

Saliency drives non-spatial feature repetition effects in cueing tasks

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Abstract In an exogenous cueing task repeating a non-spatial feature can benefit performance if the feature is task-relevant to a discrimination response. Previous studies reporting this effect have used complex displays. In the current study, we look at the generalizability of this effect, by extending it to a simple exogenous cueing paradigm in which the cue and target displays each consist of single-object onsets. We also investigate the influence of task-relevant and irrelevant features independently within the same experiment. Consistent with previous studies, we find non-spatial feature repetition benefits in all three experiments. Importantly, and unlike previous studies, we find that the most salient, rather than the task-relevant, feature drives the non-spatial feature repetition benefit. Furthermore, in addition to the previously observed non-spatial feature repetition benefits, we also found a spatially specific feature repetition benefit. We argue that these new findings are consistent with habituation accounts of attentional cueing effects.

Keywords Attention · Space-based · Priming · Repetition effects

A salient, transient external event will typically capture attention and facilitate processing at its location for a brief time. Following this facilitation window, a prolonged period of

inhibited processing occurs at that location. Posner and Cohen (1984) reported these phenomena in a cue-target paradigm in which they asked participants to ignore a task-irrelevant, non-predictive cue stimulus and detect the presence of a subsequent target stimulus. Participants responded faster to targets appearing at the same location as the cue stimulus when the target appeared within 300 ms of the cue stimulus. In contrast, participants responded faster to targets appearing at different locations than the cue if the target appeared more than 300 ms after the cue stimulus. This basic pattern of early facilitation and later inhibition (typically termed inhibition of return; IOR), found in dozens of studies (Castel, Chasteen, Scialfa, & Pratt, 2003; Hilchey, Satel, Ivanoff, & Klein, 2013; Klein, 2000; Lupiáñez, Milliken, Solano, Weaver, & Tipper, 2001; Taylor & Klein, 1998; Tipper, Driver, & Weaver, 1991), has become a cornerstone of the visual attention literature.

Over the years, extensive research has been conducted to determine the conditions under which facilitation and inhibition are found at peripheral cue locations. For example, the duration of the cue, the length of the inter-stimulus interval, and the presence or absence of placeholders play roles in determining if and when facilitatory and inhibitory effects are observed (McAuliffe & Pratt, 2005; Taylor, Chan, Bennett, & Pratt, 2015). Task type also plays a role, with IOR occurring earlier for detection tasks than for discrimination tasks (Lupiáñez, Milán, Tomay, Madrid, & Tudela, 1997). In addition, in target-to-target experiments, task, target non-spatial features (e.g., color and orientation), and target locations all interact to produce different patterns of facilitation and inhibition (Pratt & Castel, 2001; Rajsic, Bi, & Wilson, 2014).

The effects of non-spatial features on early facilitation and later IOR have also been investigated using cue-target tasks (Kwak & Egeth, 1992; Lachter, Remington, & Ruthruff, 2009; Pratt, Hillis, & Gold, 2001; Remington & Folk, 2001;

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Taylor & Donnelly, 2002). Particularly relevant to the current study, Hu, Samuel, and Chan (2011)¹ used a modified version of a paradigm developed by Samuel and Weiner (2001) to investigate how non-spatial features influence the time course of facilitation and inhibition effects. The paradigm is a variation of the Posner cue-target paradigm, but with added complexity, including variations in non-spatial feature overlap between the cues and targets. On each trial, the researchers presented participants with eight white circular placeholder stimuli organized in a circle around fixation. Four of these placeholders contained two smaller red or blue circles and the remaining four placeholders were empty. Next, they presented a single red or blue circle in one of the empty placeholders as an uninformative cue stimulus. After a variable time, ranging from 200–3,500 ms, a second individual red or blue circle appeared in the same placeholder as the cue (though at a different location within the placeholder) or one of the remaining empty placeholders. The key variable of interest was how repeating versus switching non-spatial features across the cue and target stimuli affected cueing effects. The researchers asked participants to make a speeded detection response as soon as they saw the target onset. The significant finding from this study was reduced IOR in the non-spatial feature switch condition. In contrast, the early facilitation was unaffected by non-spatial feature switches versus repetitions.

Following this study, Hu and Samuel (2011) used a similar method except participants made discrimination rather than detection responses. They observed the opposite pattern of effects as Samuel and Weiner. Whereas for detection tasks non-spatial feature switches lead to less IOR and do not affect early facilitation, for discrimination tasks non-spatial feature switches have no effect on IOR and lead to reduced early facilitation, regardless of the cue-target location overlap. That is, when the time between cues and targets was less than 300 ms, responses were slower if color switched across the cue and target, independent of the cue's location. Thus, they concluded, whether or not non-spatial features impact cueing effects depends on what type of response the task requires (detection or discrimination).

Klein, Wang, Dukewich, He, and Hu (2015), however, suggested that task type is not what accounts for the response time (RT) differences between the detection and discrimination experiment findings. Instead, they argued that the

differences were due to the non-spatial feature being task-relevant in the discrimination task, but task-irrelevant in the detection task. That is, in both tasks the non-spatial feature may have been, for example, color. In the discrimination case, then, cues and targets could be red or blue and the response was whether the target was red or blue, so color was task-relevant. Yet in the detection task, the color was irrelevant since they were responding to its onset. Klein and colleagues (2015) hypothesized that the non-spatial feature's task relevance was the critical difference between the detection and discrimination tasks, rather than the switch between task types, *per se*. To test this, they first closely replicated the detection and discrimination results and then conducted a third experiment in which they had participants discriminate a non-spatial feature (shape) that was orthogonal to a second feature that also repeated or switched (color). Consistent with their hypothesis, when participants discriminated an orthogonal feature, the pattern of results mirrored those previously observed in detection tasks. Thus, task relevance, rather than task type, appears to be the main factor determining whether non-spatial feature repetitions affect cueing effects.

One of the open questions raised, and potentially answered, by the work of Klein and colleagues (2015) is how feature repetitions lead to an early, non-spatial benefit on performance. That is, why are responses to targets sometimes faster when preceded by a cue with the same features at short cue-target onset asynchronies? Notably, contemporary models of cueing effects, such as the habituation (Dukewich, 2009) and three-component (Lupianez, 2010) frameworks, do not predict that task-relevance should modulate non-spatial feature repetition benefits. Thus, answering this question is critical for evaluating those cueing effect models. To reconcile their findings with these models, Klein et al. proposed that early feature repetition benefits might be a consequence of a separate mechanism: cue-generated response activation. When target responses are selected based on feature values (i.e., discrimination tasks where, for example, subjects press one key for red targets and another for blue targets), cues possessing one of those features may pre-activate the associated response, speeding responses on feature repetition trials regardless of the cue-target location overlap. In other words, when a cueing task with discrimination responses uses cues that have task-relevant features, those task-relevant features will activate the associated response. This response activation leads to faster responses when the target repeats that task-relevant feature value. Such an account explains both the presence of feature repetition benefits in the non-orthogonal discrimination tasks of Hu and Samuel (2011) and Klein et al. (2015, Exp. 2), and the absence of the benefit for detection tasks (Hu, Samuel, & Chan, 2011; Klein et al., 2015, Exp. 1) and orthogonal discrimination tasks (Klein et al., 2015, Exp. 3).

The main question that emerges from these aforementioned studies is whether or not the task relevance account suggested

¹ As a point of clarity, the focus of the present research is to examine non-spatial feature repetition effects at short cue-target onset asynchronies (CTOAs). While the study of Hu, Samuel, and Chan (2011), and others that we cite later (Hu & Samuel, 2011; Klein et al., 2015), are typically categorized as IOR studies (i.e., long CTOA studies), we view them as cueing studies in the more general sense in that they all examined both short and long CTOAs. Given that we only test a single short CTOA in the present study, we do not make any claims about cueing effects at late CTOAs (i.e., IOR effects); rather, our experiments investigate the factors that influence the early occurring cueing effects reported by these past studies.

by Klein et al. (2015) extends to the sparser displays that dominate the cueing study literature. To answer this question, we adopted the following approach. Because we are primarily interested in early non-spatial feature repetition benefits, we only test the early facilitation phase of cueing effects and do not test for later IOR. Additionally, rather than using the complex displays of Samuel and Weiner (2001), we used displays that included only an isolated cue followed by an isolated target. This was done to more closely approximate the typical cueing study design that has provided most of the evidence that prominent cueing models seek to explain. Thus, we can test the viability of the task relevance explanation in relation to the existing literature. Also, because Klein et al. (Appendix point 2, 2015) express uncertainty as to why task relevance should determine whether non-spatial feature repetition benefits occur at short cue-target onset asynchronies (CTOAs), examining the explanation with a range of experimental designs will provide useful converging or diverging evidence. Because Klein and colleagues' (2015, Exp. 3) had participants respond to shape and then analyzed the effect of color repetition or switch, we also looked to replicate this result as well as investigate whether the same result holds when color is task-relevant.

In addition, we also wanted to assess the impact of both the relevant and the irrelevant features within the same experiment. That is, what, if any, is the benefit of repeating only the irrelevant feature versus neither feature, what is the benefit of repeating the relevant feature versus the task-irrelevant feature, and is there a benefit for repeating both the task-relevant and task-irrelevant features versus only task-relevant or task-irrelevant feature repetition? Previous studies have collapsed these four trial types into two by only looking at whether the task-relevant *or* task-irrelevant features repeated. This means previous studies classified trials in which no features repeated or task-irrelevant features repeated as switches, and trials in which both features or only the task-relevant feature repeated as repetitions. Consequently, it is possible that the trials with no features repeating masked the task-irrelevant feature's impact. If a more comprehensive analysis reveals that the task-irrelevant feature can affect performance, then the Klein et al. (2015) hypothesis will require revision.

Experiment 1

Experiment 1 conceptually matched Hu and Samuel's (2011) design in which they used a single non-spatial feature and asked participants to discriminate its identity. Differing from their design, we used a simple Posner cueing task in which we presented participants with single onsets as cues and targets. Cues and targets were either circles or diamonds and participants reported the shape. According to Klein et al. (2015), this design should lead to the spatially non-specific feature repetition benefit that they, and Hu and Samuel (2011), observed

because feature repetition and response selection are both based on shape (i.e., this is a non-orthogonal discrimination task). If we do not find the predicted feature repetition benefit, however, it may be due to the reduced complexity of our displays relative to the methods of Hu and Samuel (2011) and Klein et al. (2015).

Methods

Participants

Eleven undergraduates from the University of Toronto participated in exchange for partial course credit for an introductory psychology course. All participants provided informed consent, were naïve to the task's purpose, and reported normal or corrected-to-normal visual acuity and normal color vision.

Stimuli and apparatus

Stimulus generation and presentation were programmed in C++ and presented on a CRT monitor with a screen resolution of $1,024 \times 768$ and a refresh rate of 100 Hz. Viewing distance was kept constant at 52 cm using a chin and forehead rest for the duration of the experiment. All stimuli were white presented on a black background. The placeholder display was made up of a central fixation cross (0.8° visual angle in width and height) and two placeholder boxes (3.2° visual angle in width and height) placed along the horizontal meridian 8° visual angle to the left or right of fixation. Cues were the outline of either a diamond or circle (both 1.1°) and targets were the same shapes, but filled in rather than outlines.

Procedure

Each trial began with a centrally presented fixation cross on which we instructed participants to maintain their gaze throughout the experiment (Fig. 1). After a random 500- to 1,500-ms interval, a cue appeared in one of the two placeholders and remained for 50 ms before offsetting. Following a 100-ms delay after the cue offset, a target appeared either in the same or opposite placeholder as the cue and remained until the participant responded or 1,500 ms passed. Participants reported whether the target was a circle or diamond using the '/' and 'Z' keys, respectively, on a standard QWERTY keyboard. If the participant did not respond within 1,500 ms or they made an incorrect response, a 200-Hz tone sounded for 100 ms.

Design

Participants completed the task in ten blocks of 48 trials. Cue identity, target identity, cue location, and target location were

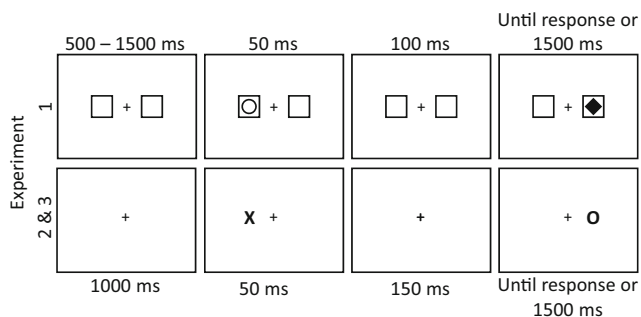


Fig. 1 Procedure for Experiments 1, 2, and 3. In Experiment 1, cues and targets could be either *circles* or *diamonds*, and participants reported the target’s shape. In Experiment 2, cues and targets could either be an ‘X’ or an ‘O’ and *green* or *red*, and participants reported the target’s color (Experiment 2) or shape (Experiment 3). In all experiments, cue location and the non-spatial feature(s) were non-predictive of the target location and its non-spatial features

all determined randomly on each trial so that no cue feature was predictive of a target feature.

Results

We excluded error trials (4.0 %) and trials with RTs more than 2.5 SDs away from each participant’s mean RT (1.2 %) from the following RT analysis. We coded trials in terms of whether the target repeated cue shape or switched to a new shape. A 2 (shape repetition: repetition or switch) × 2 (cue validity: valid or invalid), repeated measures ANOVA with RT as the dependent variable was then conducted.

The RT analysis (Fig. 2) revealed main effects of both cue validity, $F(1, 10) = 135.147, p < .001, \eta_p^2 = .931$, with faster responses in validly cued ($M \pm SD$; 508 ± 42 ms) than invalidly cued trials (553 ± 47 ms), and shape repetition, $F(1, 10) = 44.352, p < .001, \eta_p^2 = .816$, with shorter response times in the shape repetition condition (509 ± 48 ms) than the shape switch condition (553 ± 43 ms). Cue validity and shape repetition also interacted, $F(1, 10) = 10.182, p = .002, \eta_p^2 = .505$, indicating a larger cueing effect in the repeat condition (60 ± 24 ms) than in the switch condition (31 ± 14 ms).

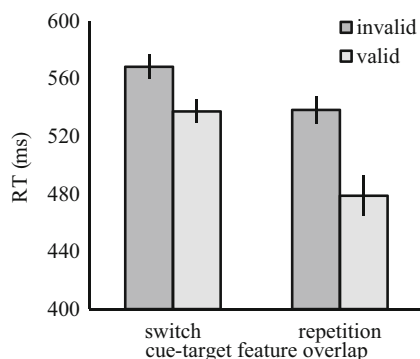


Fig. 2 The effect of cue validity by cue-target feature overlap in Experiment 1. Error bars represent the within-subject SE (Cousineau, 2005)

The same ANOVA with proportion of errors (PE) as the dependent variable revealed a significant feature repetition effect, $F(1, 10) = 7.229, p = .022, \eta_p^2 = .422$. The shape repetition main effect and two-way interaction were not statistically significant, $F_s < 2.249, p_s > .164$. The feature repetition effect indicated more errors in the switch condition (4.7 %) than repetition condition (3.3 %), so did not indicate a speed-accuracy tradeoff.

Discussion

Consistent with Klein et al. (2015), when participants responded to shape, and shape repetition benefits were analyzed, there was a significant non-spatial feature repetition benefit. When the target’s shape repeated the cue’s shape, participants responded faster than when it did not. Inconsistent with Klein and colleagues, however, we found an interaction between non-spatial feature repetition and cue validity, indicating that the cue validity effect was larger when shape repeated than when it switched. Thus, on the one hand, the current data are consistent with the notion that task-relevant feature repetition benefits are due to response activation, since there was a spatially non-specific benefit for feature repetition, regardless of cue validity. On the other hand, this benefit increased when location repeated, suggesting that response activation does not tell the entire story since response activation should only produce spatially non-specific effects. Furthermore, this interaction distinguishes our observed feature repetition effects from the independent (i.e., non-interactive) effects of spatial and feature priming (Asgeirsson, Kristjánsson, & Bundesen, 2014).

One explanation for the interaction between non-spatial feature repetition and cue validity is that task-relevant features are given increased attentional weight, allowing cues to activate the task-relevant feature code to a stronger degree. This increased activation leads to the code still being partially active at target presentation, which facilitates processing that feature. We will detail the feature re-weighting hypothesis further in the General Discussion after reporting two additional experiments that directly pit task-relevant and irrelevant features against each other.

Experiment 2

We designed Experiment 2 to test the role of task-relevant and task-irrelevant features repeating or switching within a single experiment. Once again, we used relatively sparse displays so that we could test the generalizability of the task-relevance hypothesis with regard to the stimulus displays that dominate the cueing literature. In addition, we also simultaneously tested for the effects of task-relevant and task-irrelevant feature repetitions, previously only examined in separate

experiments. Our logic in using this experimental design is that it is possible task-irrelevant features affect performance in cueing tasks, but larger effects of the task-relevant features are wiping out their influence (see, for example, partial repetition costs, Hommel, 1998). That is, it is possible that task-irrelevant non-spatial feature repetition did facilitate responses in the previous studies, but simultaneous task-relevant feature switch costs negated that facilitation. By looking at both levels of task relevance simultaneously, we might observe that task-irrelevant non-spatial features can generate non-spatial feature repetition benefits.

Procedurally, Experiment 2 was similar to Experiment 1 in that it is a simple, discrimination Posner cueing task. It differed in that the cue and target stimulus set consisted of green and red X's and O's. In this experiment, participants responded to the color of the target while shape was task-irrelevant. This design is conceptually similar to the orthogonal discrimination task from Klein et al. (2015), but using the simplified visual displays, and makes the same predictions if, in fact, task-relevant feature repetition facilitates responses through response activation. If task-relevant non-spatial feature repetition benefits result from a different mechanism, however, we predict the task-relevant, non-spatial feature repetition benefits will interact with cue validity, as in Experiment 1. Furthermore, by extending Klein et al.'s design by simultaneously manipulating both task-relevant and task-irrelevant feature switches, the present experiment will allow us to test the feature re-weighting hypothesis. According to this account, repeating both features will produce a larger benefit than repeating only the task-relevant feature, and switching the task-relevant feature will wipe out the relatively smaller benefit of repeating only the task-irrelevant feature.

Methods

Participants

Twenty-one undergraduates from the University of Toronto participated in exchange for partial course credit for an introductory psychology course. All participants provided informed consent, were naïve to the task's purpose, and reported normal or corrected-to-normal visual acuity and normal color vision.

Stimuli and apparatus

Stimulus generation and presentation was controlled using the psychophysics toolbox libraries (Brainard, 1997; Pelli, 1997; version 3.0.12) for Matlab (MathWorks, Natick, MA, USA) on a CRT monitor with a screen resolution of $1,080 \times 768$ and a refresh rate of 85 Hz. Viewing distance was kept constant at 52 cm using a chin and forehead rest for the duration of the experiment. Cues and targets consisted of red (RGB: 255, 000, 000) and green (RGB: 000, 255, 000) X's and O's

presented with a 20-font size resulting in four possible cues and targets, and targets could repeat the cue's shape and color, either shape or color, or neither shape nor color. All cue feature values were non-predictive of target feature values.

Procedure

Each trial began with a centrally presented fixation cross on which we instructed participants to maintain their gaze throughout the experiment (Fig. 1, lower panel). After 1,000 ms, a cue appeared 4° (compared to 8° in Exp. 1) to the left or right of fixation and remained for 50 ms. A screen consisting of only the fixation cross was then presented for 150 ms (compared to 100 ms in Experiment 1). The target then appeared at either the same location as the cue or the opposite location and remained until the participant responded or 1,500 ms elapsed. We instructed participants to report whether the target was red or green with their left hand using the 'Z' key and right hand using the '/' key, respectively, as quickly and accurately possible. After incorrect responses, a feedback screen was presented for 2,000 ms displaying "MISTAKE!" in red. If participants did not respond within 1,500 ms, the trial terminated and was logged as an error.

Design

Cue color, shape, location, and target color, shape, and location were counterbalanced and repeated five times each, totaling 320 trials. For analyses, we coded the non-spatial feature relationship between the cues and targets in terms of whether both features repeated (full repetition), only the relevant feature repeated (relevant repetition), only the irrelevant feature repeated (irrelevant repetition), or neither feature repeated (full switch). This design resulted in each of the possible cue-target relationships repeating 40 times in both the invalid and valid location cue conditions for the analyses.

Results

We removed trials with incorrect or missing responses (7.3 %) or RTs greater than 2.5 SDs from each participant's mean RT (2.6 %) for the analyses. Repeated measures, 2 (cue validity: valid or invalid) \times 4 (feature repetition: full switch, irrelevant feature repetition, relevant feature repetition, full repetition) ANOVAs were then conducted with mean RT and PE as dependent variables.

In the RT data (Fig. 3), the main effect of cue validity was not significant, $F(1, 20) = 1.575$, $p = .224$, $\eta_p^2 = .073$, and the feature repetition main effect was significant, $F(3, 60) = 47.872$, $p < .001$, $\eta_p^2 = .792$. The feature repetition effect reflected shorter RTs in the relevant repetition condition (483 ± 57 ms) than both the full switch (542 ± 71 ms), $t(20) = 6.973$, $p < .001$, $d = 1.48$, and irrelevant repetition conditions (527

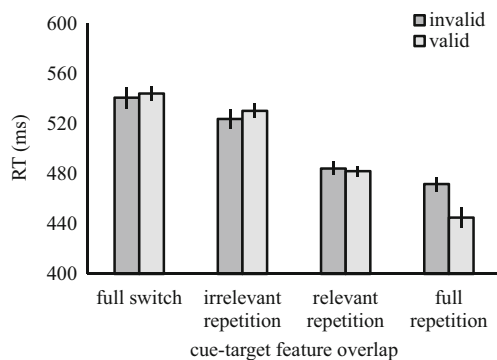


Fig. 3 The effect of cue validity by cue-target feature overlap in Experiment 2. Error bars represent the within-subject SE (Cousineau, 2005)

± 65 ms), $t(20) = 5.714$, $p < .001$, $d = 1.205$. Furthermore, shorter RTs were found in the full repetition (458 ± 56 ms) condition than the relevant repetition condition, $t(20) = 5.033$, $p < .001$, $d = 1.082$. We also found shorter RTs in the irrelevant repetition condition than in the full switch condition, $t(20) = 2.943$, $p = .008$, $d = .633$.

Qualifying the above patterns, and consistent with Experiment 1, the cue validity \times feature repetition interaction was significant, $F(3, 60) = 2.749$, $p = .051$, $\eta_p^2 = .121$. Paired t -tests (two tailed, $\alpha = .05$) indicated that the cue validity effects were not significantly different between the full switch condition (-3 ± 47 ms) or from either the irrelevant repetition condition (-6 ± 46 ms), $t(20) < 1$, $p = .838$, $d = .05$, or the relevant repetition condition (2 ± 26 ms), $t(20) < 1$, $p = .649$, $d = .10$. The cue validity effect was marginally larger in the full repetition condition (27 ± 38 ms) than the full switch condition, $t(20) = 1.965$, $p = .064$, $d = .43$, and was larger than in the irrelevant repetition condition, $t(20) = 2.750$, $p = .012$, $d = .60$, and relevant repetition condition, $t(20) = 2.241$, $p = .037$, $d = .49$.

Conducting the same ANOVA as above on PEs indicated a main effect feature repetition, $F(3, 75) = 8.703$, $p < .001$, $\eta_p^2 = .303$, but differences were in the same direction as the RT data (full switch: 10.9 %, irrelevant repetition: 11.2 %, relevant repetition: 6.1 %, full repetition: 6.1 %) and do not indicate a speed-accuracy tradeoff. The effect of cue validity was not significant, $F(1,20) < 1$, $p = .351$, $\eta_p^2 = .044$, nor was the cue validity \times feature repetition interaction, $F(3,57) < 1$, $p = .381$, $\eta_p^2 = .019$.

Discussion

In Experiment 2, we found that both the relevant and irrelevant non-spatial features affected performance. This is notably inconsistent with Klein et al.'s (2015) claim that task-relevant non-spatial feature repetition produces effects through response activation. This is because, since the task-irrelevant feature has no response assigned to it, there is no reason to assume that it will produce response activation. Task relevance did, however,

still modulate the extent to which the non-spatial feature affected performance. That is, repeating the task-irrelevant feature sped responses compared to repeating no features, and repeating the task-relevant feature sped responses compared to repeating the irrelevant feature. Additionally, and critically, repeating both the relevant and the irrelevant feature generated a larger benefit than repeating the relevant feature alone. This is further evidence that the task-irrelevant feature is influencing performance and that both are impacting performance through the same mechanism.

Additionally, in contrast to Klein et al. (2015) and Hu and Samuel (2011), we found an interaction between the feature repetition and cue validity factors.² This reflected significantly larger spatial cueing effects when both the relevant and the irrelevant features repeated, but not when only one repeated, adding to the case that task-irrelevant features can influence performance in a Posner cueing task. We will return to this discrepancy between the current and previous studies in the *General discussion*.

Experiment 3

Experiment 2 demonstrated that both task-relevant and task-irrelevant features influence RTs in cueing tasks when responding to target color. In that experiment, color was task-relevant and shape was irrelevant, and color produced more pronounced non-spatial feature repetition benefits. One possibility is that this was the case because color was task-relevant. Alternatively, it may be because color is typically found to be more salient in that it is more likely to be processed when it is a distracting and irrelevant feature (Theeuwes, 1992). We designed Experiment 3 to distinguish between these possibilities by swapping the task relevance of color and shape. If task relevance determines which feature will generate the larger non-spatial feature repetition benefit, then shape will produce a non-spatial feature repetition benefit, even if color alternates. If color continues to produce the larger non-spatial feature repetition benefit, then it would suggest that feature salience plays a role in determining if a feature generates a feature repetition benefit.

Methods

Participants

Twenty undergraduates from the University of Toronto participated in exchange for partial course credit for an introductory

² These studies did find an interaction between feature repetition, spatial cueing, and CTOA, but this was driven by increased IOR magnitudes at the later CTOAs. At the short CTOA, the magnitude of spatial cueing was unaffected by non-spatial feature overlap.

psychology course. All participants provided informed consent, were naïve to the task's purpose, and reported normal or corrected-to-normal visual acuity and normal color vision.

Stimuli, apparatus, procedure, and design

The stimuli, apparatus, and design of Experiment 3 matched Experiment 2 precisely. The only procedural difference is that we asked participants to respond to the target's shape rather than color.

Results

We removed trials with incorrect or missing responses (4.8 %), or RTs greater than 2.5 *SDs* from each participant's mean RT (2 %) for the following analyses (Fig. 4). We observed statistically significant main effects of cue validity, $F(1, 19) = 68.428, p < .001, \eta_p^2 = .783$, and feature repetition, $F(3, 57) = 26.157, p < .001, \eta_p^2 = .579$ (Fig. 4). Once again, the cue location validity effect reflected faster responses in the valid (494±75 ms) compared to the invalid condition (543±86 ms). The feature repetition effect reflected shorter RTs in the full repetition condition (502±78 ms) than in the full switch condition (535±86 ms), $t(19) = 6.143, p < .001, d = 1.37$, and the relevant repetition condition (527±75 ms), $t(19) = 5.953, p < .001, d = 1.33$, but not the irrelevant repetition condition (510±83 ms), $t(19) = 1.965, p = .064, d = .44$. Importantly, RTs in the irrelevant repetition condition were significantly lower than the relevant repetition condition, $t(19) = 4.406, p < .001, d = .99$.

As with Experiments 1 and 2, these main effects were qualified by a significant cue validity × feature repetition interaction, $F(3, 57) = 4.699, p = .005, \eta_p^2 = .198$. The cue validity effect magnitude in the full switch condition (31±33 ms) was significantly smaller than in the irrelevant repetition condition (55±42 ms), $t(19) = 2.692, p = .014, d = .60$, smaller than in

the relevant repetition condition (43±37 ms) – though this difference was not statistically significant, $t(19) = 2.014, p = .058, d = .45$, and significantly smaller than the full repetition condition (65±35 ms), $t(19) = 4.576, p < .001, d = 1.05$.

The same analysis with PE as the dependent variable revealed a significant cue validity effect, $F(1, 19) = 12.337, p = .002, \eta_p^2 = .394$, but the difference was in the same direction as the RT effects (i.e., fewer errors at cued locations, valid: 4.8 %, invalid: 6.6 %) and does not represent a speed-accuracy tradeoff. The effect of feature repetition was not significant, $F(1, 19) = 1.169, p = .330, \eta_p^2 = .058$, nor was the cue validity × feature repetition interaction, $F(3, 57) < 1, p = .528, \eta_p^2 = .038$.

Discussion

Once again, we found substantial evidence that a task-irrelevant feature can affect performance in a Posner cueing task. In fact, repeating color shortened RTs more than repeating shape despite color being task-irrelevant and shape task-relevant. This finding is mirrored by attentional capture effects from the additional singleton paradigm in which additional singletons are more distracting if they are color rather than shape singletons (Theeuwes, 1992) and from visual search where color is believed to more successfully guide search (Treisman & Souter, 1985; for a review: Wolfe & Horowitz, 2004). Accordingly, the current experiment indicates that salience and task relevance can interact in determining whether non-spatial features generate repetition benefits at short CTOAs. While it is true that Experiment 3 from Klein et al. (2015) used color as the task-irrelevant feature, the overall display was also much more complex. The display's overall complexity and relatively small cue size may have reduced the relative salience of the task-irrelevant color. Furthermore, we observed no difference between the relevant repetition and full switch conditions, demonstrating that task relevance cannot predict, in itself, when a feature will produce a repetition benefit. Instead, task relevance may increase the feature's attentional weight, which will interact with other factors that increase a feature's weight such as salience.

Like Experiments 1 and 2, in Experiment 3 we found a location specific feature repetition benefit. That is, the spatial cueing effect increased with non-spatial feature repetition. This finding is notably different from the previous studies that only found location specific effects in IOR, and not facilitation effect magnitudes. Determining this discrepancy's cause will require further empirical work, but possibilities are the reduced display complexity, the fact that we used cues and targets drawn from the same stimulus set, and/or that cues and targets appeared in exactly the same location rather than only on the same placeholder. We will discuss the possibility that this latter difference reflects feature integration effects below.

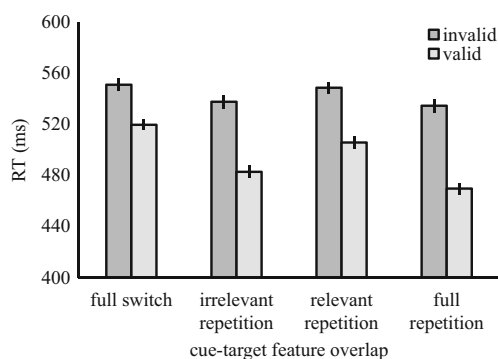


Fig. 4 The effect of cue validity by cue-target feature overlap in Experiment 3. Error bars represent the within-subject *SE* (Cousineau, 2005)

General discussion

In three experiments we tested how non-spatial feature repetition impacts behavior in a simple attentional cueing paradigm. In Experiment 1, participants responded to the target's shape, which could repeat or switch from the cue's shape and we observed both spatially non-specific and specific non-spatial feature repetition effects. In Experiments 2 and 3, we had participants discriminate the target's color or shape, respectively, and manipulated cue/target feature repetitions of both feature types in both experiments. In Experiment 2, we again found spatially non-specific and specific feature repetition benefits. RTs were overall faster when either non-spatial feature repeated (with shorter RTs in the relevant repetition condition than the irrelevant repetition condition), regardless of cue validity, and cue validity effects were larger when both non-spatial features repeated. That repeating the task-relevant feature decreased RTs is consistent with previous research, but finding a benefit for repeating task-irrelevant features has not been reported before. In Experiment 3, however, repeating just the task-relevant feature (shape) did not benefit performance, but we did find a spatially non-specific feature repetition benefit for repeating the task-irrelevant color. In addition, we once again find a spatially specific feature repetition benefit in the full repetition condition. Taken together, these experiments provide two novel findings. First, they demonstrate spatially non-specific feature repetition benefits for repeating task-irrelevant features, and second, consistently show an interaction between cue validity and non-spatial feature repetition.

Klein et al. (2015) proposed that a task-relevant feature influences performance by activating the associated response which produces a benefit if the target repeats that feature (i.e., the activated response is correct). This proposal cannot accommodate the current data as Experiment 3 demonstrated that when shape was the task-relevant feature, its repetition did not influence performance, but task-irrelevant color repetition did. Speaking more broadly, however, the task relevance explanation may not be inconsistent with the current data insofar as task relevance can be said to increase a feature's attentional weight (Bundesen, 1998; Bundesen, Vangkilde, & Petersen, 2014; Desimone & Duncan, 1995). For example, repetition priming, in which visual search targets are responded to faster when they repeat the previous trial's target (Maljkovic & Nakayama, 1994), is eliminated when the previous trial's target was passively viewed (Kristjánsson, Saevarsson, & Driver, 2013), rather than responded to, or when there is minimal interference from distractors (Goolsby & Sazuki, 2001). Recently, it has been suggested that this is because responding to, or selecting a target out of, interfering distractors increases the pertinence value of a stimulus's feature (Ásgeirsson, Kristjánsson, & Bundesen, 2015). This biases the visual system toward selecting that feature upon subsequent presentation. Applied to feature

repetition benefits in cueing studies, the task relevance of a feature likewise increases that pertinence and generates repetition benefits. According to this view, it does not matter to the visual system whether a stimulus's salience is driven by physical characteristics or is because it is task-relevant (see also: Memelink & Hommel, 2013). Either of these factors can increase the stimulus's pertinence and generates biases upon future presentation. If that is the case, it can then be said that feature salience, and not task relevance directly, is what drives the feature repetition benefits in both Klein et al.'s (2015) and our studies (here because of the stimulus's physical characteristics; in Klein et al. because of the stimulus's task relevance).

Despite this potential reconciliation, it remains unclear why Klein et al. (2015) found effects of the task-relevant shape while we only found feature repetition benefits for color regardless of task relevance. Visual display complexity is one possibility. Increasing the visual display complexity might increase cognitive load which, in turn, might lead to a higher emphasis on processing only features most relevant for completing the task quickly (Lavie & Tsal, 1994). For example, repetition priming (Maljkovic & Nakayama, 1994) is eliminated by using high density displays (Rangelov, Zehetleitner, Muller, & Zehetleitner, 2013). This is because feature differences, rather than actual feature values, are processed in the dense displays. Thus, the previous failures to observe task-irrelevant feature repetition may have been because complexity forced the visual system to prioritize which features are processed. In contrast, when only one item is present at any given time there are adequate processing resources for both the task-relevant and irrelevant features.³ When all features are processed, the more salient one affects performance more such that it alternating produces a large enough cost to counteract any task-irrelevant feature repetition benefits. Our Experiment 2 finding that task-irrelevant shape repetition does reduce RTs as long as the task-relevant color feature also repeats further supports that idea.

Another discrepancy between the current data and previous cueing experiments (Hu & Samuel, 2011; Klein, Wang, Dukewich, He, & Hu, 2015) looking at non-spatial feature repetition is that we found spatially specific non-spatial feature repetition benefits. That is, the cue validity effects were larger when the task-relevant and task-irrelevant features repeated than when either or both switched. One question generated by this discrepancy is why previous experiments studying non-spatial feature repetition effects did not find such effects. One possibility is that the simplified displays allow the

³ From a feature integration point of view, evidence that the visual system forms more elaborate object files so long as circumstances allow for it is found in Braet and Humphreys (2009), who demonstrate that increased stimulus exposure increased the likelihood of feature binding. Humphreys (2015) also advocated for different degrees of feature binding depending on the types of features being bound and whether attention was focused on the stimulus.

visual system to bind the cue into a location-specific object file. According to feature integration theories (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Kahneman, Treisman, & Gibbs 1992; Treisman & Gelade, 1980), a target partially repeating the cue's feature will incur a RT cost. This is consistent with our finding that the location-specific feature repetition benefits were largest when both non-spatial features repeated. This is because if some, but not all, of the features change across the cue and target, the cue's object file must be unbound to allow for the binding of the repeated feature in the target's event file. An inconsistency with strong versions of feature integration theories is that RTs were similar in the full switch condition and partial repetition conditions. While this is a prediction of feature integration and an observed phenomenon (e.g., Hommel, 1998), the temporal interval between cues and targets in this study are substantially shorter than feature integration studies typically use, leading to the possibility of other intervening factors such as the incorrect response still being active at the time of target presentation. Notably, a recent study has demonstrated significant differences in external information processing following response selection as a function of how long after response selection the presentation of external information occurs (Gozli & Ansorge, 2016). Specifically, participants were less sensitive to non-spatial feature information that appeared following longer durations after response selection. Given that study, it is possible participants in the current study were more sensitive to the target non-spatial information since it appeared shortly after response activation.

Identifying which factors determine whether non-spatial features generate repetition benefits is relevant for distinguishing between the three-component (Lupianez, 2010) and habituation (Dukewich, 2009) models of attentional cueing. The three-component model hypothesizes that whether facilitation or IOR is observed in a cueing experiment is a result of an onset detection cost, a spatial orienting benefit, and a spatial selection benefit. Alternatively, the habituation model suggests that orienting toward a given location becomes habituated so that a target appearing at the same location as a cue generates a weaker orienting response than targets at new locations. At early CTOAs, this smaller activation builds upon residual cue-generated activation so that responses are fast, while at long CTOAs the cue-generated activation has dissipated so there is only the weaker activation and thus IOR is found. Following their observation that non-spatial feature repetition effects vary as a function of response type, Hu and Samuel (2011) argued that their findings were most consistent with the three-component model which specifically predicts differences between detection and discrimination tasks since the onset detection cost is increased in detection tasks. By demonstrating that non-spatial feature relevance, and not response type, determined the presence or absence of non-spatial feature repetition benefits, Klein and

colleagues (2015) reopened the possibility for the more parsimonious habituation model to account for the data. The current data extends the Klein et al. findings by demonstrating that feature salience, regardless of whether it is salient because of task relevance or physical attributes, determine whether non-spatial feature repetition benefits are observed. Additionally, finding evidence that both task-relevant and irrelevant features influenced performance satisfies Klein and colleagues' concern about why task relevance would matter according to the habituation model (Klein et al., Appendix, point 2), because task relevance does not have a special role, but instead is one way in which stimulus saliency can be increased. When the cue feature is more salient, it is more likely to cause activation in the channels representing it, which, when the duration between the cue and target is short, facilitates detecting that feature again.⁴

It is important to note that, while it is not necessary for a feature to be task-relevant for generating non-spatial feature repetition benefits, under some circumstances task relevance does play a role. This is obvious when considering the previous studies that have looked at how non-spatial feature repetition affects RTs in detection and localization tasks and found different non-spatial repetition effect patterns to those found here (Hu, Samuel, & Chan, 2011; Hu & Samuel, 2011; Klein et al., 2015; Patel, Peng, & Sereno, 2010; Pratt, Hillis, & Gold, 2001; Red, Patel, & Sereno, 2012; Taylor & Donnelly, 2002). Instead, we are suggesting that task relevance matters in that it increases the relevant feature's salience making it more likely to generate feature repetition benefits. Although, as Experiment 3 demonstrates, it is possible for physically salient stimulus attributes to outweigh any salience gains from task relevance. As noted above, whether feature repetition benefits are found might be dependent on whether the task allows for processing of the irrelevant stimulus dimension and how salient that feature is.

In summary, across three experiments, we find support for the claim that task relevance partially determines whether a non-spatial feature generates repetition effects. In each experiment, the relevant feature contributed significantly to a spatially non-specific and/or spatially specific feature repetition effect in isolation or in combination with the task-irrelevant feature repetition. Critically, however, we also found that the task-irrelevant feature produced repetition benefits, demonstrating that task relevance is not necessary for non-spatial features to generate repetition effects. In addition, we found a spatially specific benefit for repeating non-spatial features such that cueing effects were larger when the non-spatial feature repeated, a previously unobserved finding. While the exact factors that led to the difference between current study and

⁴ In addition, of course, when the CTOA is sufficiently long, the feature activation turns into habituation, leading to altered inhibition of return effects, as observed previously (Hu et al., 2011; Klein et al., 2015)

previous ones remain to be determined in future research, we suggest that non-spatial feature relevance can overcome the influence of task relevance, and produce non-spatial feature repetition effects. In complex displays, like those used previously, we speculate that the role of feature salience is reduced, leading task relevance to play the dominant role in determining non-spatial feature repetition effects. As for the spatially specific effects, while we suggest feature integration as a mechanism underlying this component of the data, we recognize that this stands in contrast to a purely habituation account of attentional cueing effects. Such feature integration effects are implemented in the three-component model, however, so it is possible that a full account of attentional cueing effects will require components of each of these models. In any case, these experiments clearly demonstrate that there are multiple factors that contribute to non-spatial feature repetition effects, and that non-spatial feature repetition can interact with spatial cueing.

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