1   **Contextual cuing in the presence of an endogenous cue for attention**

2   Tom Beesley[1], Louise Earl[1], Hope Butler[1], Inez Sharp[1], Ieva Jaceviciute[1], and & David

3   Luque[2]

4   [1] Lancaster University

5   UK

6   [2] Universidad de Málaga

7   Spain

8   **Author Note**

9

10   Correspondence concerning this article should be addressed to Tom Beesley,

11 Department of Psychology, Lancaster University, UK, LA1 4YD. E-mail:

12 t.beesley@lancaster.ac.uk

Abstract

Three experiments explored the interaction between an endogenous cue of attention and the repetition of a visual search display during contextual cuing. In Experiment 1, participants readily learnt about repeated configurations of visual search, before being presented with an endogenous cue for attention towards the target on every trial. Participants used this cue to improve search times, but the repeated contexts continued to guide attention. Experiment 2 demonstrated that the presence of the endogenous did not impede the acquisition of contextual cuing. Experiment 3 confirmed the hypothesis that the contextual cuing effect relies largely on localised distractor contexts, following the guidance of attention. Together, the experiments point towards an interplay between two drivers of attention: after the initial guidance of attention, memory representations of the context are flexibly deployed to facilitate the target detection.

Public significance statement:

Keywords: visual search; contextual cuing; endogenous cuing

Word count: 7812

Contextual cuing in the presence of an endogenous cue for attention

It is well established that the process of visual search is guided by past experience. When we encounter a scene, the extent to which the configuration of stimuli matches stored representations in memory will determine the effectiveness of the processing and subsequent search through the elements of that scene. This cognitive process is studied in the lab using the contextual cuing (CC) task: participants typically experience a standard visual search task (i.e., serial processing; slow search), such as searching for a T amongst L shapes. A set of search configurations is repeated across trials, and response times to targets are faster compared to those in configurations that do not repeat. Thus, the repetition of the search configurations leads to a stored representation of (some aspect of) the configuration in memory, and future processing of the same configuration activates the memory representation, driving more efficient search behaviour within that scene.

Much work has focused on the nature of the memory and attention processes responsible for contextual cuing. The effect was initially suggested to be implicit in nature, with repeated configurations seemingly guiding search unconsciously: typically participants are unable to articulate their knowledge of the repeated configurations, and show poor ability to recognise configurations in memory tests (e.g., Chun & Jiang, 1998; Colagiuri & Livesey, 2016), although this view of CC has been strongly contested (e.g., Smyth & Shanks, 2008; Vadillo et al., 2016). There are also a number of plausible models of how memory representations of repeated configurations might guide search (e.g., Beesley et al., 2015; Brady & Chun, 2007), with the predominant view being that the memory representations are best characterised as associative in nature, whereby distractors (or groups of distractors, see Beesley et al., 2016) form associations that activate more likely target positions.

The exact nature of how repeated configurations facilitate visual search is also the focus of much debate within the literature. There is a question as to whether CC reflects

enhanced attentional processing of the display, such as by reducing the number of distractors processed (e.g., Beesley et al., 2018), or whether it facilitates the decision process once targets have been detected (e.g, Kunar et al., 2007; Sewell et al., 2018). The current article focuses on the assumed attentional advantage for repeated configurations, and explores the extent to which this results in an automatic form of attentional bias. That is, to what extent does the processing of the search configuration control the guidance of attention, and to what extent does that guidance persist even in the presence of other top-down control processes that might be driving attention.

A number of studies have explored how flexible the learned behaviours are in contextual cuing. For example, a number of studies have shown that moving the target to a new position within the display will abolish the established CC effect (Makovski & Jiang, 2011; Manginelli & Pollmann, 2009). Notably, Zellin et al. (2013) explored the remapping of target positions over a longer training period, observing that with extended training, new associations will form for these new target positions, though the effects are limited to targets that appear closer to those that are initially trained. This suggests that any relocation effect is driven strongly by a generalisation of the pre-existing associations. Furthermore, strong contextual cuing effects were observed for the initially trained targets in a final "return phase" at the end of the experiment. All of these results point towards CC constituting a fairly inflexible behaviour that is activated somewhat automatically during search.

More direct examination of the role of top-down control processes on CC comes from Luque et al. (2017) (Experiment 3). They used a task in which participants were initially given a standard CC experiment (search for a T amongst Ls), before then being told in a second phase that the target would appear in two designated positions along the horizontal mid-line of the screen. Participants were given an explicit instruction to search in these two locations for a new target (a Y); in this phase participants engaged in a new search task requiring controlled attention to specified locations. Yet the underlying

configuration of repeated distractors was still present, as was the original target, which appeared in its trained location for that configuration. Luque et al. found that the acquired knowledge of the configurations did not affect performance in this second phase: responses to the new target were comparable when the old target was pointed in either the same or opposite direction to the new target, suggesting that there was no detectable processing of the old target (see also Luque et al., 2021). The suggestion is that contextual cuing can be controlled in the presence of a top-down instruction to search in a new location - search is not automatic in nature in the CC task.

One potential issue with the studies presented by Luque and colleagues (Luque et al., 2017; Luque et al., 2021) is that participants are instructed to engage in a new search process for a new target object: participants initially search for a T and are later instructed to search for a Y. The role of a prior target template is important for visual search (Vickery et al., 2005; Võ & Wolfe, 2012), and object identities appear to play an important role in the contextual cuing effect (Makovski, 2018, 2017). While it is unclear how dependent CC is on the identity of the target, it is possible that distractor-target associations may well be sensitive to target identity and to the goals of the participant. For this reason, the current study assesses the impact of top-down instruction on CC when participants maintain the same task goal of searching for a single target identity within the display.

The overarching aim of the current study is to explore the interaction between controlled (top-down) attentional processes and the pattern of search behaviour established by the repeated configurations. Specifically we seek to understand whether repeated configurations continue to guide attention even when participants are directed to alter their natural search patterns by the presence of an endogenous cue (an arrow that instructs the participant to direct attention in a specific direction). The experiments explore both the performance aspect of CC in terms of whether it continues to guide behaviour once an endogenous cue is introduced, and also whether the development of the search behaviour is impeded when trained concurrently with the endogenous cue.

Transparency and Openness

The raw data, analysis scripts, experimental materials, and the manuscript source files, are available at http://github.com/tombeesley/CC_Control. The analyses reported in this manuscript are computationally reproducible from the manuscript source files (using R v4.3.1), which are available at the github repository. The study design and analyses were not pre-registered.

Experiment 1

Experiment 1 sought to examine whether the learnt attentional behaviour that develops during contextual cuing is expressed when participants are directed by an endogenous (instructional) cue to search in a particular region of the visual scene. Participants were first trained with a set of four repeating configurations in phase 1 across 5 epochs of 32 trials each. Then prior to phase 2, participants were told that an arrow would appear before every trial indicating the side of the screen on which the target would be located. This arrow was valid on every trial. In phase 2, the repeating configurations were presented in two forms: "consistent", where the target appeared in the same position as it has appeared for that configuration in phase 1; and "inconsistent", where the target appeared in a position in the opposite quadrant of the screen from where it had appeared in phase 1. Random configurations were also presented in this phase. If the contextual cues within the repeated configurations continue to guide attention in the presence of the instructional cue, then we would expect that response times would be faster on consistent trials compared to random trials. In addition, we would also expect that the contextual cues would guide attention *away* from the (new) target quadrant on inconsistent trials, and so response times should be slower on these trials compared to those on random trials.

Method

Participants

Thirty-one undergraduate students from Lancaster University were recruited (mean age = 20.13, SD = 1.09; 17 identified as female and 14 as female) via the Psychology Research Participation System in the Department of Psychology at Lancaster University, in return for the opportunity to use the recruitment system for their own research in future years.

Materials

Participants were tested individually in a quiet room with a Dell laptop with a 15.6" screen, a screen resolution of 1920 x 1080, and a full size external keyboard for participants to use to respond to the task. Participants sat approximately 50 cm from the screen. Stimulus presentation was controlled by MATLAB using the Psychophysics Toolbox extensions (Brainard, 1997; Kleiner, Brainard & Pelli, 2007; Pelli, 1997). Responses to the target stimulus were made by pressing the 'c' or 'n' key on a standard keyboard. All experimental materials are available at the github repository for this study.

Distractor stimuli were an 'L' shape (rotated 0°, 90°, 180°, or 270°) while the target stimulus was a 'T' shape (rotated at either 90° or 270°). Stimuli were 8 mm square and arranged in a square grid of 144 evenly spaced cells (12 x 12) which was positioned centrally on the screen and was 170 mm square. The grid itself was invisible to participants. The fixation cross (displayed centrally before each trial) was 4 mm square. The background of the screen was grey (RGB: .6, .6, .6) and the stimuli were presented in black (RGB: 1, 1, 1). There was a small offset in the vertical line of the 'L' distractors, which increased the similarity between the 'L' distractors and the target 'T', making the search task more difficult (Duncan & Humphreys, 1989).

Design

Phase 1 employed a within-subjects design with factors of epoch (1-5) and configuration (repeated and random). All configurations contained 16 distractors, equally divided between the four quadrants of the display, and one target. Four repeated configurations were trained. Four target locations were used, with one from each quadrant assigned to each of the repeated configurations. These same four target positions were used for the random configurations throughout the task. Each of these four target positions was chosen at random from one of five locations within each quadrant, that were approximately equidistant from the center of the screen. Distractors could not appear in these target locations.

Phase 2 employed a within-subjects design with factors of epoch (6-10) and configuration (repeated: consistent; repeated: inconsistent; random: consistent; random:inconsistent). On each trial, there was a .5 probability that an "inconsistent" version of the configuration would be presented. This meant that the target was relocated to a diametrically opposed target position such as to maximise the displacement from the trained target position (see Figure 1). This could occur for both the repeated and random configurations, hence creating four unique trial types for this phase. While random configurations did not have a "trained", associated, target position, it is necessary to divide the random trials into consistent and inconsistent trial types in this way in order to assess any target frequency effects that may occur, since the inconsistent target locations used in this phase were novel.

Procedure

Participants were tested individually in a quiet testing room. They were given instructions on how to complete the task, including the presentation of an example of a search trial. Participants were shown the two correct responses for the two possible orientations of targets.
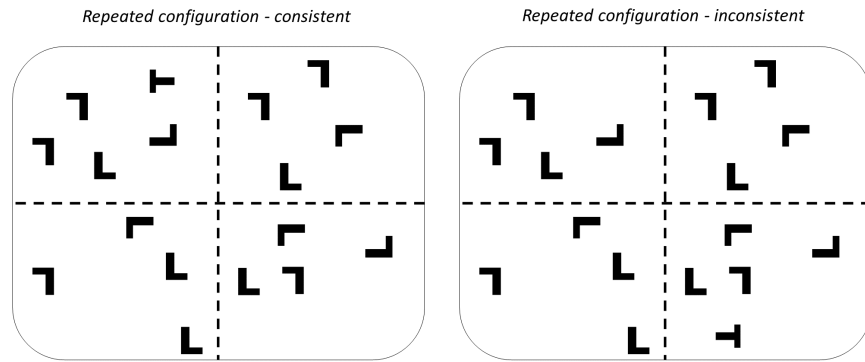
Figure 1

Schematic of the manipulation of target position in consistent and inconsistent trials of phase 2. The dashed lines show the division of the stimuli into quadrants, but were not present in the task procedure.

¹⁸¹ Each trial commenced with a fixation cross presented in the center of the screen for

¹⁸² 500 ms, which was then replaced immediately by the search configuration. Participants

¹⁸³ searched for the target stimulus and responded with a left or right response depending on

¹⁸⁴ its orientation. Reaction times (RTs) were recorded from the onset of the search

¹⁸⁵ configuration. Following a valid response (c or n), the configuration was removed from the

¹⁸⁶ screen. The ITI was 1000 ms. If participants made an incorrect response to the target

¹⁸⁷ orientation, "INCORRECT RESPONSE" appeared in red in the center of the screen for

¹⁸⁸ 3000 ms, prior to the ITI. If participants did not respond within 6000 ms, "TIMEOUT -

¹⁸⁹ TOO SLOW" appeared in red in the center of the screen for 3000 ms, prior to the ITI.

¹⁹⁰ Each block of eight trials contained each of the four different repeated

¹⁹¹ configurations and four random configurations. These eight configurations could appear in

¹⁹² any order with the constraint that the position of the target did not repeat across trials or

¹⁹³ across consecutive blocks.

¹⁹⁴ A rest break of 30 seconds was given every 80 trials. Trials started automatically

¹⁹⁵ after these breaks.

196   After 160 trials, prior to phase 2, participants were given an instruction screen

197 which detailed the arrow that would appear on the screen prior to the configuration. They

198 were able to ask any questions they had at this stage and then proceeded to phase 2. The

199 arrow appeared for 1000ms following the fixation cross, before the presentation of the

200 search configuration. The task was otherwise identical to that used in phase 1.

201 **Results**

202   Our criterion for removing outlier data, at both the participant level and the trial

203 level, was 2.5 standard deviations above or below the mean of the sample. On average,

204 trials ended with a timeout on 1.97% of trials (SD = 2.53). Two participants had an

205 usually high proportion of timeouts and were removed from the analysis. The mean

206 accuracy of participants (not including timeout trials) was 98.10% (SD = 1.65%). One

207 participant had an unusually low proportion of accurate trials and was also removed. The

208 only participant deemed to be an outlier in terms of mean response time (hereafter RT)

209 was also excluded on the basis of the timeout criterion, noted above.

210   For the remaining twenty-eight participants we removed trials with a timeout and

211 inaccurate trials, before removing outliers from the RT data. On average, the proportion of

212 outliers removed was 3.03% (SD = 0.79%). Zero participants had an unusual proportion of

213 trials removed as outlier RTs (greater than 2.5 SDs above the mean).

214   Figure 2 shows the RT data across the 10 epochs of the experiment. In phase 1

215 (epochs 1-5) a contextual cuing effect emerged, with faster responses to repeated over

216 random configurations. In phase 2, the presence of the guiding arrow led to a clear

217 reduction in the response times. For all participants, the mean RT across epochs 4 and 5

218 was higher than the mean RTs across epochs 6 and 7. Despite the clear evidence for the

219 processing of the endogenous cue, the underlying search configuration continued to play a

220 role in the guidance of attention, with faster response times for (consistent) repeated

221 configurations compared to random configurations.
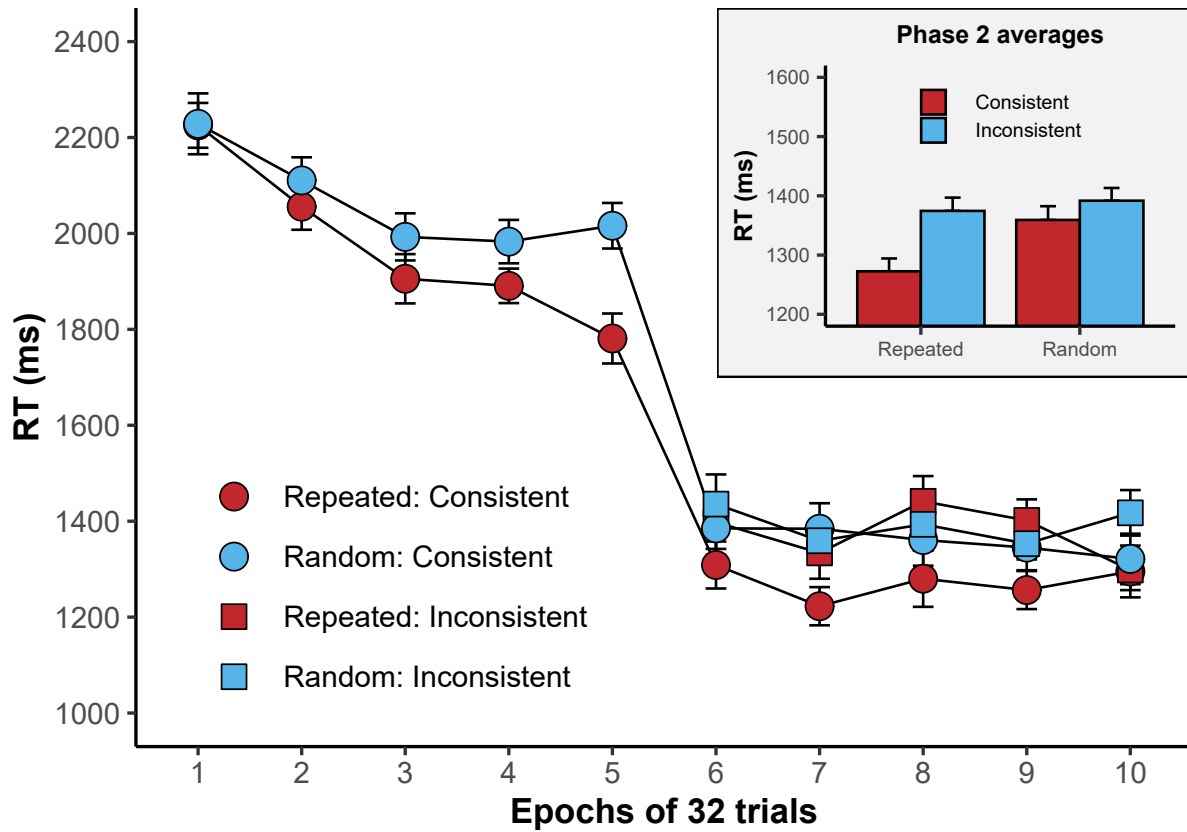
Figure 2

RT data for Experiment 1. The phase 2 averages across the four trial types are shown inset. Within-subject error bars were computed by a process of normalising the RT data for the sample (Cousineau, 2005).

²²²   These data were analysed with a Bayesian ANOVA[1], using the

²²³ *BayesFactor::anovaBF()* function in R. All analyses in this study used the default

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[1] The Bayesian analyses here follow the process outlined in Rouder et al. (2017). Briefly, we present the best fitting model evaluated against the null model, and then compare this fit to that of other models. Where the comparison of two models (i.e., A against B) reveals a Bayes Factor of greater than 3, this is taken as support for the components of model A that are not present in model B. Bayes Factors of less than 0.33 are taken as evidence in support of the equivalence of two models. Following Wetzels et al. (2011) we use the terms "substantial" (BF>3; BF<1/3), and "strong" (BF>10; BF<1/10) to reflect the levels of support for the results of the model comparisons.

parameters for the priors, which "places mass in reason-able ranges [of effect sizes] without being overcommitted to any one point" (Rouder et al., 2017, p. 317). First taking the data from phase 1 (epochs 1-5), there was strong support for the model containing the factors of epoch and configuration (repeated vs. random), $BF_{10} = 2.2 \times 10^{12} \pm 0.83\%$. The addition of the interaction term did not improve the model fit, $BF = 0.45 \pm 1.37\%$, though there was no evidence for the absence of the interaction. The best fitting model was a better fit than the two models containing only one of the factors, smallest $BF = 35.83 \pm 0.89\%$, providing strong support for both the effects of configuration and epoch. Partial eta-squared (n_p^2) effect sizes were calculated using *effectsize::eta_squared*, giving values of: 0.22 for the effect of configuration; 0.39 for the effect of epoch; and 0.10 for the interaction effect.

A Bayesian ANOVA on the data from phase 2 (epochs 6-10) found strong support for the model containing the factors of configuration (repeated vs. random) and target position (consistent vs. inconsistent), $BF_{10} = 46.97 \pm 1.44\%$. The next best fitting model contained these two factors and the interaction term, and was not a substantially worse fit to the data, $BF = 0.54 \pm 2.76\%$. The best fitting model (with factors of configuration and target position, but no interaction) was a substantially better fit to the data than the model containing only the factor of configuration $BF = 21.09 \pm 1.59\%$ providing evidence that RTs were faster on consistent than inconsistent trials. There was no evidence for a difference between the best fitting model and the model containing only the factor of target position, $BF = 2.39 \pm 1.55\%$. The relevant effect sizes (n_p^2) were: 0.14 for the effect of configuration; 0.22 for the effect of target position; and 0.14 for the interaction of these two factors.

To further explore responses to the different trial types in phase 2, Bayesian t-tests were run using BayesFactor::ttestBF (using the default Cauchy prior) for comparisons between the repeated and random configurations, across the two target position conditions (consistent and inconsistent). This revealed substantial support for a difference between the response times on "repeated: consistent" trials and those on the respective random

trials (random: consistent), $BF_{10} = 4.14 \pm 0\%$. There was also substantial evidence to

suggest there was no meaningful difference between the response times for the "repeated:

inconsistent" trials and the respective random trials, $BF_{10} = 0.24 \pm 0.03\%$.

Discussion

Experiment 1 sought to examine the consequence of an endogenous cue that

prompts top-down control of the search process on contextual cuing. In phase 1 we

established a robust contextual cuing effect. Following this, participants received

instruction that each trial would be preceded by an arrow stimulus that would signal the

side of the screen on which the target would appear. This cue was valid on all trials in

phase 2. Consistent with these instructions and the processing of this cue, we observed

substantially reduced search times in phase 2 compared to phase 1. The same set of

repeated configurations were presented in phase 2, but for half of the trials, the target was

relocated to the diagonally opposed quadrant of the screen. Therefore, on these "repeated

inconsistent" trials, the underlying configuration of distractors predicted the target in a

location that opposed that of the (valid) endogenous cue. Across this phase we observed

significant contextual cuing for the repeated consistent trials, demonstrating that the

underlying configuration of distractors continued to guide attention in the presence of the

endogenous cue. However, the repeated inconsistent trials did not lead to an impairment in

response times relative to random trials, suggesting that the underlying configuration did

not influence search on these trials.

Experiment 2

In Experiment 1 we demonstrated that an established effect of contextual cuing is

maintained even when attention is being guided by the presence of a valid endogenous cue.

That is, we found that the *performance* of an established search behaviour in contextual

cuing is not disrupted by concurrent top-down goals to guide attention in a controlled

manner. In Experiment 2 we wanted to explore whether the *learning* of the contextual cue

itself was affected by the presence of a valid endogenous cue. That is, does the presence of a valid endongenous cue, which leads to a controlled command of attention, limit the development of a contextual cuing effect. To do this, we trained each participant on two sets of repeating configurations. One of these sets was always presented in the presence of a valid endogenous cue, while the other set was always presented in the absence of the endogenous cue. The extent to which there is a "cue-competition" effect between the endogenous cue and the contextual cues can be examined by comparing the contextual cuing effect we observe for the two sets of configurations. Given the clear difference in RTs we observed in Experiment 1 between the trials with the endogenous cue present and the cue being absent, we anticipated the same difference in responding in Experiment 2. Therefore we also included a second phase of Experiment 2 in which we removed the endogenous cue entirely from the task. This second phase therefore allowed us to directly compare the contextual cuing for the two sets of configurations when RTs were at a comparable level.

 "Cue-competition" effects have been examined previously in contextual cuing. Endo and Takeda (2004) trained participants with a contextual cuing task composed of distractor location configurations and repeating distractor identities. Their experiments suggested that the stronger configural (spatial) cue out-competed the cue provided by the distractor identities. Similarly, Kunar et al. (2014) found that when colour cues and configural cues both predicted the target location, configural cues were dominant and tended to overshadow the weaker colour cue. Beesley and Shanks (2012) looked at the cue-interaction effects *within* a configuration of distractors. Participants were first trained with half a configuration of repeating distractors that predicted the target (8 out of 16 distractors). In a later stage these distractors were paired with a new half-configuration, such that the whole configuration now predicted the same target location. In contrast to the predictions of the vast majority of models of contingency learning, learning about these new predictive distractors was facilitated, rather than impaired in this second phase

304 (relative to a control condition). Thus, Beesley and Shanks (2012) found that

305 cue-competition was not observed within a configuration of equally predictive distractors.

306 Together these studies suggest that the spatial configuration serves as a strong cue for the

307 target and will out-compete non-configural cues for access to the learning mechanism. The

308 dominance of the configuration in these situations may therefore lead to the prediction that

309 the endogenous cue would not "block" the learning of the configuration in the current task.

Method

Participants

312 Thirty-four undergraduate students from Lancaster University were recruited (mean

313 age = 20.74, SD = 5.29; 28 identified as female and 6 as male) via the Psychology Research

314 Participation System in the Department of Psychology at Lancaster University, in return

315 for the opportunity to use the recruitment system for their own research in future years.

Materials

317 Participants were tested in a quiet laboratory testing cubicle, with a standard PC

318 and a 24" monitor set at a resolution of 1920 x 1080 pixels. Since the monitor was larger

319 for this experiment, the dimensions of the presented stimuli had a proportional increase in

320 size: Distractor stimuli were 11 mm square; the search grid was 240 mm square; the

321 fixation cross was 6 mm square. In all other respects, the materials were the same as those

322 detailed in Experiment 1.

Design

324 Four repeated configurations were created in an identical manner to those used in

325 Experiment 1. For each participant, two of these configurations were used for the

326 "cue-competition" condition, in which the arrow cue was presented before the

327 configuration, while two were used for the "control" condition (no arrow presented). As in

328 Experiment 1, the four repeated configurations were paired with unique target positions

329 from each of the four quadrants. We counterbalanced the use of the target quadrants

330 across the factors of configuration type (repeated and random) and cue condition

331 (cue-competition and control). For half of the participants, targets in the top left and

332 bottom right were used for the repeated configurations presented with the arrow

333 (cue-competition) condition, with targets in the top right and bottom left used for

334 repeated configurations in the no-arrow (control) condition. For these participants, random

335 configurations presented with the arrow had targets in the top right and bottom left, and

336 random configurations without the arrow had targets in the top left and bottom right. For

337 the other half of the participants these assignments were reversed (repeated-arrow:

338 top-right and bottom-left; repeated-no arrow: top-left and bottom-right; random-arrow:

339 top-left and bottom-right; random-no arrow: top-right and bottom-left).

340 *Procedure*

341   The procedure was the same as Experiment 1 with the following differences.

342 Participants received 320 trials in total. For the first 160 trials, the arrow was presented for

343 the relevant conditions. For the final 160 trials, the arrow was never presented. Rest breaks

344 were given every 60 trials.

345 **Results**

346   Our criteria for removing outlier data were identical to Experiment 1. On average,

347 trials ended with a timeout on 2.13% of trials (SD = 1.83). Zero participants had an

348 usually high proportion of timeouts. The mean accuracy of participants (not including

349 timeout trials) was 95.85% (SD = 6.10%). One participant had an unusually low

350 proportion of accurate trials and were removed from the sample. Zero participants were

351 deemed to be an outlier in terms of mean RT.

352   For the remaining thirty-three participants we removed trials with a timeout and

353 inaccurate trials, before removing outliers from the RT data. On average, the proportion of

354 outliers removed was 2.81% (SD = 1.04%). One participant had an unusual proportion of

355 trials removed as outlier RTs and were not included in the final analysis.
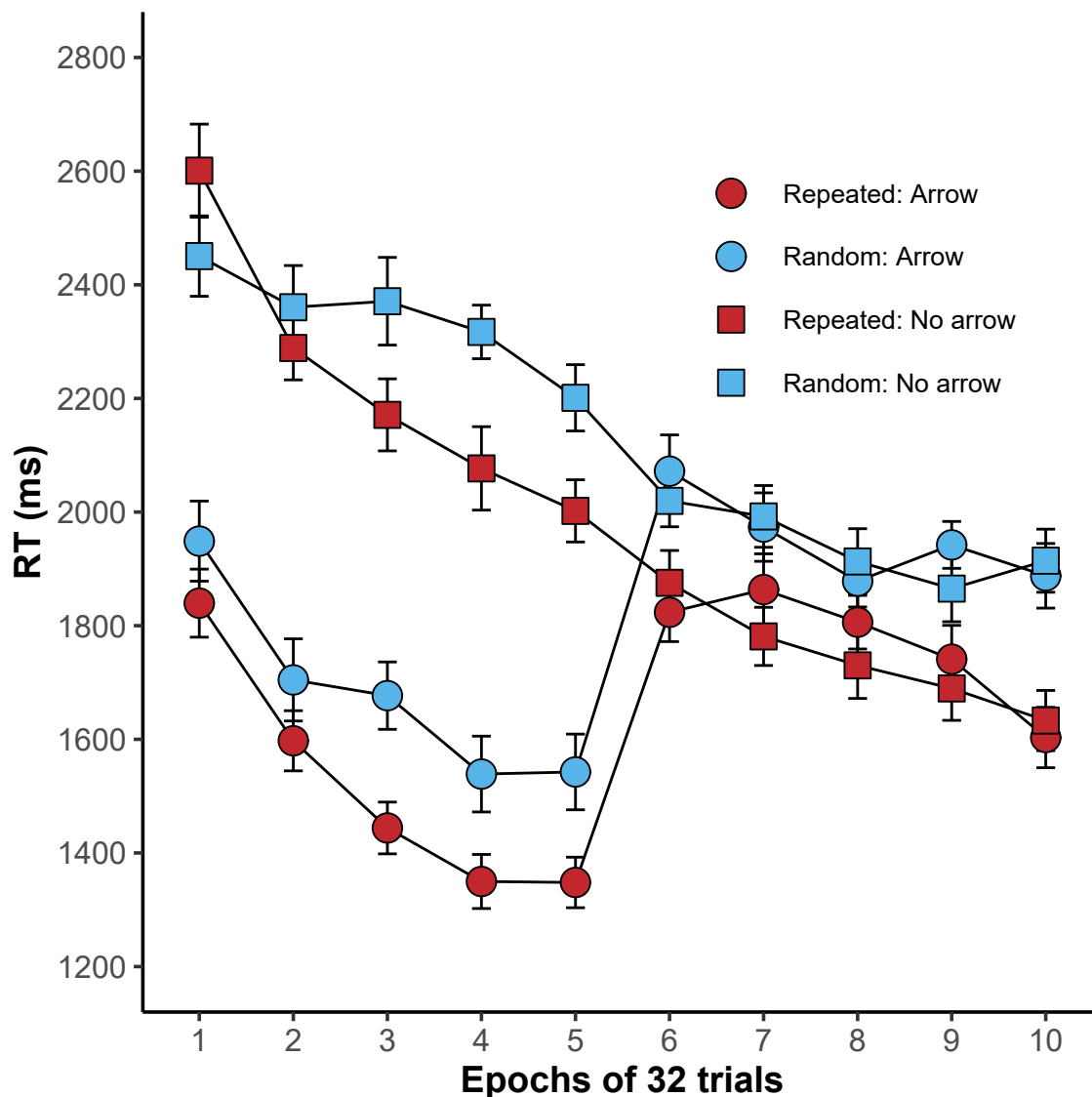
Figure 3

RT data for Experiment 2. Error bars show standard error of the mean on normalised data.

356   Figure 3 shows the RT data across the 10 epochs of the experiment. Contextual

357 cuing emerged rapidly in both the arrow and no-arrow conditions, with little suggestion

358 that the CC effect was different in the two conditions. The phase 1 data were explored

359 with a Bayesian ANOVA, which revealed that the best fitting model contained the factors

360 of epoch, configuration (repeated vs. random), and endogenous cue (arrow present

361 vs. arrow absent), with no interaction terms, $BF_{10} = 7.1 \times 10^{100} \pm 1.01\%$. The next best

362 fitting model contained all three factors and the interaction of epoch and configuration,

363 $BF_{10} = 5.1 \times 10^{100} \pm 1.02\%$, and this model was not a substantially worse fit to the data,

364 $BF = 0.72 \pm 1.44\%$. All other models were substantially worse fits than the best fitting

365 model, largest $BF = 0.27 \pm 3.18\%$. Importantly, the interaction term between the factors

366 of endogenous cue and configuration did not improve the fit of the model, providing

367 substantial support for the absence of this interaction, $BF = 0.2 \pm 3.18\%$. The relevant

368 effect sizes (n_p^2) were: 0.02 for the effect of epoch; 0.40 for the effect of configuration; 0.85

369 for the effect of endogenous cue; 0.12 for the interaction effect between configuration and

370 epoch; and 0.02 for the interaction between configuration and endogenous cue.

371   When the endogenous cue was removed in the second half of the experiment, RTs

372 were equivalent across the two conditions. An effect of configuration was seen for both

373 cuing conditions, with little discernible difference between the size of the cuing effects. We

374 conducted a Bayesian ANOVA with factors of epoch, configuration and endogenous cue

375 condition (arrow vs. no-arrow). The best fitting model was that with just the factors of

376 epoch and configuration with no interaction between the factors, $BF_{10} = 9.5 \times 10^{14} \pm$

377 0.7%. There was substantial support for this model over the next best fitting model, $BF =$

378 $8.67 \pm 2.29\%$. To examine the interaction of the configuration and endogenous cue factors,

379 we compared the model containing those two factors to the model containing the two

380 factors plus the interaction of configuration and endogenous cue, which revealed substantial

381 support for the absence of an interaction, $BF = 0.13 \pm 2.58\%$. The relevant effect sizes

382 (n_p^2) were: 0.62 for the effect of configuration; and 0.25 for the effect of epoch.

383   To provide further support for the absence of the interaction between the factors of

384 configuration type and endogenous cue, the data from across the experiment (epochs 1-10)

385 were analysed with a Bayesian ANOVA with only the factors of configuration and

386 endogenous cue. The best fitting model was that with the two factors and no interaction,

387 $BF_{10} = 3.6 \times 10^{51} \pm 1.04\%$. The addition of the interaction term did not strengthen the

388   model, with substantial evidence for the absence of the interaction, BF = 0.09 ± 2%. The

389   relevant effect sizes (n_p^2) were: 0.77 for the effect of the endogenous cue; and 0.61 for the

390   effect of configuration.

Discussion

392   Experiment 2 sought to examine whether the presence of a valid endogenous cue

393   would impair the acquisition of a contextual cuing effect. In the first phase, two sets of

394   configurations were trained, one of which was always presented in the presence of the

395   endogenous cue, and one set which was presented without the endogenous cue. Overall

396   there was considerable evidence that the cue was processed and acted upon, as response

397   times to the target were much faster on cued trials. However, there was no evidence to

398   suggest that this initial guidance of attention impaired the acquisition of the configurations

399   on those trials. Furthermore, when the endogenous cue was never presented in the final

400   phase of the experiment, the size of the contextual cuing effect was equivalent between the

401   two sets of configurations; the Bayesian analyses found support for the equivalence of these

402   CC effects.

403   The lack of competition effects seen in Experiment 2 are at odds with some findings

404   in the CC literature (i.e., Endo & Takeda, 2004; Kunar et al., 2014), where competition has

405   been seen by more dominant or salient features of the displays. Instead, the findings point

406   towards a more automatic nature to contextual cuing, whereby associations form

407   ubiquitously, so long as they receive the focus of attention at some point within the search

408   process (e.g., Beesley & Shanks, 2012).

409   Taken together with the findings of Experiment 1, these data suggest that when

410   attention is cued in an endogenous manner, the underlying search configuration will still

411   play a significant role in guiding search for the target. Since the endogenous cue appears at

412   the point of fixation, the most plausible interaction of these processes is that the guidance

413   by the endogenous cue is followed by the guidance by the repeated context. The

equivalence of the CC effects in the two conditions (cued and uncued) would therefore suggest that the guidance by the context was driven largely (or perhaps entirely) by the distractors that appear close to the target. Accordingly, the longer search times in the uncued condition suggest that more distractors are processed in this condition, but that the influence of the repeated distractors on attentional guidance may be limited to those occurring later in the search process, and therefore those nearer to the target. Alternatively, the interaction of these two processes (endogenous and configuration-driven attention) need not interact in this order. It is at least possible that the configuration is processed rapidly at the onset of the trial, before the effects of the endogenous cue on attention are observed. If this is the case, then those repeated distractors that influence search (producing the CC effect) need not be localised around the target. Experiment 3 provided a test of these two possible accounts.

Experiment 3

Existing data from studies of contextual cuing has pointed towards a localised learning effect for repeated configurations, with those distractors closest to the target being preferentially weighted in the learning process over those located further from the target. For example, Olson and Chun (2002) trained participants with three sets of repeating configurations that differed in terms of which distractors repeated across trials. For one set, the entire global context (all of the distractors) repeated, while for the other two sets only the short-range (those close to the target) or the long-range distractors (those far from the target) repeated across trials. They found no difference between the CC effect in the short-range and global configurations, while the CC effect was not significant for the long-range context. Similar results have been shown by Brady and Chun (2007) which led to the development of the spatial constraints model of contextual cuing, in which distractor-target associations occurring in close proximal space are weighted more heavily in the learning process (over those occurring across greater spatial distance).

440   It is important to consider how the bias towards local learning may interact with

441 the attentional scanning process during contextual cuing. The analysis of eye-movements

442 during contextual cuing tasks (Beesley et al., 2018; Tseng & Li, 2004) has revealed a

443 characteristic scanning pattern comprising two phases: search initially occurs in a

444 seemingly random manner, as the eyes move between distractors in the central region of

445 the distractor field, before then moving in a more directed manner towards the target

446 position. Contextual cuing appears to result from a cessation of the first (random) search

447 phase at an earlier time point in the entire search process, such that processing of repeated

448 distractors will, on average, result in fewer fixations. With respect to the current study, in

449 Experiments 1 and 2 we have initially directed attention towards the side of the screen that

450 contains the target on cued trials. This may bring about an early cessation of the first

451 phase of the search process. From here, however, it seems that search is still facilitated by

452 the repetition of the context.

453   To test this characterisation of the interaction between the endogenous cue and the

454 repeated context, we exposed participants to the same procedure as used in phase 1 of

455 Experiment 1, which establishes a contextual cuing effect prior to the use of the

456 endogenous cue. In a second phase we then presented the endogenous cue on every trial (as

457 in Experiment 1), but we manipulated the presence of the repeated distractors within the

458 configurations. For each repeated configuration we created two variations: in the

459 "proximal" configurations, only the distractors in the quadrant containing the target match

460 those from the full repeated configuration, while the distractors in the other three

461 quadrants were randomly arranged on each trial; in the "distal" configurations, the

462 distractors closest to the target were randomised, while the distractors in the other three

463 quadrants were the same as those in the full repeated configuration. During this phase we

464 also presented fully repeated configurations and fully randomised configurations.

465 Comparison of the response times across these four trial types will allow us to determine

466 the contribution of proximal and distal distractors to the CC effect when attention is cued

467 endogenously.

Method

Participants

470 Forty-two undergraduate students from Lancaster University were recruited (mean

471 age = 18.64, SD = 2.84; 28 identified as female and 14 as male) via the Psychology

472 Research Participation System in the Department of Psychology at Lancaster University, in

473 return for the opportunity to use the recruitment system for their own research in future

474 years.

Materials

476 All materials, including stimuli and testing environment were identical to

477 Experiment 2.

Design

479 The design of phase 1 was identical to Experiment 1, with four repeated

480 configurations created and presented with random configurations during this phase. For

481 phase 2, each of the four configurations was manipulated to create two alternative

482 conditions. In the "Repeated distal" condition, the four distractors in the target quadrant

483 were randomly arranged on each trial, while the 12 distractors in the other three quadrants

484 were presented in the same positions as had been trained in phase 1. Thus, slower response

485 times for this condition (compared to the fully repeated configurations) would indicate the

486 extent to which participants CC was governed by the distractors closest to the target. For

487 the "Repeated proximal" condition, the four distractors in the target quadrant were

488 presented in the same positions as had been trained in phase 1, while the 12 distractors in

489 the other three quadrants were randomly arranged on each trial. Thus, slower response

490 times for this condition (compared to the fully repeated configurations) would indicate the

491 extent to which CC was governed by the distractors further from the target. Comparison

of the RTs for these different configurations with those of the random configurations would allow for the assessment of whether these subsets of distractors had *any* contribution to the CC effect that had developed during phase 1.

Procedure

The procedure was identical to Experiment 1.

Results

Our criteria for removing outlier data were identical to Experiment 1. On average, trials ended with a timeout on 2.81% (SD = 2.25) of trials . Two participants had an usually high proportion of timeouts and were removed from the sample. The mean accuracy of participants (not including timeout trials) was 96.09% (SD = 8.57%). Two participants that had an unusually low proportion of accurate trials and were also removed. Zero participants were deemed to be an outlier in terms of mean RT.

For the remaining thirty-eight participants we removed trials with a timeout and inaccurate trials, before removing outliers from the RT data. On average, the proportion of outliers removed was 3.17% (SD = 0.71%). Zero participants had an unusual proportion of trials removed as outlier RTs.

Figure 4 (main panel) shows the RT data across the 10 epochs of Experiment 3. As in Experiment 1, contextual cuing was readily established in phase 1. These data were subjected to a Bayesian ANOVA which revealed that the best fitting model contained the factors of configuration (repeated vs. random) and epoch, and an interaction between those factors, $BF_{10} = 5.4 \times 10^{24} \pm 0.88\%$. However, the model without the interaction provided a strong fit to the data, $BF_{10} = 5.1 \times 10^{24} \pm 0.8\%$, and a comparison between the two models did not find any evidence in support of the interaction term, $BF = 0.95 \pm 1.19\%$. There was strong support for the best fitting model over the remaining models, smallest $BF = 3938.38 \pm 0.93\%$, providing strong support for the factors of epoch and
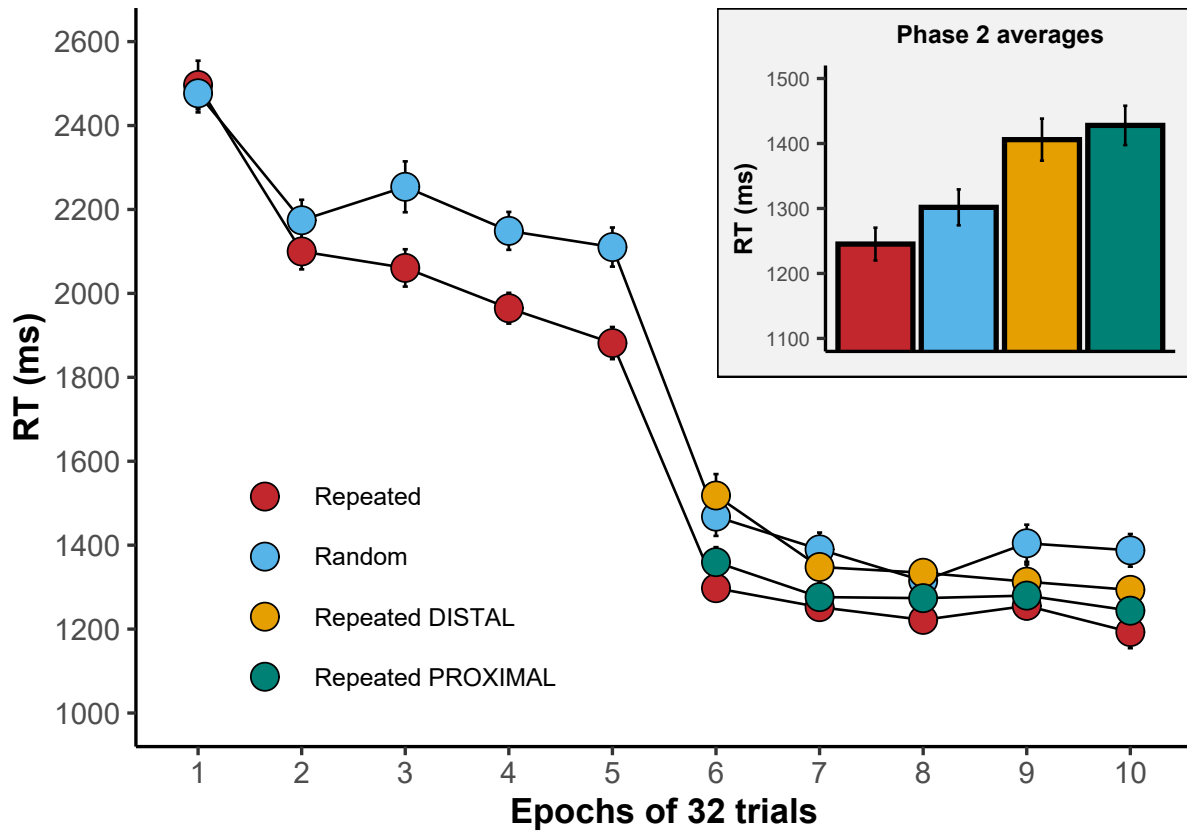
Figure 4

RT data for Experiment 3. Error bars show standard error of the mean on normalised data.

configuration. The relevant effect sizes (n_p^2) were: 0.38 for the effect of the endogenous cue;

and 0.47 for the effect of configuration; and 0.08 for the interaction of these two factors.

The response times decreased significantly with the presentation of the valid

endogenous cue in phase 2. Response times to the fully repeated configurations were

somewhat comparable to those when just the proximal repeated distractors were present.

Response times for the distal repeated distractors appeared to be slower and comparable to

the fully random configurations. The phase 2 data were subjected to a Bayesian ANOVA

which found that the best fitting model contained the factors of configuration and epoch

but no interaction between the factors, $\text{BF}_{10} = 1.4 \times 10^{14} \pm 0.44\%$. This model provided a

superior fit to the data compared to the next best fitting model that included the two

factors and the interaction term, BF $= 122.53 \pm 0.9\%$, providing strong support for the

contribution of the two factors and the absence of an interaction between the two factors.

The relevant effect sizes (n_p^2) were: 0.37 for the effect of configuration; and 0.16 for the

effect of epoch.

The inset graph in Figure 4 shows the mean RTs to the four types of configuration,

averaged across the 5 epochs of phase 2. To explore the differences in response times,

Bayesian t-tests were run for all pairwise comparisons. The response times to repeated and

repeated-proximal configurations were both faster than those to random configurations,

smallest $BF_{10} = 10313.81 \pm 0\%$. In contrast, there was no evidence that the response times

to repeated-distal configurations were different from those to random configurations, BF_{10}

$= 0.39 \pm 0.04\%$. Response times to repeated configurations were faster than those to

repeated-proximal configurations, $BF_{10} = 4.67 \pm 0\%$. Response times to repeated-proximal

configurations were faster than those to repeated-distal configurations, $BF_{10} = 31.88 \pm 0\%$.

Discussion

Experiment 3 explored the localisation of the distractors driving contextual cuing

when attention is guided by an endogenous cue. As expected, there was substantial

evidence that contextual cuing was present when the distractors close to the target were

maintained, but not when these distractors were randomly arranged. These data suggest a

particular order to the interplay between the two drivers of attention: initially attention is

guided by the endogenous cue towards one half of the screen, and then search is refined by

the presence of the valid configural cues (the repeated distractors). Like in Experiment 1,

the phase 2 data demonstrate the resilience of the CC effect to changes in the search

process. Despite visual search never commencing in a cued manner during the initial

acquisition period of phase 1, a CC effect was readily observed in phase 2. Thus it seems

that the stored representations of configurations surrounding target positions are very

flexibly deployed in visual search. Notably the fully repeated configurations exerted more

of a benefit on search than those containing only the proximal distractors, suggesting that

the repeating distractors beyond the target quadrant have some (but possibly lesser)

influence on search (Brady & Chun, 2007).

These data lend support to the notion that the effect of the repeated configuration

is a late process within visual search, and that each trial commences with a random search

process that is not guided by the repeated configuration (Beesley et al., 2018; Tseng & Li,

2004). In some ways, these findings represent a paradox of CC: the cuing effect occurs

almost at the point at which target detection has been made. One interpretation would be

that this exemplifies the role of spatial contiguity in the formation of visual associations

(Renaux et al., 2017). Alternatively, it provides support for the proposed "decision

threshold" accounts of CC (Kunar et al., 2007; Sewell et al., 2018), which posit that the

repeated distractors close to the target ensure a reduced threshold for target detection,

resulting in faster response times.

General Discussion

Three experiments explored the impact of a central endogenous cue on the

contextual cuing of visual search. In Experiment 1, having established a contextual cuing

effect, each trial was preceded by an central endogenous cue of attention in the form of an

arrow, directing attention towards the side of the screen in which the target was positioned

(this arrow cue was always valid in each of the three experiments). Despite participants

clearly using this cue, visual search was still facilitated by the presence of the repeating

pattern of visual search. This experiment demonstrated that, once acquired, the activation

of the memory representation and its impact on performance of visual search remains

intact in the presence of a top-down instruction to guide attention. Experiment 2 examined

the storage of these contextual representations, and whether these were impaired by an

endogenous cue guiding search. We found equivalent levels of contextual cuing for two sets

of configurations, one of which was paired with the cue and one which was not. Together,

these two experiments suggest a seamless interplay between these two factors governing attention in visual search: the endogenous cue initially guides attention and the repeated configuration continues to refine and guide attention towards a fixation on the target. In Experiment 3 we therefore explored whether the localised distractors around the target were sufficient to generate CC following the guidance by the endogenous cue. Indeed, there was a significant CC effect in the case of the proximal distractors, albeit slightly weaker than that generated by the entire repeated configuration. Importantly, those repeated configurations that did not contain the proximal distractors failed to generate a CC effect, suggesting that the proximal distractors play a crucial role in search following the guidance of attention by the endogenous cue.

The effect of CC on visual search has frequently been characterised as an automatic influence on behaviour (e.g., Chun & Jiang, 1998; Chun & Nakayama, 2000; Geyer et al., 2021). This characterisation of CC comes from multiple aspects of the observed effect. Updating of the associations is somewhat slow and seemingly inflexible to changes in the acquired associations (Makovski & Jiang, 2011; Manginelli & Pollmann, 2009; e.g., Zellin et al., 2013), and therefore perhaps reflects a habitual form of behaviour. In addition, contextual cuing has frequently been observed in the absence of above-chance recognition memory for the repeating search configurations (e.g., Colagiuri & Livesey, 2016), which suggests a non-conscious, automatically evoked form of behaviour. Despite this persistent characterisation, the automaticity (or controllability) of CC has rarely been directly tested in the literature. To our knowledge, only the experiments of Luque and colleagues (Luque et al., 2017; Luque et al., 2021) have directly assessed this aspect of CC, by placing the influence of the configuration in competition with top-down goals in the task. Their findings supported the conclusion that CC performance can be controlled and will not guide search for the target when another aspect of the task governs attentional control. In the current study, the repeated configurations continued to have an influence on search performance even when attention had been guided by the endogenous cue. These results

are therefore somewhat at odds with the conclusions of Luque and colleagues (Luque et al., 2017; Luque et al., 2021).

To what extent is this behaviour best characterised as "automatic" in nature? Arguably the clearest demonstration of an automatic effect of a stimulus on behaviour is when the associated behaviour is elicited even when it is counter-productive to the current goals (Moors & De Houwer, 2006). Such a test was constructed in the repeated inconsistent trials of Experiment 1, in which the repeated configuration was associated with a target that was previously located in a position on the opposite side of the screen to the direction indicated by the endogenous cue. If the repeated configuration had an effect on behaviour on these trials, we would have expected to see slower response times compared to random trials. This was not the case: response times were equivalent in these two conditions. As such it is hard to claim here that the configuration is having an *automatic* effect on behaviour, according to this strict characterisation of such an effect. Nevertheless, the experiments here reveal an interplay between top-down processes and stimulus driven effects on attention in CC.

The current data reveal that the influence of repeated contexts has a relatively late control on behaviour in visual search. Previous analysis of eye-movements during CC (Beesley et al., 2018; Tseng & Li, 2004) has shown that contextual cuing (and visual search more generally) has two characteristic components. The first of these is an inefficient search process where search fails to move towards the target in trials with more fixations. This is followed by a phase in which monotonic, positive increments are made toward the target position in the final 3 to 4 fixations. CC reduces the frequency of trials with the initial (random) search period (there are more of such trials for random configurations and fewer for repeated configurations). Thus, the effect of the endogenous central cue in the current study is to eliminate, or considerably reduce, the engagement with this first phase of the search process. The results of this study strongly imply that the positive associative information in the repeating configurations is extracted in the final stages of search and is

633 localised to the target. This is true both in terms of the performance of an acquired

634 configuration (Experiments 1 and 3) and the acquisition of the representation for that

635 configuration (Experiment 2). Perhaps paradoxically, the benefit of repeated configurations

636 in search occurs shortly before the target is fixated. These data therefore support the view

637 that late-stage "response threshold" processes may play an important role in the CC of

638 visual search (Sewell et al., 2018). Notably, the results of Experiment 2 show that the

639 curtailing of the initial (random) search process, which significantly reduces search times,

640 does not limit the development of an adequate contextual cuing effect.

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