A Configural Dominant Account of Contextual Cueing: Configural Cues are Stronger than Colour Cues

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Running Title: Configural versus Colour Cues in CC

Abstract

Previous work has shown that reaction times to find a target in displays that have been repeated are faster compared with displays that have never been seen before. This learning effect, termed ‘contextual cueing’ (CC), has been shown using contexts such as the configuration of the distracters in the display and the background colour. However, it is not clear how these two contexts interact to facilitate search. We investigated this here by comparing the strengths of these two cues when they appeared together. In Experiment 1, participants searched for a target that was cued by both colour and distracter configural cues, compared with when the target was only predicted by configural information. The results showed that the addition of a colour cue did not increase contextual cueing. In Experiment 2 participants searched for a target that was cued by both colour and distracter configuration compared with when the target was only cued by colour. The results showed that adding a predictive configural cue led to a stronger CC benefit. Experiments 3 and 4 tested the disruptive effects of removing either a learned colour cue or a learned configural cue and whether there was cue competition when colour and configural cues were presented together. Removing the configural cue was more disruptive to CC than removing colour, and configural learning was shown to overshadow the learning of colour cues. The data support a Configural Dominant account of CC, where configural cues act as the stronger cue in comparison to colour when they are presented together.

Introduction

People perform visual search tasks on a daily basis. These can range from searching for a car in a car park to looking for a friend in a crowd. In these tasks, an abundance of information can enter the visual system and if a person were to attend to all the stimuli at once they would be overwhelmed. To compensate for this the visual system has numerous mechanisms designed to help the selection and processing of relevant information, and the filtering and rejection of irrelevant information. For example, visual mechanisms can prioritise new or recently added information (e.g., Yantis & Jonides, 1984), inhibit already searched or old information (e.g., Klein, 1988; Klein & MacInnes, 1999; Watson & Humphreys, 1997) and form top-down sets for stimuli that match an attentional goal-state (e.g., Egeth et al., 1984; Wolfe, Cave & Franzel; 1989; Folk, Remington & Johnston, 1992). Scientists in the laboratory typically investigate human search behaviour by asking participants to find a pre-defined target item among competing distracter items and recording the reaction times (RTs) and error rates. From these measures, it can be determined how quickly, accurately and efficiently people search different types of displays.

Previous work has shown that the context of a search task can influence a person's search behaviour. For example, responses to objects were facilitated when they appeared in semantically appropriate contexts and positions (e.g. Biederman, 1972; Biederman, Mezzanotte & Rabinowitz, 1982). This learning has also been shown to facilitate response times even in displays that were absent from semantic meaning. Chun and Jiang (1998) showed that when participants were asked to search for a target, T, among rotated distracters, Ls, participants were faster to respond if the target-distracter layout was repeated across the experiment, in comparison with an unrepeated display that had never been seen before. This learning benefit, known as ‘contextual cueing’ (CC), was suggested to be based on implicit memory (Chun & Jiang, 1998; 2003, although see Smyth & Shanks, 2008, for evidence of explicit learning). Through the literature, contextual cueing has been shown to be a robust effect (e.g., Chun, 2000; Chun & Jiang, 1998; Chun & Jiang, 1999; Chun & Jiang, 2003; Endo & Takeda, 2004; Hoffmann & Sebald, 2005; Jiang & Chun, 2001; Jiang & Leung, 2005; Jiang, Song & Rigas, 2005; Jiang & Wagner, 2004; Kunar et al., 2006; Kunar et al., 2007; Kunar et al., 2008, Kunar & Wolfe, 2011; Lleras & Von Mühlenen, 2004; Olson & Chun, 2002; Tseng & Li, 2004) and is known to survive certain display transformations such as being displaced, re-scaled or combined with another display (Jiang & Wagner, 2004).

Since the initial paper there have been several studies investigating how different properties can act as contextual cues. In the standard version of contextual cueing the layout of the distracters cued the target’s location (Chun & Jiang, 1998). Brady and Chun (2007) suggested that in these types of display it was the association between the target and its nearby surrounding distracters that were important in obtaining a facilitation effect (see also Kunar & Wolfe, 2011 and Olson & Chun, 2002). When these local associations were preserved a contextual cueing effect was seen even in cases where the rest of the display changed (Brady & Chun, 2007; Olson & Chun, 2002). Although traditionally the CC effect was demonstrated using spatial configurations, more recently, other contextual cues have been identified. For example, Brockmole and Henderson (2006a, 2006b) found that a repeated background using photographs of natural scenes facilitated both RTs (2006a) and eye movements (2006b) to a single target letter. Furthermore, a contextual cueing benefit was found if the repeated context was defined by complex ‘fractals’ and geometrical images that made up the background of the search display (Goujon et al., 2012, Kunar et al., 2006), the colour of the search stimuli (Kunar et al., 2006; Jiang & Song, 2005; Jiang & Chun, 2001) or, important to this paper, the colour of the search background (Kunar et al., 2006). Understanding how these different contextual cues interact is important to obtain a unifying theory of how predictive contexts work together to benefit search overall. We investigated this here by examining the relative strength of colour and configural cues when they appeared together to facilitate search.

As mentioned above, Kunar et al. (2006) found that a predictive background colour could be used to speed response times to find a target among competing distracters. In Kunar et al.'s (2006) experiment the location of the target was predicted by the global colour of the background, rather than the configuration of the distracter items (which were randomly generated from trial to trial). In this case people learned that in a context where the background colour was red, regardless of where the distracters appeared, the target would appear at location (x, y). However, the role of colour as a predictive indicator of target in contextual cueing is controversial. Clearly, on its own in the absence of any other predictive cue it can act as a successful contextual cue (Kunar et al., 2006). However, when it is combined with other predictive properties its role as an associative cue produces differing results. Ehinger and Brockmole (2008) investigated the role that colour plays in contextual cueing using real-world scenes. In their experiments, Ehinger and Brockmole measured the rate of contextual learning in photographic images with their natural colours compared to those that had their colours manipulated. In one condition they varied the colours of repeated photographs across the experiment (i.e., the picture stayed the same but the colours changed across repetitions). They found that despite these colour changes the contextual cueing effects were similar across conditions, suggesting that colour was not important for real-world CC.

In contrast, Goujon et al. (2012) used geometrical figures as the repeated context. In their experiments, instead of using the configuration of distracter items, Goujon et al. (2012) used the pattern of different complex fractals (presented as display backgrounds) as the predictive cues. Here, participants learned to associate a specific fractal image with a specific target location. Their results found that, when using these repeated images, colour played an important role. In their first experiment they found that if the learned repeated image underwent a colour change then contextual cueing was reduced. Furthermore, when the colours of the image were varied across the experiment (similar to the methodology of Ehinger & Brockmole, 2008) the contextual cueing effect was reduced compared to a condition in which the colours of the repeated geometrical images were invariant. Goujon et al. (2012) suggested that with non-semantic displays, composed of visually complex images, colour played a more important role. From these previous studies it seems that the importance of colour as a cue depends on what other contexts were present. With the presence of semantic information colour was irrelevant, however in more abstract displays, colour becomes important.

Note that in the work of Goujon et al. (2012) the target was the only stimulus present in the display. In their experiments, as the predictive context was established by the repeated geometrical images, there was no need for a predictive configural context outlined by the distracter layout. However what happens if predictive configural cues become available? Although the fractal displays of Goujon et al. (2012) and the scene displays of Ehinger and Brockmole (2008) were matched for visual complexity (i.e., they were matched for feature congestion, entropy and edge density, see Rosenholtz et al., 2007) there were other differences in their displays. For example, in photographic images, objects in the scenes could also act as ‘configural’ landmarks predicting the target location (e.g. in the photograph with the bridge, the target appeared to the right of the building). In contrast, the geometric patterns used by Goujon et al. (2012) were made up of repeating fractals and thus contained fewer distinctive configural ‘landmarks’. It may be that when configural cues become available they are weighted as more important than colour cues. If so this should also occur in non-semantic displays. We examined this here by investigating whether configural cues or colour cues were more effective in producing contextual cueing when they were presented together.

The interaction of different contextual cues is important when we think about cue competition. It has been suggested that when two associative cues are presented concurrently they compete for attentional resources, leading to one of the cues being ‘overshadowed’ by the other (e.g., Matzel, Schachtman & Miller, 1985). In this case, the presence of a stronger cue results in weaker learning of a lesser cue when they are presented together, compared to when both cues are presented separately. This has been shown by Endo and Takeda (2004) who found a contextual cueing effect occurred when distracter configuration on its own provided the predictive context and when object identities of the stimuli on their own provided the predictive context. However, when the predictive cues of distracter configuration and object identity were learned concurrently, participants only showed a contextual cueing effect for the configural context but not for object identity. Furthermore, Rosenbaum and Jiang (2013) found that although both repeated scenes and repeated distracter configurations produced robust contextual cueing when presented on their own, when these cues were presented concurrently, the contextual learning provided by scenes overshadowed the learning provided by distracter configuration.

It is clear that presenting two cues together may lead one cue to overshadow the other. Knowing this, we investigated whether cue competition also occurs when distracter configuration and colour background cues are presented concurrently in a contextual cueing task. We tested two accounts looking at the relative strengths of colour and configural cues when they are combined. The *Colour Dominant* account suggests that when configural cues and colour cues were presented together in simple search tasks, colour cues would act as the dominant cue, producing a stronger RT benefit. Ehinger and Brockmole (2008) predicted this, suggesting that if color could be used to recognize familiar contexts with more abstract stimuli (such as letter search stimuli) it would play an important role. In contrast, the *Configural Dominant* account suggests that when invariant configural cues and colour cues were presented together, configural cues would act as the more dominant cue. Thus, even with the presence of a highly salient colour cue, the addition of configural information would lead to stronger CC.

We present four experiments. Experiment 1 compared the CC effect when participants were cued with both a predictive colour background *and* a predictive configuration to when they were just cued by the configuration on its own. If colour acts as a stronger cue, as predicted by the Colour Dominant account then we would expect to see a larger CC effect when the colour cue was present. Experiment 2 compared the CC effect when participants were cued with both a predictive colour background *and* a predictive configuration to when they were just cued by a colour cue on its own. If configuration acts as a stronger cue, as predicted by the Configural Dominant account, then we would expect to see a larger CC effect with the addition of predictive distracter layouts. Experiment 3 investigated whether the CC effect was disrupted more if the learned colour cue was removed from the display compared with the predictive configuration. Participants were trained on contexts where both the configuration and the background colour predicted the target location. In a subsequent test phase, either the configuration or the colour cue was removed. The results showed that removing configural cues disrupted CC more than removing color cues. Experiment 4 tested whether the learning of configural cues overshadowed the learning of background colour cues. Participants were trained on contexts where both the configuration and the background colour predicted the target location. In a subsequent test phase, the configuration cue was removed. The results showed that when colour cues had been learned in combination with configural cues, a weaker CC effect was observed compared to when colour cues had been learned on their own. The results add to the evidence showing cue competition in contextual learning and are discussed in favour of a Configural Dominant account of CC.

Experiment 1

Method

Participants:

Twenty participants (14 female) were recruited to take part in the experiment. Their ages ranged from 20 to 49 (mean = 22.5 years). All participants had normal or corrected to normal vision.

Apparatus and Stimuli:

Displays were generated and responses recorded by Blitz Basic running on a PC. The distracter items were white L shapes presented randomly in one of four orientations (0, 90, 180 or 270 degrees). The target item was a white T, rotated 90 degrees either to the left or to the right with equal probability. Each L contained a small offset (approximately 0.3 degree) at the line junction to make search more difficult. All stimuli subtended 1.7° x 1.7°, at a viewing distance of 57.4 cm.

Procedure:

There were two conditions in this experiment: the configural condition and the combined condition. Both conditions consisted of a Training Phase, which established learning, and a Test Phase, which measured CC (see also Brady & Chun, 2007, Makovski & Jiang, 2010, Kunar & Wolfe, 2011). The Training Phase consisted of seven epochs. Each epoch had four repeated displays which were shown eight times per epoch. Thus, over 7 epochs, each repeated display was shown 56 times. Previous work has shown that by increasing the number of repetitions and decreasing the number of repeated displays, stronger contextual learning occurs, resulting in large contextual cueing effects (e.g., Kunar et al., 2006, 2007, 2008). This is important when it comes to comparing contextual cueing across conditions as it is crucial to demonstrate strong contextual learning to start with, before measuring any detrimental effect, resulting from the experimental manipulation (e.g., Kunar et al., in press). The Test Phase was presented straight after the training phase and contained 96 repeated trials (the four repeated trials from the training phase, each shown 24 times to ensure that sufficient data was collected to reduce measurement error) and 96 unrepeated trials which had never been seen before. Following past studies the number of possible target locations in the unrepeated trials matched those of the repeated trials to show that in repeated trials participants were learning the contexts and not just the target locations (e.g., Chun & Jiang, 1998, Kunar et al., 2007, Kunar & Wolfe, 2011).

In the configural condition the distracter locations cued the target position (similar to the original task of Chun & Jiang, 1998). Here, the background colour for each trial was always black. At the beginning of the condition, each repeated target was paired with a randomly generated set of distracter locations that remained invariant throughout the experiment (making four repeated displays, see also Kunar et al., 2006, Kunar et al., 2007, Kunar et al., 2008). For the unrepeated trials the distracter configuration for each target location was randomly generated at the start of every trial, to produce new displays that had never been seen before. The combined condition was similar to the configural condition, except that the repeated trials also had an extra cue of the background colour of the display. Here, each repeated target location was paired with a set of invariant distracter locations *and* a unique background colour (red, green, blue or yellow). Each stimulus in the combined condition was presented in a surrounding black box of dimensions 2.6° x 2.6°, at a viewing distance of 57.4 cm. This was done to ensure that the luminance contrast of all stimuli to their local background was equated across trials, regardless of the global background colour (see Kunar et al., 2006). Like the configural condition, the distracter configuration for the unrepeated trials was also randomly generated at the start of every trial so that it was uninformative as to the target's location and the background was always black.

The total set size of each display was twelve (one target item and eleven distracter items). For all trials, participants were asked to search for the target, T, and press the letter 'm' or 'z' if the bottom of the T was facing right or left, respectively and respond as quickly but as accurately as possible. Each condition was presented in a separate block of trials (each block lasting approximately 30 minutes) and a within-participants design was used where each participant completed both blocks in one experimental session. The presentation of conditions across participants was counterbalanced and participants were given a short practice session before each experimental block. Example displays can be seen in Figure 1.

Figure 1 about here

Results and Discussion

Overall errors were low at 3.0%. Unless otherwise noted, all effects referred to as statistically significant throughout the text are associated with p values below 0.05, two-tailed. Reaction times less than 200 msec and greater than 4000 msec were removed. This led to the removal of 0.4% of the data. Figure 2a shows the mean correct reaction times across epochs for the configural cueing condition and the combined cueing condition in the Training Phase. A 2 x 7 ANOVA on correct RTs with factors of Condition (configural cue vs combined) and Epoch (Epochs 1-7) revealed a main effect of Epoch, $F(6, 114) = 55.27$, $p < 0.01$, where RTs decreased across the experiment. However, there was no main effect of Condition ($F < 1$), neither was the Condition x Epoch interaction significant ($F < 1$). The results showed that there was no difference in RTs to find a target when it was predicted by the distracter configuration, in the training phase, or by both the distracter configuration and the background colour of the display.

Figure 2b shows the mean correct RTs for both the repeated and unrepeated trials in the configural and combined conditions. Contextual cueing occurs when RTs for repeated displays are faster than those of unrepeated displays (Chun & Jiang, 1998). To investigate the extent of cueing, mean correct RTs in the Test Phase were entered into a 2 x 2 ANOVA with factors of Condition (configural vs combined) and Display Type (repeated vs unrepeated). The analysis showed an overall contextual cueing effect, with a main effect of Display Type, $F(1, 19) = 20.16$, $p < 0.01$. RTs for repeated displays were faster than those for unrepeated displays. However, there was no main effect of Condition, $F(1, 19) = 1.25$, $p = 0.28$. Neither was the Condition x Display Type interaction significant, $F(1, 19) = 1.14$, $p = 0.30$. There was no statistical difference in CC effects between the two conditions[1]. Corresponding

[1] Given that there were 24 repetitions of repeated trials in the Test Phase, additional learning of the repeated displays could have continued. However, further analysis of both conditions showed that there was no difference in the contextual cueing effect between the first and last halves of the Test Phase ($t(19) = 1.61$, $p = 0.12$ and $t(19) = 1.65$, $p = 0.12$, for the configural and combined condition respectively). This is likely to be because contextual cueing had already reached an asymptotic level (e.g. see also Chun & Jiang, 1998).

analysis of error rates (for the Training phase and Test phase) showed no significant effects (all $Fs < 1.3$).

Figure 2 about here

Adding a predictive colour cue to the display did not elicit a larger CC effect compared to when the spatial layout predicted the target location on its own. In the Training Phase, RTs in both conditions decreased at the same rate, suggesting equivalent learning, regardless of the extra colour cue in the combined condition. This notion was confirmed in the Test Phase, where although there was an overall CC effect, there was no CC difference between the two conditions. Despite the extra colour cue, the contextual cueing benefit was not increased.

The data are difficult to reconcile with the Colour Dominant account of CC. This account proposed that, when colour and configural cues were presented together, colour would dominate producing evidence of strong contextual cueing. However this did not occur. These data are surprising given that colour is a highly salient cue. Goujon et al. (2012) found that when using abstract stimuli where only the target was present, colour played an important role. In contrast, in these displays colour cues were presented alongside predictive configural cues. Under these circumstances adding colour did not lead to greater CC over and above the distracter configuration. Although these data are difficult to account for in terms of a Colour Dominant account of CC, they could be explained by a Configural Dominant account. To investigate this further, Experiment 2 compared the RT advantage obtained when configural cues were presented in addition to predictive colour cues. According to a Configural

Dominant account, a greater CC effect would occur when a predictive spatial layout was added.

It may also be the case that instead of configuration being the dominant cue, people contextually learned whatever cue was available and consistently predictive. That is as configuration was a consistent and predictive cue in both conditions in Experiment 1 it was preferentially learned over colour. If this was the case then if colour was the consistently predictive cue in both conditions it should act as the stronger cue. This was also tested in Experiment 2 where colour rather than configuration was the constant cue.

Experiment 2

Participants:

Twenty-four participants (17 female) were recruited to take part in the experiment. Their ages ranged from 19 to 41 (mean = 21.4 years). All participants had normal or corrected to normal vision.

Apparatus and Stimuli:

The apparatus and stimuli were similar to those in Experiment 1.

Procedure:

There were two conditions: the colour cueing condition and the combined cueing condition. The combined cueing condition was identical to that in Experiment 1. The colour cueing condition was similar to the combined cueing condition, except that only the background colour cued the target location. Here, the target position remained invariant within a repeated display, however the distracter positions were randomly generated at the start of each trial. Example displays can be found in Figure 3.

Figure 3 about here

Results and Discussion

Overall errors were low at 3.3%. Reaction times less than 200 msec and greater than 4000 msec were removed. This led to the removal of 0.7% of the data. Figure 4 shows the mean correct reaction times (RTs) for the colour cueing condition and the combined cueing condition for the Training Phase across epochs and for the Test Phase. In the Training Phase, a 2 x 7 ANOVA on correct RTs with factors of Condition (colour vs combined) and Epoch (Epochs 1-7) showed there to be a main effect of Condition, $F(1, 23) = 10.76$, $p < 0.01$, where RTs in the combined condition were faster overall than those in the colour condition, and a main effect of Epoch, $F(6, 138) = 29.55$, $p < 0.01$, where RTs decreased across the experiment. However there was no significant Condition x Epoch interaction, $F(6, 138) = 1.09$, $p = 0.37$.

Figure 4 about here

To investigate the extent of cueing, mean correct RTs from both cueing conditions in the Test Phase were entered into a 2 x 2 ANOVA on correct RTs with factors of Condition (colour vs combined) and Display Type (repeated vs unrepeated). The analysis showed that there was a main effect of Condition, $F(1, 23) = 9.27$, $p < 0.01$, with faster RTs in the combined condition than the colour condition and a main effect of Display Type, $F(1, 23) = 22.46$, $p < 0.01$, with faster RTs for repeated displays than unrepeated displays. The Condition x Display Type interaction was also significant, $F(1, 23) = 6.74$, $p < 0.05$. Post-hoc t-tests between repeated and unrepeated RTs showed that a contextual cueing effect occurred for both the colour and combined conditions, $t(23) = 2.53$, p < 0.05 and $t(23) = 4.54$, $p < 0.01$, respectively. However the magnitude of the CC effect for the combined condition (235 ms) was greater than that of the colour condition (89 ms). Corresponding analysis of error rates (for the Training phase and Test phase) showed no significant effects, all $Fs < 1.5$, except the effect of Condition in the Test phase, $F(1, 23) = 3.05$, $p = 0.09$, where there was a trend for more errors to be made in the combined cueing condition compared to the colour cueing condition. However, this difference was small (3.8 % vs 2.8%, respectively).

The data showed a number of interesting results. First, in the Training Phase, RTs were faster when both the configuration and colour information predicted the target location compared to when just the colour information was predictive. This was different from the results of Experiment 1 where there was no benefit of adding colour information to configural cues. These results suggest that in the presence of configuration, colour acts as a weaker cue. The results from the Test Phase supported this. Here, the CC effect was larger with the addition of the predictive configural cues compared to just the colour on its own. Although colour cues produced a facilitation of RTs, adding invariant spatial cues to the display led to a greater CC effect. These results again contrasted to those from Experiment 1, where adding extra colour cues did not enhance CC. Taken together, the two experiments suggest that when presented concurrently configuration has a greater effect on CC than colour. These results run counter to the Colour Dominant account of CC. Furthermore the results run counter to the hypothesis that people learned whatever cue that was consistently predictive. Here the consistently predictive cue across all conditions was colour; however, the addition of the colour cue did not lead to stronger CC. Instead the results are in favour of the Configural Dominant account of CC.

Experiments 1 and 2 suggested that colour was a weaker contextual cue than distracter configuration. To examine this further we investigated the disruptive effect of removing either previously learned configural cues or previously learned colour cues in Experiment 3. In this experiment participants learned both predictive colour and configuration cues in a Training Phase, however in a Test Phase, the colour cue was removed from one condition and the configural cue was removed from the other. If the Colour Dominant account is correct then with colour acting as the stronger cue, removing the colour background should be more disruptive to CC than removing the spatial layout. However if the Configural Dominant account is correct then with configural cues acting as the stronger cue, removing the invariant distracter configuration should be more disruptive to CC then removing the colour.

Experiment 3

Participants:

Twenty participants (18 female) were recruited to take part in the experiment. Their ages ranged from 20 to 41 (mean = 21.9 years). All participants had normal or corrected to normal vision.

Apparatus and Stimuli:

The apparatus and stimuli were similar to those in Experiment 1.

Procedure:

The procedure was similar to that of Experiment 1, except where stated otherwise. There were two conditions: the colour-removed condition and the configuration-removed condition. In each condition there was a Training Phase of repeated trials and a Test Phase of both repeated and unrepeated trials. For both conditions the Training Phase was the same as the combined conditions in Experiments 1 and 2 (i.e., both the configuration of the distracters and the background colour cued the target location). In the colour-removed condition, the predictive background colour was removed in the Test phase. Thus, for repeated trials the background was black and the spatial layout was the only remaining contextual cue. In the configuration-removed condition, the predictive spatial layout of the distracters was removed in the Test phase. Thus, the distracter positions were randomly generated at the start of each trial, however the colour cue remained the same as the Training phase. In both conditions, the unrepeated trials had neither a predictive colour nor spatial layout cue (all backgrounds were black and the distracter positions were randomly generated on each trial). Example displays are shown in Figure 5.

Figure 5 about here

Results and Discussion

Overall errors were low at 2.7%. Reaction times less than 200 msec and greater than 4000 msec were removed. This led to the removal of 0.1% of the data. Figure 6 shows the mean correct reaction times (RTs) for the colour-removed condition and the configuration-removed condition in both the Training Phase, across epochs, and the Test Phase. In the Training Phase a 2 x 7 ANOVA on correct RTs with factors of Condition (colour-removed vs configural-removed) and Epoch (Epochs 1-7) showed there to be a main effect of Epoch, $F(6, 114) = 41.06$, $p < 0.01$, where RTs decreased across the experiment. However, there was no main effect of Condition, $F(1, 19) = 1.41$, $p = 0.25$, neither was the Condition x Epoch interaction significant, $F(6, 114) = 1.57$, $p = 0.16$. As expected, given that the displays in the training phase were identical, there was no difference in RTs between the two conditions.

Figure 6 about here

To investigate the effect of removing each cue type, mean correct RTs from both conditions in the Test Phase were entered into a 2 x 2 ANOVA with factors of Condition (colour-removed vs configuration-removed) and Display Type (repeated vs unrepeated). The analysis showed that there was an overall cueing effect, with a main effect of Display Type, $F(1, 19) = 18.88$, $p < 0.01$. RTs in repeated displays were faster than those in unrepeated displays. However, there was no main effect of Condition, $F(1, 19) = 2.72$, $p = 0.12$. The Condition x Display Type interaction, on the other hand was significant, $F(1, 19) = 4.81$, $p < 0.05$. Post-hoc t-tests between repeated and unrepeated RTs showed that a contextual cueing effect occurred for the colour-removed condition, $t(19) = 5.09$, $p < 0.01$, and a significant contextual cueing effect occurred for the configuration-removed condition, $t(19) = 1.93$, $p < 0.04$ (one-tailed). However, the magnitude of the CC effect for the colour-removed condition (180 ms) was greater than that of the configural-removed condition (77 ms). Corresponding analysis of error rates (for the Training phase and Test phase) showed no significant effects (all Fs < 3.1).

Removing the predictive configural cues impaired contextual cueing more than removing the colour background. This occurred despite colour being a highly salient feature. Collectively, the results from Experiments 1 - 3 showed that, when presented together configural cues act as a stronger contextual cue in comparison to colour cues. These results are consistent with a Configural Dominant account of CC.

Previous work has shown that when two cues compete with one another, learning of one of the cues may be overshadowed by the other (e.g. Endo & Takeda, 2004; Rosenbaum & Jiang, 2013). Experiments 1 – 3 showed configuration to be the dominant cue over colour. Experiment 4 examines whether learning predictive configural cues interferes with the ability to learn predictive colour cues. Here, we compared the contextual cueing effect found from purely learning predictive colour backgrounds, to the contextual cueing effect found when people are trained on predictive colour backgrounds and configurations and then just tested with colour cues. If people are able to effectively learn colour cues in both conditions, a similar CC effect should be observed in each condition. However, if the presence of configural cues overshadows learning of colour cues then a smaller CC effect should be observed when participants learned colour and configuration cues combined.

Experiment 4

Participants:

Fourteen participants (10 female) were recruited to take part in the experiment. Their ages ranged from 19 to 36 (mean = 22.9 years). All participants had normal or corrected to normal vision.

Apparatus and Stimuli:

The apparatus and stimuli were similar to those in Experiment 2.

Procedure:

The procedure was similar to that of Experiment 2, except where stated otherwise. There were two conditions: the colour cueing condition and the configuration-removed condition (taken from Experiment 3). In each condition there was a Training Phase of repeated trials and a Test Phase of both repeated and unrepeated trials. Therefore the effect of colour cueing in the Test phase can be established in conditions where people learned a predictive context of colour alone (the colour cueing condition) and when colour cues were learned in combination with configural cues (the configuration-removed condition).

<u>Results and Discussion</u>

Overall errors were low at 1.4%. Reaction times less than 200 msec and greater than 4000 msec were removed. This led to the removal of 1.0% of the data. Figure 7 shows the mean correct reaction times (RTs) for the colour cueing condition and the configuration-removed condition in both the Training Phase, across epochs, and the Test Phase. In the Training Phase, a 2 x 7 ANOVA on correct RTs with factors of Condition (colour cueing vs configural-removed) and Epoch (Epochs 1-7) showed there to be a main effect of Condition, $F(1, 13) = 5.29$, $p < 0.05$, where RTs in the configuration-removed condition were faster than RTs in the colour condition, and a main effect of Epoch, $F(6, 78) = 21.07$, $p < 0.01$, where RTs decreased across the experiment. However, the Condition x Epoch interaction was not significant, $F(6, 78) = 1.18$, $p = 0.32$.

Figure 7 about here

To investigate the effect of colour cueing, mean correct RTs from both conditions in the Test Phase were entered into a 2 x 2 ANOVA with factors of Condition (colour cueing vs configuration-removed) and Display Type (repeated vs unrepeated). The analysis showed that the cueing effect of Display Type just missed the conventional level of significance, $F(1, 13) = 4.12$, $p = 0.06$, where there was a trend for RTs in repeated displays to be faster than those in unrepeated displays. The main effect of Condition was not significant, $F(1, 13) = 3.19$, $p = 0.097$. Importantly, the Condition x Display Type interaction was significant, $F(1, 13) = 4.84$, $p < 0.05$. Post-hoc t-tests between repeated and unrepeated RTs showed that a contextual cueing effect occurred for the colour condition, $t(13) = 3.15$, $p < 0.01$ but there was no contextual cueing effect observed in the configuration-removed condition, $t(13) = 0.02$, $p = 0.98$. Corresponding analysis of error rates (for the Training phase and Test phase) showed no significant effects, all *Fs* < 2.3, except the Condition x Epoch interaction in the Training phase, $F(6, 78) = 3.68$, $p < 0.01$, where there tended to be fewer errors in Epochs 4-6 for the colour condition but this pattern was reversed in other epochs, and the effect of Display Type in the Test phase, $F(1, 13) = 3.32$, $p = 0.09$, where there was a trend for more errors in the repeated displays compared to the unrepeated displays. However, this difference was small (1.8% vs 1.0% for repeated and unrepeated displays, respectively).

The results showed that the learning of predictive colour cues was overshadowed by the learning of the predictive configuration. A contextual cueing effect was observed when participants were presented with predictive colour backgrounds alone in the colour cueing condition (see also Kunar et al., 2006). However, little evidence of colour contextual cueing was observed when predictive colour cues were presented alongside configural cues in the configuration-removed condition. Similar to Experiments 1 – 3, the results showed that when presented with both predictive colour cues and configural cues, the learning of configuration seems to dominate.

One final point to note is that the configuration-removed condition in this experiment was similar to the configuration-removed condition in Experiment 3. However, the results of this experiment showed there to be little advantage of having learned the predictive colour cues, while Experiment 3 showed that there was a CC benefit provided by the colour cues. It may be that with both predictive colour and configuration cues, there is a weak benefit of learning the predictive colour cues (as suggested by Experiment 3). However, importantly to note both experiments show that this learning is dramatically reduced when configural cues are present. We discuss this further in the General Discussion.

General Discussion

In contextual cueing, RTs to find targets in repeated contexts are faster than RTs to find targets in unrepeated contexts (Chun & Jiang, 1998). Contextual cueing effects have been shown to occur with cues such as distracter configurations (e.g., Chun & Jiang, 1998, Brady & Chun, 2007), background colours (Kunar et al., 2006) and naturalistic scenes (Brockmole & Henderson, 2006a, 2006b). This paper compared the influence of background colours and distracter configurations on contextual cueing. Experiment 1 investigated whether adding a predictive background colour to a predictive configuration increased CC. The results showed that there was little benefit of adding colour over and above the distracter configuration. Experiment 2 investigated whether adding a predictive configuration to a predictive background colour cue increased CC. In this experiment adding a predictive configural context led to a stronger contextual cueing effect. Experiment 3 showed that removing learned configural cues was more disruptive to CC than removing learned colour cues, while Experiment 4 showed that when configural cues and colour cues were presented concurrently, configural cues overshadowed the learning of colour cues. The data from Experiments 1 - 4 support a Configural Dominant account of CC suggesting that when both configural and colour cues accurately predicted the target location, configural cues acted as a stronger contextual cue in comparison to colour cues.

The fact that configuration dominated in this study may be due to the nature of the task. In visual search, participants need to attend to the search stimuli to make a response and not the background. In these experiments as participants have to process the search stimuli to respond to the target, it makes sense that the configuration of the stimuli, rather than the background, becomes associated with the target and acts as the dominant cue. Please note that our results are different to the results of Rosenbaum and Jiang (2013) who found that when configuration was presented with predictive scenes, configuration acted as the weaker cue. However, the difference may occur as scene-based learning is thought to occur due to explicit memory, rather than implicit memory. Explicit memory may help people directly guide their attention to the target location via top-down processes, leading to larger cueing effects (Rosenbaum & Jiang, 2013, see also Kunar et al., 2006; Jiang et al., 2013) than those produced by implicit memory (Endo & Takeda, 2004, Kunar et al., 2007; Kunar et al., 2008). Further evidence of this is reported by Jimenez and Vazquez (2010) who found that implicit learning of a sequence did not interfere with configural contextual cueing, however explicit memory of the same sequence interfered with the expression of contextual cueing, but not the acquisition.

Within the literature, it is debated how one stimulus overshadows another. For example, Rescorla and Wagner (1972) have suggested that when two cues are presented together they both compete for the same resources. As these resources are limited the learning of a stronger cue would impede learning of the weaker cue. In contrast, Matzel et al., (1985) suggested that the presence of the stronger cue prevents expression of the weaker cue. In this case, the association between the stimulus and response of the weaker cue would still be learned but the expression of this learning would not be visible in the presence of the stronger cue. Cleeremans (1997) investigated whether the presence of a stronger cue actually hindered learning of the overshadowed stimulus or prevented expression of it. In two experiments he gave participants a dual-stimulus setting where a sequential context could be implicitly learned to indicate where the next stimulus would appear or the explicit presence of an 'X' cue could indicate where the next stimulus would appear. Cleeremans (1997) found participants still showed sensitivity to the structure of the sequence, suggesting that participants had acquired knowledge of the sequential structure even when a superior and more explicit cue (e.g. the X) had been presented. Beesley and Shanks (2012) also found that when two predictive contexts were trained in compound, by the end of the experiment learning of both sets of distracter patterns had occurred. In relation to the work presented here, the presentation of colour and configural cues could be thought of as a dual-stimulus setting as both cues predicted the target location. Our results suggest that, similar to the work of Cleeremans (1997) and Beesley and Shanks (2012), the presence of the stronger configural cue did not hinder learning of the predictive colour cues as both colour and configural cues showed evidence of being learned in unison (e.g. Experiment 3). Instead having a stronger cue present was more likely to interfere with the expression of the weaker cue when they were presented together compared to when they are presented apart.

How do these results relate to others in the literature? Ehinger and Brockmole (2008) found that when using photographic stimuli colour was not an important contextual cue. Despite this they predicted that colour would be profitable when the displays were made of simpler stimuli. Goujon et al. (2012) found this to be the case when using abstract geometrical patterns as cues. However, this did not occur here: when configuration and colour were presented together, using simple letter visual search arrays, colour was the weaker cue. Although on first glance these results run counter to the predictions of Ehinger and Brockmole (2008), a Configural Dominant account can explain the differences, if the semantic information in the photographs acted to produce configural landmarks. With the presence of configural information, colour does not act as a strong cue. However, when there were no distinctive landmarks (buildings, bridges, roads in photographic stimuli or invariant distracter layouts in simple search tasks) colour acted as the dominant cue making the backgrounds more distinctive (Goujon et al., 2012).

One could argue that, in these series of experiments, participants did not process the background and so were unable to use it as a cue. Although possible, this seems unlikely. Previous research has shown that the background colour of a display was able to cue the target's location, leading to a robust facilitation effect (Kunar et al., 2006, see also Experiments 2 and 4 here). Furthermore, it has been well established that participants were able to process the statistics of a display early on in the visual process. For example, Chong & Treisman (2003) showed that the mean estimates of a scene could be accurately judged within 50 msecs, while Oliva & Torralba (2006) showed that people could process gists of scenes rapidly after first presentation (see also Chong & Treisman, 2005a, 2005b; Oliva & Torralba, 2001, Rensink, 2002, Potter, 1975, 1976, Potter et al., 2004, Thorpe et al., 1996 for evidence of fast processing of scene statistics). Given that the backgrounds in Experiments 1

– 4 here provided a contextual cueing effect, were highly salient and that scene statistics were assimilated early on it is highly unlikely that the background colour was not processed.

Instead, our results suggest that compared with colour, configuration acts as the stronger contextual cue. The fact that configural information was weighted higher than colour, makes sense if we think about our everyday visual environment. Here physical and spatial structures are often more stable across time compared with colour information. To borrow an example from Jiang and Song (2005) imagine walking around a new city on a warm sunny day. As you navigate about the streets you learn the landmarks that will act as context to help you navigate around on future occasions. However, on future visits the day may be more dark and gloomy changing the overall perceptual colour of what we see (e.g. a bright green patch of grass on a sunny day may appear darker and muddier on a rainier day). A visual system that weighted configuration over colour would be optimal in this situation as it would be unaffected by colour transients. Instead it would be able to use the more stable spatial layout to optimally navigate, respond to and recognize the environment.

Does this mean that colour does not play a role in contextual cueing? Previous evidence suggests otherwise. In the absence of other competitive contextual cues, colour provides strong predictive information to help target detection (Experiments 2 and 4, see also Kunar et al., 2006). Other work has shown that it is not just the colour of the backgrounds that provide predictive contexts but the colour of the search stimuli can act as a repeated context, too (Kunar et al., 2006). Kunar et al. (2006) had participants search for a target T among distracter Ls. Crucially, from trial to trial the colour of the stimuli changed (e.g. in one trial all the stimuli were red, in another trial all the stimuli were green). They found that if the colour of the stimuli was paired with a target location (e.g. if all the stimuli were red the target would appear in position X, if all the stimuli were green the target would appear in position Y) then participants showed a contextual cueing benefit, similar to the benefit provided by having a coloured background (Kunar et al., 2006). Importantly, in these tasks participants actively attended the coloured letters during the search task – if attention was not applied to the coloured stimuli, no contextual cueing would have been found (see also Jiang & Chun, 2001). To conclude, the role of colour in contextual cueing is complex. Although important in the absence of configural cues, when configural information is available, colour learning was overshadowed and only acted as a weak contextual cue. Instead invariant spatial layouts elicit strong cueing effects - in line with a Configural Dominant account of CC.

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Figure Legends

Figure 1 – Example displays for Experiment 1. In the configural condition the target location was predicted by the spatial layout. In the combined condition the target location was predicted by both the spatial layout and the background colour (depicted by the different shades of grey). Note that in the experiment proper the set size equalled 12 and a black box surrounded each stimulus in the combined/colour conditions.

Figure 2 - Mean correct RTs for (a) the Training Phase across epoch and (b) the Test Phase in Experiment 1. Error bars represent the standard error.

Figure 3 – Example displays for Experiment 2. In the colour condition the target location was predicted by the background colour (depicted by the different shades of grey). In the combined condition the target location was predicted by both the spatial layout and the background colour.

Figure 4 - Mean correct RTs for (a) the Training Phase across epoch and (b) the Test Phase in Experiment 2. Error bars represent the standard error.

Figure 5 – Example displays for Experiment 3. In the test phase of the Colour-Removed condition the background colour cue was removed so that only the spatial layout cue predicted the target location. In the test phase of the Layout-Removed condition the spatial layout of the distracters changed so that only the background colour predicted the target location.

Figure 6 - Mean correct RTs for (a) the Training Phase across epoch and (b) the Test Phase in Experiment 3. Error bars represent the standard error.

Figure 7 - Mean correct RTs for (a) the Training Phase across epoch and (b) the Test Phase in Experiment 4. Error bars represent the standard error.

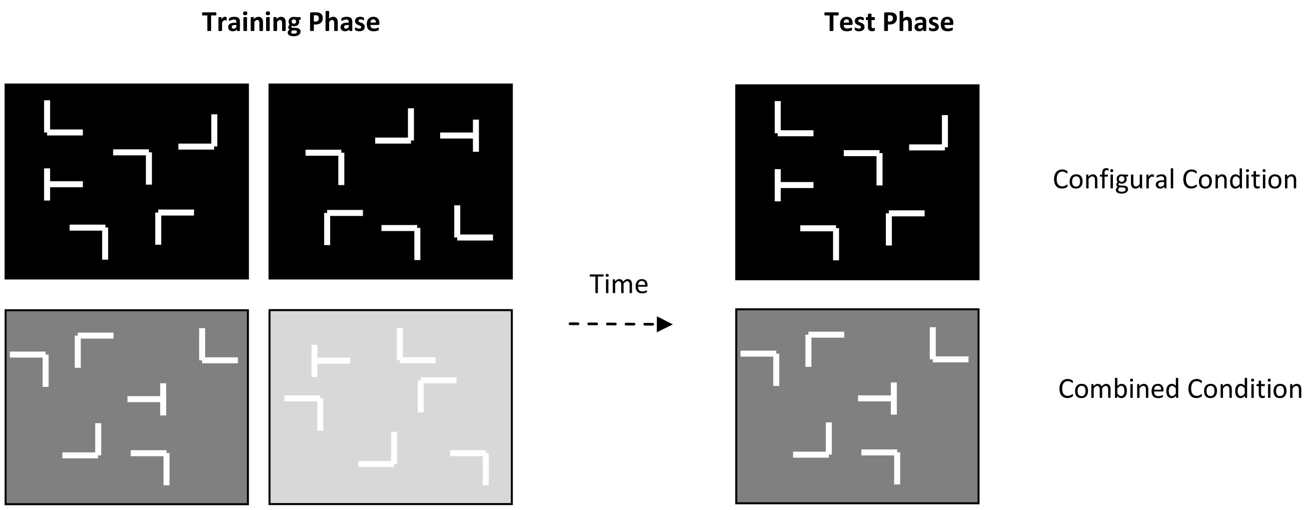
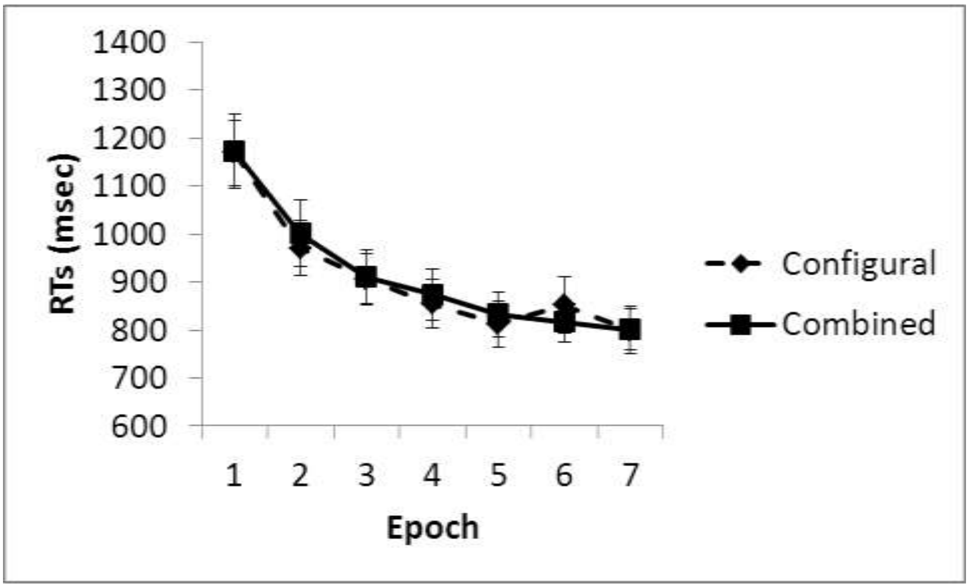

Training Phase
Test Phase
Configural Condition
Time
Combined Condition

Figure 1

a)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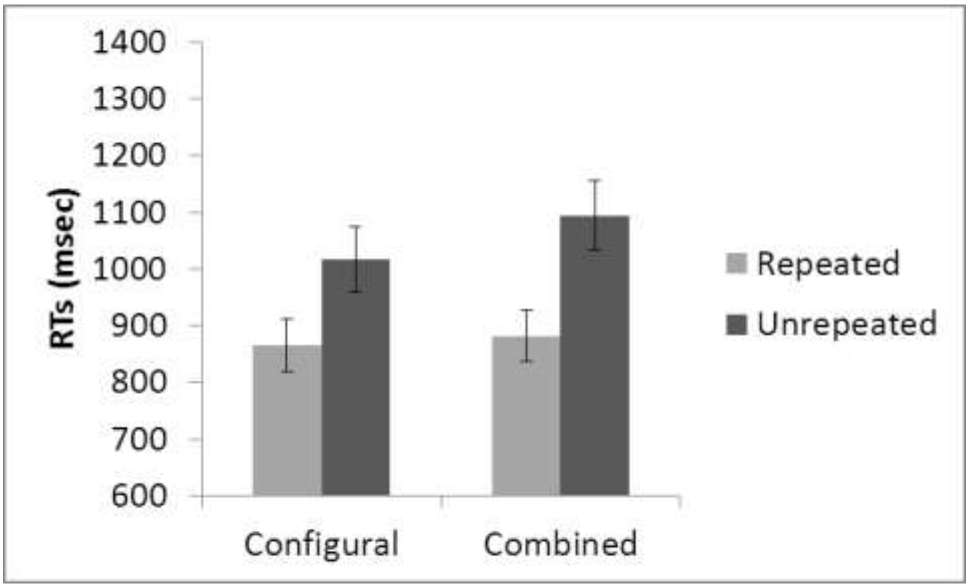
Epoch
Configural
Combined

b)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RTs (msec)
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Repeated
Unrepeated

Figure 2

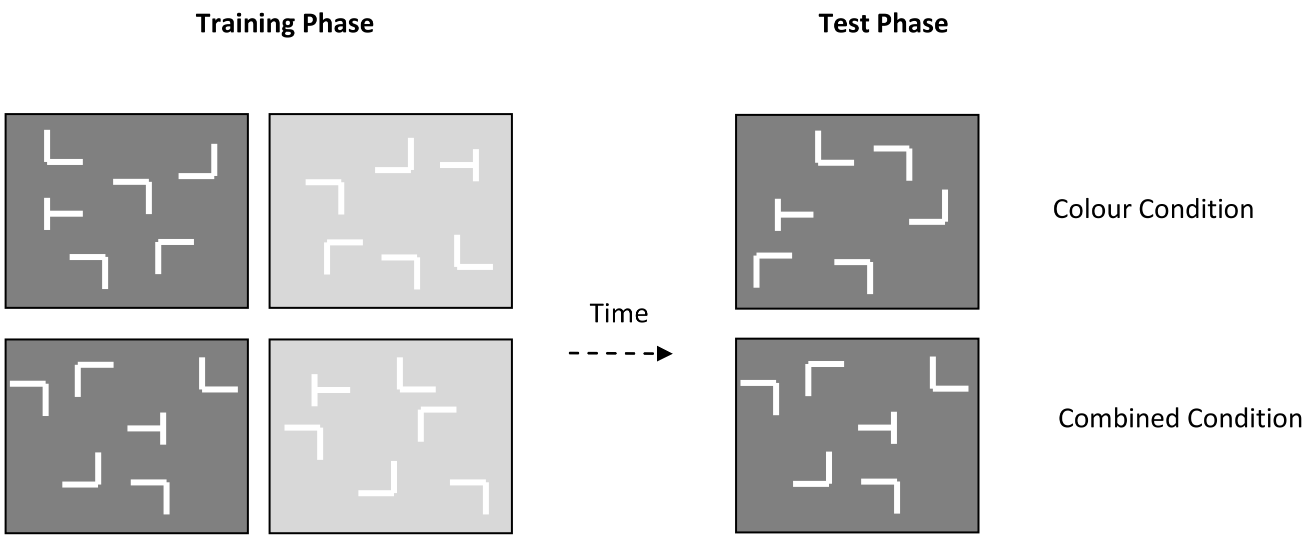
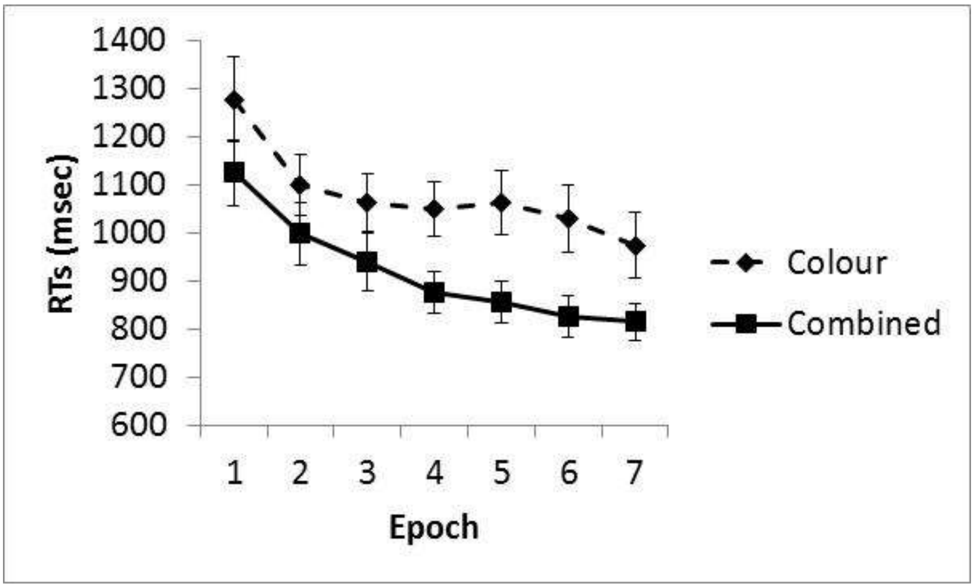

Training Phase
Test Phase
Time
Colour Condition
Combined Condition

Figure 3

a)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Colour
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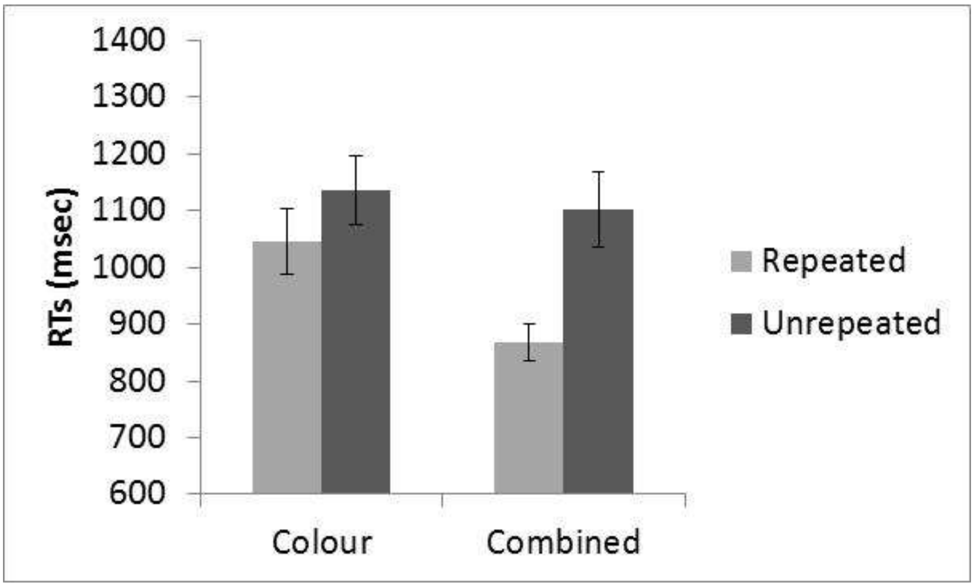
b)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RTs (msec)
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Repeated
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Figure 4

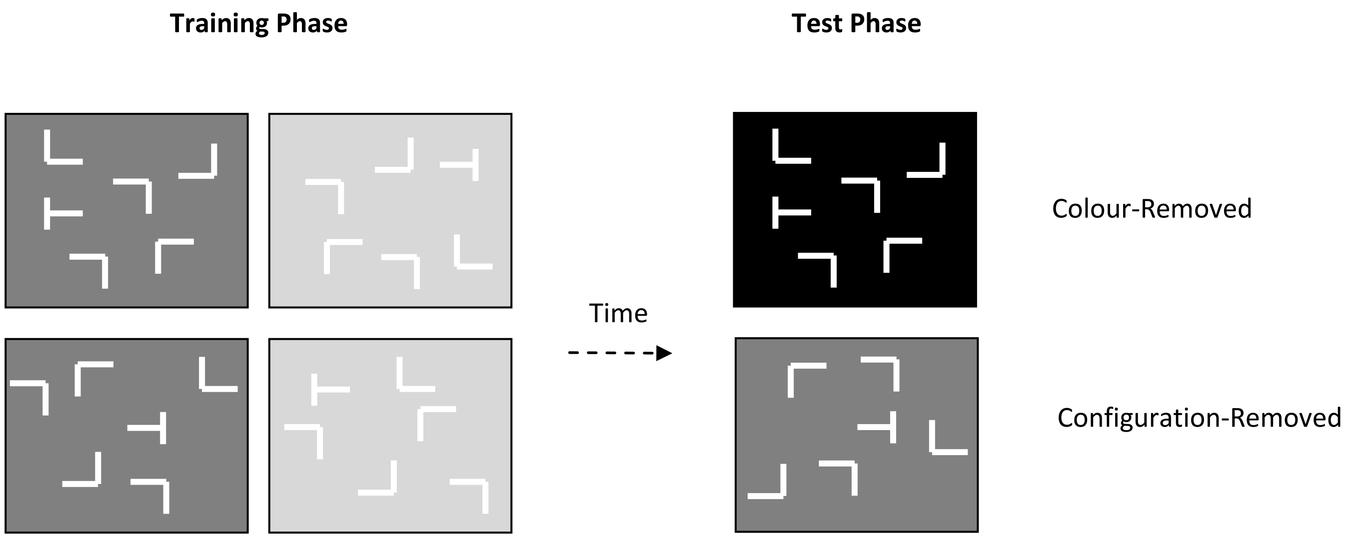
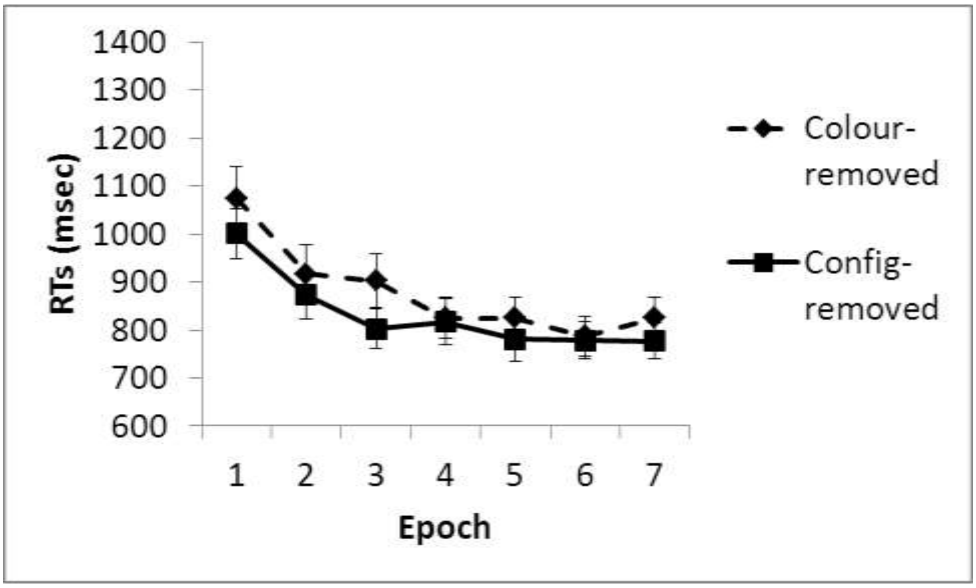

Training Phase
Test Phase
Time
Colour-Removed
Configuration-Removed

Figure 5

a)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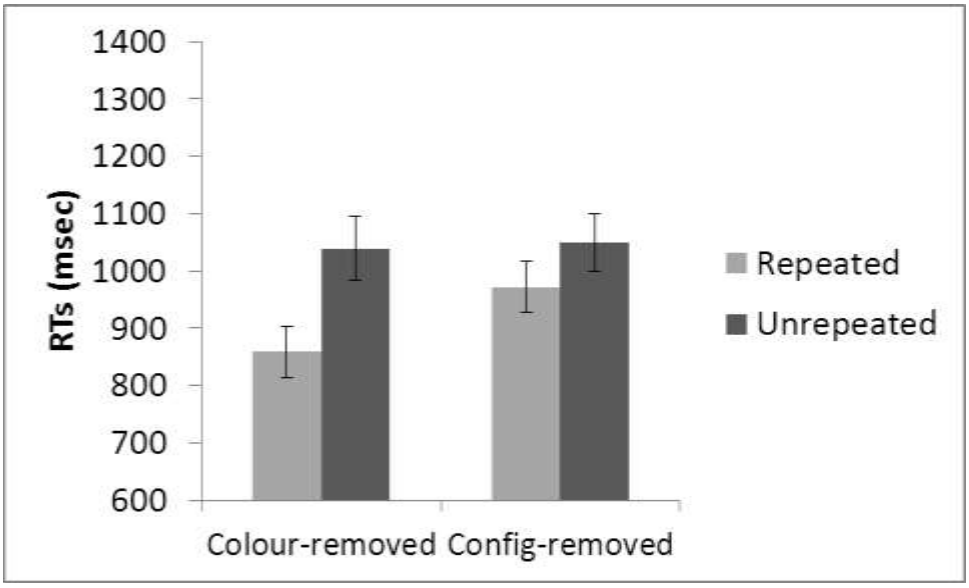
Colour-removed
Config-removed

b)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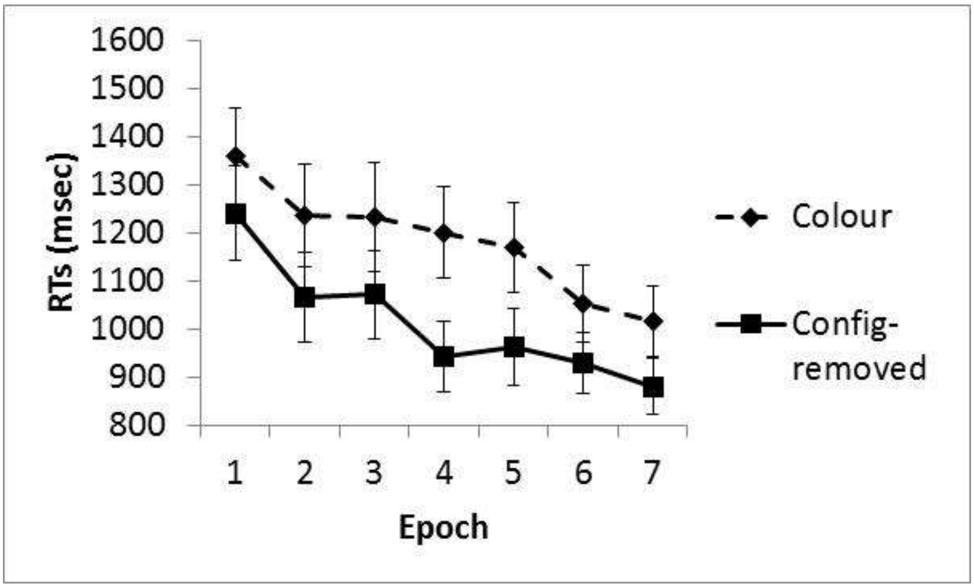
RTs (msec)
Colour-removed
Config-removed
Repeated
Unrepeated

Figure 6

a)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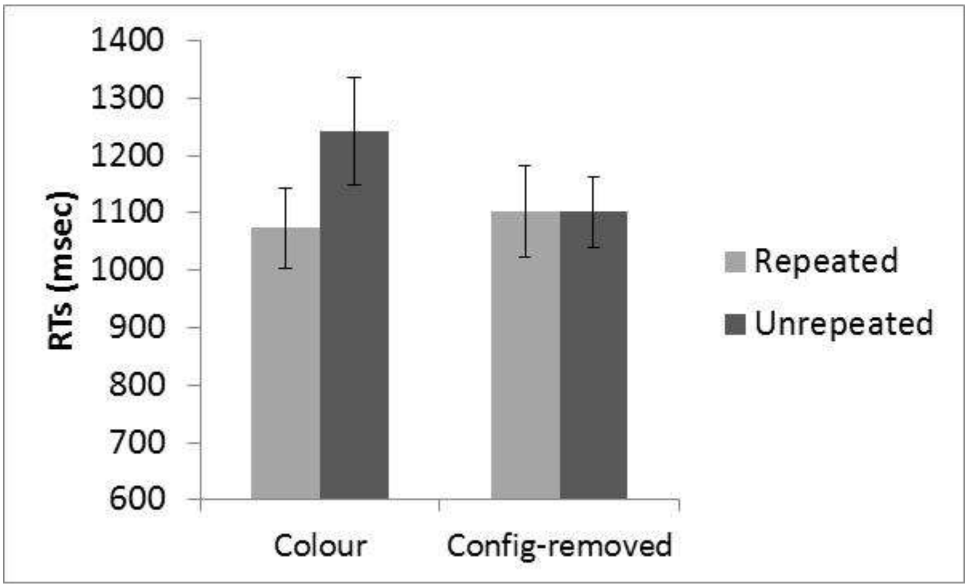
Epoch
Colour
Config-removed

b)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RTs (msec)
Colour
Config-removed
Repeated
Unrepeated

Figure 7