locations are those only present in the Multiple condition. Error bars represent 95% confidence intervals.

To test if a CSPC effect was present for distal locations, an analysis comparing only the locations shared by both NOL conditions (viz. the outer locations) was conducted. A 2 (Trial Type) x 2 (PC) x 2 (NOL) mixed-design ANOVA found a main effect of Trial Type, $F(1, 46) = 489.66$, $MSE = 1736$, $p < .001$, $\eta^2_p = .914$, due to slower RT on incongruent trials ($M = 798$) compared to congruent trials ($M = 665$). The main effect was qualified by a significant Trial Type x PC interaction, $F(1, 46) = 11.83$, $MSE = 472$, $p = .001$, $\eta^2_p = .205$, due to a CSPC effect of 22 ms. The Trial Type x PC x NOL interaction was not significant, $F < 1$ (see Figure 3).

2.2.2 Error Rate Analyses

Overall, error commission was low (*M* = 0.02%). Error rates between each half of the screen were compared using a 2 (Trial Type) x 2 (PC) x 2 (NOL) mixed design ANOVA. A main effect of Trial Type was found, $F(1, 46) = 29.43$, $MSE = 0.001$, $p < .001$, $\eta^2_p = .390$, due to fewer errors on congruent trials (*M* = 0.1%) compared to incongruent trials (*M* = 3.0%). A main effect of NOL was also found, $F(1, 46) = 6.60$, $MSE = 0.001$, $p = .014$, $\eta^2_p = .125$, due to fewer errors in the Single condition (*M* = 0.9%) compared to the Multiple condition (*M* = 2.3%). The Trial Type x NOL interaction was significant, $F(1, 46) = 4.81$, $MSE = 0.001$, $p = .033$, $\eta^2_p = .095$, due to a larger difference in the compatibility effect on error rates in the Multiple condition (*M* = 4.1%) compared to the Single condition (*M* = 1.8%). Last, the Trial Type x PC interaction was significant, $F(1, 46) = 4.43$, $MSE = 0.00$, $p = .041$, $\eta^2_p = .088$, due to a larger compatibility effect on error rates in the MC half (*M* = 3.5%) compared to the MI half (*M* = 2.3%). See Table 1.

Table 1

Error Rates by Condition, Proportion Congruency, and Trial Type in Experiment 1

	Mostly Congruent		Mostly Incongruent	
Condition	Congruent	Incongruent	Congruent	Incongruent
Single Condition	0.1 (0.01)	2.4 (0.1)	0.0 (0.01)	1.1 (0.06)
Multiple Condition	0.1 (0.01)	4.8 (0.1)	0.3 (0.01)	3.8 (0.06)

Note. Values expressed as percentages. Values outside of parentheses are means, those within are standard errors.

Error rates for the outer locations were submitted to a 2 (Trial Type) x 2 (PC) x 2 (NOL) mixed design ANOVA, revealing only a main effect of Trial Type, $F(1, 46) = 18.92$, $MSE = 0.002$, $p < .001$, $\eta^2_p = .291$, due to fewer errors on congruent trials (*M* = 0.2%) compared to incongruent trials (*M* = 2.6%). Finally, middle locations were analyzed with a 2 (Trial Type) x 2 (PC) within-subjects ANOVA, again revealing only a main effect of Trial Type, $F(1, 23) =$

26.57, $MSE = 0.002$, $p < .001$, $\eta^2_p = .536$, due to fewer errors on congruent trials ($M = 0.2\%$) compared to incongruent trials ($M = 4.6\%$).

2.3 Discussion

The first question examined in Experiment 1 was whether MC and MI locations placed closer to one another relative to distal locations that shared their biases (MC and MI, respectively) exhibit a CSPC effect. A location-specific version of the episodic retrieval account predicted that a CSPC effect would be present when comparing the MC middle locations to the MI middle locations of the Multiple condition. In contrast, the relative proximity hypothesis allowed for the possibility that the two proximal but opposing locations may influence the same episodic representation, such that the summation of the two biases would result in an unbiased, 50% congruent representation and therefore no CSPC effect. Results of the middle location analysis found no CSPC effect present, supporting the relative proximity hypothesis. When considering the Multiple condition, there appeared to be three episodic representations forming: one MC representation and one MI representation, which produce the outer location CSPC effect, and one large unbiased representation formed by the four middle locations.

The second question examined in Experiment 1 was whether increasing the number of biased locations influences the magnitude of the CSPC effect. When comparing all locations in the upper half of the screen to those in the lower half of the screen, no difference in the CSPC effect was found between the Single and Multiple condition. However, this result was likely influenced by the formation of the central unbiased representation, thereby weakening any effect multiple locations may have had on strengthening a biased representation. Still, no difference in the CSPC effect was found when comparing only the outer locations in both NOL conditions (though the CSPC effect in the Multiple condition was numerically higher). These findings suggest that, contrary to the speculation of Crump et al. (2006), purely having less certainty of where the next stimulus will appear across the whole screen does not seem to influence the strength of the CSPC effect. Finally, error rates in general concurred with the RT results. Trials presented in MC locations led to more errors than trials in MI locations, consistent with a shift of cognitive control to rely more on distractors when distractors typically signal the correct response.

Chapter 3: Experiment 2

Experiment 1 demonstrated that relative spatial proximity matters when determining what attentional setting is applied to a location. When locations of two opposing biases (75% congruent versus 75% incongruent) were placed relatively closer to one another, they were treated as if they both possessed the summed bias of the two locations (50% congruent). Experiment 2 tested the inverse requirement needed to demonstrate the role of spatial proximity—if the relative distance between opposing biased locations is increased, a CSPC effect should emerge when contrasting the compatibility effects across these locations. Accordingly, the middle locations were moved further apart while the distance between biased locations on a given half of the screen was decreased. Like with the Gestalt principle of spatial proximity, doing so would cause the middle locations to no longer cluster while a new cluster would be allowed to form with the outer locations. Based on the relative proximity hypothesis, it was predicted that two episodic representations would be formed, one for the three MC locations and one for the three MI locations, thus producing a significant CSPC effect for the middle locations. Additionally, the role of increased uncertainty was again tested. Experiment 1 failed to find an increase in the CSPC effect in the Multiple condition, possibly due to the formation of the central unbiased representation. If reducing the relative spatial distance between locations of the same bias eliminates the middle unbiased representation, then a larger CSPC effect may be observed in the Multiple condition compared to the Single condition.

3.1 Method

3.1.1 Participants

A sample of 49 participants was recruited by the same means and inclusion criteria as Experiment 1. A single participant was excluded for not following task instructions (responding to distractor arrows rather than the target arrow). The final sample size was 48 (33 female, M_{age} = 19.08, SD_{age} = 1.20). Participants received either $5 or course credit to compensate them for their time and effort.

3.1.2 Procedure

Experiment 2 proceeded exactly as Experiment 1, with only the relative distance of stimulus locations in the Multiple condition changed. The outer locations remained 9.1 degrees above and below fixation while the middle locations were spread apart to a distance of 8.4 degrees from the nearest location in the opposite half of the screen. In order to maintain equal distance between stimulus locations in a given half, the distance between each location was reduced from 8.6 degrees to 5.6 degrees. This caused each middle location to then be 5 degrees from the fixation cross (refer to Figure 2B).

3.2 Results

The same outlier trimming procedures were applied as in Experiment 1, excluding less than 0.01% of trials. Trials on which an error was committed were excluded from RT analyses.

3.2.1 Reaction Time Analyses

The presence of a CSPC effect between the upper and lower halves of the screen was initially assessed. A 2 (Trial Type) x 2 (PC) x 2 (NOL) mixed-design ANOVA revealed a main effect of Trial Type, $F(1, 46) = 701.88$, $MSE = 1480$, $p < .001$, $\eta^2_p = .938$, due to slower RT on incongruent trials ($M = 773$) compared to congruent trials ($M = 626$). The Trial Type x NOL interaction was significant, $F(1, 46) = 5.27$, $MSE = 1480$, $p = .026$, $\eta^2_p = .103$, due to a larger compatibility effect in the Multiple condition ($M = 160$) compared to the Single condition ($M = 134$). The Trial Type x PC interaction was also significant, $F(1, 46) = 23.39$, $MSE = 311$, $p <$

.001, η^2_p = .337, due to a CSPC effect of 26 ms. The Trial Type x PC x NOL interaction was not significant, $F < 1$.

Next it was tested to see if a CSPC effect emerged when contrasting the middle locations in the Multiple condition. A 2 (Trial Type) x 2 (PC) within-subjects ANOVA revealed a significant Trial Type x PC interaction, $F(1, 23) = 5.82$, $MSE = 342$, $p = .024$, $\eta^2_p = .202$, indicating a CSPC effect of 18 ms. The main effect of Trial Type was also significant, $F(1, 23) = 320.93$, $MSE = 2084$, $p < .001$, $\eta^2_p = .933$, due to slower RT on incongruent trials ($M = 790$) compared to congruent trials ($M = 623$). See Figure 4.

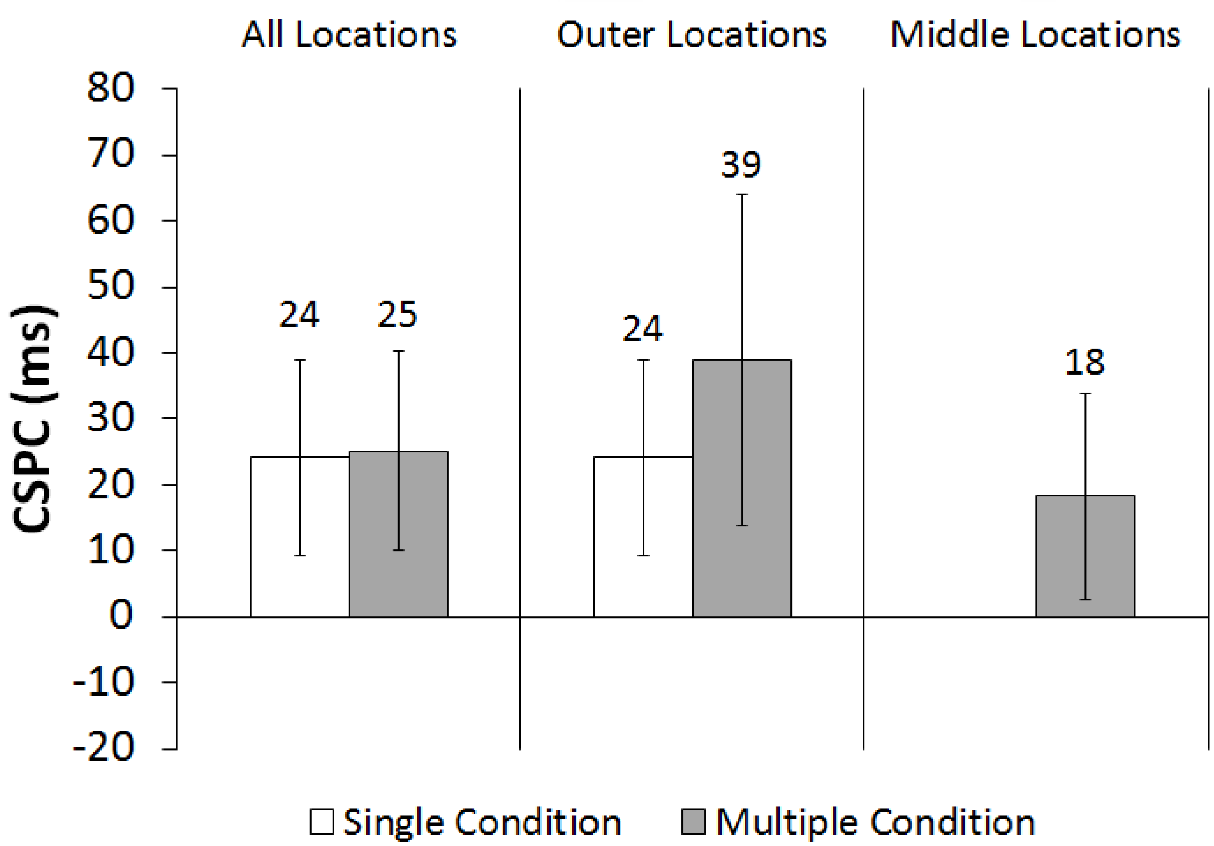

Figure 4. Average context-specific proportion congruency (CSPC) effects in Experiment 2. Outer locations are only those locations that are present in both Single and Multiple conditions. Middle locations are those only present in the Multiple condition. Error bars represent 95% confidence intervals.

Outer locations in the Multiple condition were compared to the Single condition to see if the CSPC effects between the two conditions were again similar. The 2 (Trial Type) x 2 (PC) x 2 (NOL) mixed design ANOVA found a significant Trial Type x PC interaction, $F(1, 46) = 20.01$, $MSE = 596$, $p < .001$, $\eta^2_p = .303$, due to a CSPC effect of 31 ms. The main effect of Trial Type was significant, $F(1, 46) = 584.60$, $MSE = 1608$, $p < .001$, $\eta^2_p = .927$, due to slower RT on incongruent trials ($M = 777$) compared to congruent trials ($M = 637$). The Trial Type x PC x NOL interaction was not significant, $F(1, 46) = 1.10$, $MSE = 596$, $p = .300$, $\eta^2_p = .023$.

3.2.2 Error Rate Analyses

Overall error commission was again low ($M = 0.02\%$). Error rates were compared using a 2 (Trial Type) x 2 (PC) x 2 (NOL) mixed design ANOVA, revealing a main effect of Trial Type, $F(1, 46) = 34.68$, $MSE = 0.001$, $p < .001$, $\eta^2_p = .430$, due to fewer errors on congruent trials ($M = 0.2\%$) compared to incongruent trials ($M = 3.4\%$). The main effect of PC was also significant, $F(1, 46) = 5.34$, $MSE = 0.0$, $p = .025$, $\eta^2_p = .104$, due to fewer errors on the MI half of the screen ($M = 1.5\%$) compared to the MC half of the screen ($M = 2.0\%$). The Trial Type x NOL interaction was not significant, $F < 1$. See Table 2.

Table 2

Error Rates by Condition, Proportion Congruency, and Trial Type in Experiment 2

	Mostly Congruent		Mostly Incongruent	
Condition	Congruent	Incongruent	Congruent	Incongruent
Single Condition	0.4 (0.01)	3.3 (0.09)	0.0 (0.01)	2.6 (0.07)
Multiple Condition	0.4 (0.01)	4.1 (0.09)	0.1 (0.01)	3.4 (0.07)

Note. Values expressed as percentages. Values outside of parentheses are means, those within are standard errors.

Outer location error rates were analyzed using a 2 (Trial Type) x 2 (PC) x 2 (NOL) mixed-design ANOVA, revealing only a main effect of Trial Type, $F(1, 46) = 23.84$, $MSE = 0.001$, $p < .001$, $\eta^2_p = .341$, due to fewer errors on congruent trials ($M = 0.2\%$) compared to incongruent trials (M = 2.8%). The middle locations were analyzed using a 2 (Trial Type) x 2 (PC) within-subject ANOVA. The main effect of Trial Type was significant, $F(1, 23) = 18.78$, $MSE = 0.002$, $p < .001$, $\eta^2_p = .450$, due to fewer errors on congruent trials (M = 0.2%) compared to incongruent trials (M = 4.3%). The main effect of PC was also significant, $F(1, 23) = 5.63$, $MSE = 0.0$, $p = .026$, $\eta^2_p = .197$, due to fewer errors committed on the MI half (M = 1.9%) compared to the MC half of the screen (M = 2.6%). The main effects were qualified by a significant interaction, $F(1, 23) = 4.50$, $MSE = 0.0$, $p = .045$, $\eta^2_p = .164$, due to a larger compatibility effect on the errors on the MC half (M = 4.9%) compared to the MI half of the screen (M = 3.3%).

3.3 Discussion

Consistent with the relative proximity hypothesis, the predicted CSPC effect was found when analyzing the middle locations in the Multiple condition. By reducing the relative distance between locations of the same bias, and thereby increasing the relative distance between differing biases, two separate episodic representations were allowed to form. As in Experiment 1, increased spatial uncertainty did not seem to modulate the CSPC effect. No difference in the CSPC effect was found between the Single and Multiple condition when comparing the upper versus the lower halves of the screen. The same was true when comparing the Single condition to the outer locations of the Multiple condition, although the Multiple condition again had a numerically larger CSPC effect (but lacked statistical significance). Error rates again concurred with the RT analyses. A CSPC effect on the errors emerged between the middle locations, indicating more errors were committed on MC trials compared to MI trials.

Chapter 4: General Discussion

In a series of two experiments it was demonstrated that relative spatial proximity of locations can influence the attentional setting applied to a given location. When locations of the same bias were clustered closer to one another relative to locations of differing biases, a CSPC effect was found between the two groups of locations (Experiment 2). However, when locations of differing biases were clustered closer together than to locations of a similar bias, the clustered locations no longer exhibited a CSPC effect but rather reflected the summed bias of the two locations (Experiment 1). Meanwhile, a CSPC effect was found for locations outside of the cluster. This pattern was also evident in error rates. These results cannot be explained by a strong location-specific episodic retrieval account, according to which each location cues an independent episodic representation. These results are consistent with the relative proximity hypothesis. This hypothesis expands the episodic retrieval account to explain what determines which experiences are bound together in an episodic representation. As with the account posited by Crump and Milliken (2009), experiences with a given location context are bound with an attentional setting. This attentional setting is automatically retrieved whenever that location is cued. However, the representation can be influenced by a second location of close relative spatial proximity. This representation is influenced equally by the input at each location: if both locations present the same bias (MC or MI), then the summed bias of the representation is the same as the individual locations. Alternatively, if one location is 75% congruent (i.e., MC) and the other 75% incongruent (i.e., MI), the influence of the two locations sums to an unbiased 50% congruent representation, washing out the CSPC effect between the two locations.

Two limitations to the present study should be noted. Each location in the Multiple condition presented an equivalent number of trials. As a result of this, in Experiment 1 more trials were presented at the middle of the screen compared to the outer edges of the screen, making trials that appear at the outer locations relatively rarer than trials at the middle locations. This rarity could potentially allow the outer locations to be more novel, or unexpected, when they occur. This would make the outer locations uniquely distinct from the middle locations not only due to relative spatial proximity, but also due to relative spatial novelty. This limitation is tempered by the present results, however. Experiment 2 presented the outer locations with the same relative rarity as Experiment 1 while still finding a CSPC effect between the middle locations. Future studies should manipulate relative spatial novelty in order to determine how it may potentially interact with relative proximity. Second, the concept of relative spatial proximity is inherent when locations are used as contextual cues. In recent years other cues have been found to successfully signal proportion congruency, such as shape (Crump, Vaquero, & Milliken, 2008), color (Lehle & Hübner, 2008; Heinemann, Kunde, & Kiesel, 2009; Vietze & Wendt, 2009), and number parity (Reuss, Desender, Kiesel, & Kunde, 2014). Naturally, the present study would not generalize to non-spatial cues.

More generally the phenomenon of representation summation merits replication and further inquiry. The present study only presented locations of equally opposing biases near one another. Doing so produced a representation of 50% congruency. If representations do indeed sum the biases of locations together, then this should hold for any combination of biases (e.g. a 50% congruent location proximal to a 75% congruent location should sum to a 63% congruent representation). Finally, the stimuli used in the present study were wider than they were tall. Future studies may benefit from using flanker stimuli that are as tall as they are wide (such as those used by Wendt, Kluwe, & Vietze, 2008). Doing so would allow more precise control over the location at which a stimulus is presented.

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