Birkbeck
UNIVERSITY OF LONDON

# BIROn - Birkbeck Institutional Research Online

Berggren, Nick and Nako, Rebecca and Eimer, Martin (2020) Out with the old: new target templates impair the guidance of visual search by pre-existing task goals. Journal of Experimental Psychology: General 149 (6), pp. 1156-1168. ISSN 0096-3445.

Downloaded from: https://eprints.bbk.ac.uk/id/eprint/28791/

*Usage Guidelines:*
Please refer to usage guidelines at https://eprints.bbk.ac.uk/policies.html or alternatively contact lib-eprints@bbk.ac.uk.

Running Head: ATTENTIONAL TEMPLATES

# Out with the old: New target templates impair the guidance of visual search by pre-existing task goals

Nick Berggren*, Rebecca Nako, & Martin Eimer

Department of Psychological Sciences, Birkbeck College, University of London,
Malet Street, London WC1E 7HX, UK

Word count: 9757

* Corresponding author

Phone: 0044 20 76316522

Fax: 0044 20 76316312

Email: nbergg01@mail.bbk.ac.uk

ABSTRACT

Representations of known target features (attentional templates) guide attention towards target objects during visual search. Recent research has shown that templates for different target-defining attributes can be maintained simultaneously, but interactions between multiple templates have not yet been studied systematically. Here, we investigated the competition between long-term (sustained) and short-term (transient) search goals in tasks where participants searched for targets defined by one of two possible colors. One target color remained constant across blocks or runs of trials, while the other changed on every trial. Both colors were indicated at the start of each trial by cue displays. To assess the efficiency of target selection processes guided by sustained and transient color templates, RTs and N2pc components were measured in Experiment 1 for search displays that contained a target in the constant or variable color. Results revealed robust sustained-template costs. RTs were slower and N2pc components emerged later and were smaller for sustained-color as compared to transient-color target objects. Experiments 2 and 3 demonstrated that this cost emerged rapidly, within two trials after a new constant color template had been established. These findings suggest that the activation of a new top-down search goal impairs the ability of a pre-existing template in working memory to guide attention towards target objects, reflecting a new type of retroactive interference in the control of visual search. These findings also have implications for our understanding of interactions between short-term task goals and longer-term attentional biases associated with the affective or motivational valence of objects. (249/250 words)

Keywords: Selective attention; top-down control; feature-based attention; retroactive interference; event-related brain potentials

## INTRODUCTION

Visual search for known target objects is controlled by representations of target-defining features. Such attentional templates (e.g., Duncan & Humphreys, 1989) or top-down task sets (e.g., Folk, Remington, & Johnston, 1992) are activated during the preparation for search tasks, and guide attention towards objects with template-matching attributes. For example, when searching for a cellphone, the corresponding search template might specify the particular color, shape, or size of this target object, and objects with one of these features will be more likely to attract attention.

Recent studies have shown that observers can simultaneously activate multiple attentional templates for different feature-defined target objects. For example, Irons, Folk, and Remington (2012) investigated two-color search tasks where targets could have one of two equally likely colors, and employed spatial cueing procedures to investigate whether two templates for each target color could be activated in parallel. Search displays were preceded by spatially uninformative cues that matched either one of the two target colors or a different nontarget color. In previous studies that used similar cueing procedures (Folk et al., 1992; Folk & Remington, 1998), RTs were faster when a target-matching cue and a search target appeared at the same location relative to different locations, indicating that cues which match the current search template attract attention. Critically, no such attentional capture effects were observed for non-matching cues. Irons et al. (2012) found such task-set contingent attentional capture effects for both target-color cues, but not for cues in a nontarget color. This suggests that observers were able to employ two search templates for two target colors concurrently (see also Moore & Weissman, 2010; Beck, Hollingworth, & Luck, 2012; Grubert & Eimer, 2016; Kerzel & Witzel, 2019, for additional behavioral and electrophysiological evidence for multiple simultaneously active target color templates).

These findings are problematic for models that have claimed that only a single search template can be held active at any given time (e.g., Olivers, Peters, Houtkamp, & Roelfsema, 2011). However, even if visual search can be controlled by several concurrently held target templates, this does not necessarily imply that attentional guidance is just as effective during multiple-target as compared to single-target search. In fact, several studies have observed substantial performance impairments when observers had to search for two

possible target objects relative to a single object (e.g., Houtkamp & Roelfsema, 2009), and also during multiple-color as compared to single-color search (e.g., Stroud, Menneer, Cave, Donnelly, & Rayner, 2011; see also Grubert & Eimer, 2013, for corresponding electrophysiological findings). Along similar lines, search for color conjunctions is typically inefficient (e.g., Wolfe et al., 1990), which has been interpreted as evidence that target selection can be guided by only a single feature in a given dimension at a time (Wolfe, 2007). The existence of such multiple-template costs suggests that two concurrently active target templates do not operate entirely independently, but compete with each other, resulting in impaired attentional guidance relative to search for a single visual feature or object. However, the factors that determine such interactions between multiple simultaneously active search templates have so far not been investigated systematically.

One potentially important variable for such interactions is whether target-defining features remain constant for an extended period or change between each successive selection episode. For example, strong behavioral evidence for multiple-template costs was found in experiments where observers searched for two possible target objects whose identities changed between individual trials (Houtkamp & Roelfsema, 2009). Here, new search templates have to be activated on each trial, and these templates are likely to be maintained in visual working memory. In contrast, when target-defining features remain constant for an extended period (as was the case in most studies that found evidence for multiple parallel feature templates, e.g., Irons et al., 2012; Beck et al., 2012), the corresponding search templates may no longer be held in working memory, but in a different longer-term memory store (Carlisle, Arita, Pardo, & Woodman, 2011; Woodman, Carlisle, & Reinhart, 2013; see also Neisser, Novick, & Lazar, 1963). As working memory capacity is more limited than the capacity of long-term memory, competitive interactions between multiple simultaneously active search templates may be more pronounced when these templates are maintained in working memory. In this case, attentional selection processes during multiple-feature search should be more strongly impaired when they are guided by transient templates in tasks where target definitions change on a trial-by-trial basis, relative to tasks where targets remain constant for longer periods, and sustained templates are involved.

This prediction was tested in a recent study from our lab (Grubert, Carlisle, & Eimer, 2016). Participants searched for targets defined by one, two, or three possible colors, and

these colors were always indicated at the start of each trial by color cues. Critically, target colors either remained constant or varied from trial to trial in different blocks. To assess the ability of transient and sustained color templates to guide the attentional selection of search targets, EEG was recorded during task performance, and N2pc components were measured in response to search displays. The N2pc component is an event-related potential (ERP) marker of the allocation of attention to possible target objects in visual search displays (Luck & Hillyard, 1994; Eimer, 1996). It is measured as an enhanced negativity elicited at posterior electrode sites contralateral to the visual field where these objects are presented. The N2pc typically emerges approximately 180-200 ms after search display onset, is believed to be generated within ventral extrastriate visual cortex (Hopf et al., 2000), and is interpreted as reflecting the allocation of attention to objects with target-matching features at relatively early stages of visual-perceptual processing (see Eimer, 2014, 2015, for more details). In our lab's study (Grubert et al., 2016), increasing the number of possible target colors from one to two, and from two to three, resulted in a delay of reaction times (RTs) to search targets, and in a corresponding attenuation and delay of target N2pc components. These observations confirm the existence of multiple-template costs that arise at the stage where attention is allocated to search targets. However, and importantly, the delay and attenuation of target N2pc components during multiple-color search was virtually identical in blocks where target colors changed across trials and in blocks where these colors remained constant (see Kerzel & Witzel, 2019, for corresponding behavioural results obtained in the context of a contingent attentional capture paradigm). In contrast, cueing target colors on a trial-by-trial basis slowed target RTs relative to constant-color blocks, suggesting that these behavioral costs were generated at processing stages that follow the initial attentional selection of target objects (see also Moore & Weissman, 2010, for similar suggestions).

The observation that target N2pcs did not differ between multiple-color search tasks with constant and variable target colors (Grubert et al., 2016) might suggest that the sustained versus transient nature of concurrently active search templates has no impact on the competition between these templates and thus their ability to guide attentional target selection processes. However, such a conclusion would be premature. This previous study employed search tasks that either involved sustained templates for multiple constant target colors or transient templates for multiple variable colors, but no tasks where short-term and

longer-term search goals were simultaneously active. To obtain conclusive insights into the nature of competitive interactions between transient and sustained search templates, such "mixed" search tasks are essential. Indeed, links between long-term and short-term task sets have recently become a focus in attention research. For example, there is substantial evidence that the allocation of attention to visual objects is determined not only by currently activated top-down task sets but also by the previous selection history and the long-term affective and motivational relevance associated with these objects (e.g., Awh, Belopolsky, & Theeuwes, 2012). On the one hand, selection biases associated with the previous reward value of a feature can override the effects of transient task sets (Hickey, Chelazzi, & Theeuwes, 2010). On the other hand, sustained attentional biases linked to affective value, such as the capture of attention by irrelevant objects associated with threat (e.g., Cisler, Bacon, & Williams, 2009) can be attenuated when short-term search goals are temporarily activated (e.g., Vogt, De Houwer, Crombez, & Van Damme, 2013). In other words, short-term biases on attentional selectivity can sometimes dominate longer-term biases, or vice versa, in different task contexts. Similar interactions between long-term and short-term top-down control mechanisms have also been studied in other areas of cognitive psychology. For example, classic research on human memory has demonstrated retroactive interference effects of recently encoded information on previous memory representations, as well as proactive interference from existing memory traces on the formation of new memory associations (e.g., Underwood, 1957).

The aim of the present study was to investigate the attentional guidance of visual search by short-term (transient) and long-term (sustained) target templates in mixed tasks where both types of templates had to be maintained concurrently. In such tasks, sustained templates may be more efficient in guiding attention towards search targets relative to transient templates, indicating that the attentional control of visual search is dominated by longer-term search goals. Alternatively, search may be more efficient when targets match a recently activated new template, suggesting that short-term goals override task sets that have been activated earlier. A third possibility is that there is no difference between simultaneously held sustained and transient templates in their ability to control visual search. To decide between these alternatives, we employed two-color search tasks where participants searched for one of two equally likely color-defined target bars in search displays where these targets were presented together with three distractors in three

different colors. At the start of each trial, the two possible target colors for this trial were indicated by two color cues presented to the left and right of fixation (see Figure 1). In the critical mixed tasks, one of these colors changed on every trial, while the other remained constant for several successive blocks (in Experiment 1) or for a run of successive trials (in Experiments 2 and 3).

In Experiment 1, three task conditions were compared. In the blocked transient task, the two target-defining colors changed randomly across each trial. In the blocked sustained task, the two target colors remained relevant for four successive blocks, and the same two color cues therefore appeared at the start of each trial. In the mixed task, one of the two target colors changed randomly across trials while the other remained constant throughout. Cue displays showed the constant and transient target color, randomly on the left and right side. Search targets in this mixed task unpredictably appeared in the constant or the transient color. Thus, participants maintained two short-term color templates in the transient task, two long-term templates in the sustained task, and simultaneously one transient and one sustained template in the mixed task. EEG was measured during task performance, in order to obtain N2pc components in response to targets as electrophysiological markers of template-guided attentional target selection processes, in addition to behavioral measures. Based on previous results (Grubert et al., 2016), we expected target RTs to be delayed in the transient two-color search task relative to the sustained task, without any corresponding target N2pc differences. This would confirm that the behavioral costs associated with maintaining two transient versus two sustained search templates are generated at stages subsequent to the initial template-guided allocation of attention to target objects.

The critical new question was whether there would be any systematic behavioral and N2pc differences in the mixed task in response to targets that matched either the transient or the sustained color template. It is possible that, analogous to the two other task conditions, an RT cost for transient-color targets relative to sustained-color targets will be present in the mixed task, without corresponding N2pc differences. This would show that transient and sustained templates do not differ in their ability to control attentional target selection processes, even when they are maintained simultaneously. Alternatively, one of these two templates may dominate the guidance of visual search at the expense of the other in the mixed task. One possibility is that the sustained color template is dominant, as

reflected by faster RTs as well as earlier and/or larger N2pc components to sustained-color targets. Conversely, a bias for the recently established transient-color template would be mirrored by faster RTs and earlier N2pcs for transient-color targets. To identify any costs or benefits associated with holding one transient and one sustained search template at the same time, we also directly compared search performance and N2pc components measured for sustained-color and transient color-targets in the mixed task and in the corresponding 'pure' sustained and transient search tasks.

## EXPERIMENT 1

### *Methods*

#### *Participants*

Thirteen participants were tested in Experiment 1. One participant was excluded from analysis due to a large percentage of trials rejected due to HEOG artifacts (> 60 %). Of the remaining 12 participants (*M* age = 31 years, SD = 9, 7 male; 2 left-handed, 1 declared ambidextrous), all reported normal or corrected-to-normal vision. All methods used in this experiment, and subsequent experiments, were approved by the institution's departmental ethical guidelines committee at Birkbeck, University of London. To determine a required sample size, we utilized RT data from a previous experiment (Grubert et al., 2016; Exp.2) that used similar cue and search displays in a two-color search task with constant-color and variable-color blocks. We used the observed RT differences between constant-color and variable-color blocks to calculate the effect size for the transient-template costs on target RTs in a two-color search tasks. Analysis using G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007) for two dependent mean conditions (M = 699 vs. 787 ms; SD = 86 vs. 96; assuming an RT correlation between the two blocked task conditions of .5, alpha level of 0.05 and power of 0.8) suggested a minimum required sample size of 11 participants. We set our sample size at 12 participants, also in line with previous N2pc component studies in our lab and elsewhere (e.g., Berggren, Jenkins, McCants, & Eimer, 2017; Grubert & Eimer, 2016; Luck & Hillyard, 1994).

*Stimuli and Procedures*

The experiment was programmed and executed using E-Prime 2.0 software (Psychology Software Tools, Inc.). Stimuli were presented on a 24-inch BenQ monitor (100 Hz; 1920 x 1080 screen resolution) attached to a SilverStone PC, with participant viewing distance at approximately 90 cm. Responses were registered via standard computer keyboard button presses. All stimuli were shown on a black background, with a grey fixation cross (0.25 x 0.25 degrees of visual angle) presented continuously throughout each block. Figure 1 presents an example experimental trial sequence. Each trial began with a cue display (200 ms) where two circles (0.25 x 0.25°) in two different colors were presented to the left and right of fixation at an eccentricity of 0.51° (measured from the center of a cue to fixation). Following a blank inter-stimulus interval (500 ms), search displays were presented for 100 ms. The interval between search display offset and the onset of cue display on the next trial was 1400 ms. Search displays contained four horizontally or vertically oriented rectangular bars (1.08 x 0.51°) in four different colors that appeared within the four quadrants diagonal from fixation, at an eccentricity of 1.59° (measured from the center of each bar to fixation). Each search display contained two vertically oriented and two horizontally oriented bars, at randomly selected positions. The colors used in the cue and search displays were red (CIE color coordinates: .605/.322), amber (.543/.409), yellow (.405/.470), green (.296/.604), blue (.169/.152), and magenta (.270/.134). All colors were matched for luminance (14 cd/$m^2$). Cue displays included the two target colors relevant for the current trials. Search displays contained one target bar in one of two target colors and three distractor bars in three different randomly determined nontarget colors. In all tasks, the search display was equally likely to contain a target object in either of the two cued colors, and this target appeared randomly at any of the four possible locations.

Participants' task was to find the rectangular bar in one of two possible target colors in the search displays. They reported whether this target appeared in the upper or lower visual field by pressing the '2' or '0' key on the numerical keypad with their right middle or index finger, respectively. Each participant chose a specific hand-to-key mapping, which they maintained throughout the experiment. There were three task conditions, each delivered in four successive blocks, with 96 trials per block. In the transient task, the two target-defining colors shown in the cue displays were randomly selected on each trial from the six possible colors, with the constraint that these colors differed from the two colors

selected for the immediately preceding trial. In the sustained task, two target colors remained constant throughout. These colors were randomly selected for each participant, except that the sustained target color in the mixed task for the same participant was never used. All cue displays contained the same two colors, and the side of which either of these colors appeared varied randomly across trials. Participants were informed about the two sustained target colors prior to the start of the first block of this task. In the mixed task, one target-defining color remained constant throughout, and participants were informed about the identity of this sustained target color prior to the start of the first mixed block. The other transient target color was selected randomly from the five remaining colors at the start of each trial. Immediate repetitions of the same transient target color across successive trials were not allowed. The side where the sustained and transient target colors appeared in the cue displays was randomly determined for each trial. Search displays unpredictably contained either the sustained-color or the transient-color target. The order in which the three blocked task conditions was presented was counterbalanced across participants.

---

Insert Figure 1 about here

---

*EEG Data Recording and Analysis*

EEG was DC-recorded at 27 scalp electrodes, mounted on an elastic cap at sites Fpz, F7, F8, F3, F4, Fz, FC5, FC6, T7, T8, C3, C4, Cz, CP5, CP6, P9, P10, P7, P8, P3, P4, PO7, PO8, PO9, PO10, and Oz. A sampling rate of 500-Hz was used with a 40 Hz low-pass filter applied. An electrode placed on the left earlobe acted as an online reference, with the average of signal from both earlobes used for offline re-referencing. No other filters were applied. Trials with eye blinks (exceeding ±60 μV at Fpz), horizontal eye-movements (exceeding ±30 μV in the HEOG channels), and muscle movement artifacts (exceeding ±80 μV at all other channels) were removed from EEG analyses, as were incorrect-response trials. All remaining trials were segmented into epochs spanning from 100 ms before to 500 ms after search display onset, relative to a 100 ms pre-stimulus baseline. Averaged ERPs were computed separately for search displays where the target appeared within the left or right visual field,

and separately for each task. Within the mixed task, epochs where the search display contained either the transient-color target or the sustained-color target were also separated. N2pc components were quantified based on ERP mean amplitude obtained at lateral posterior electrode sites PO7/PO8 between 200-300 ms post-stimulus onset. N2pc amplitude analyses included the factor Laterality (electrode PO7/PO8 contralateral versus ipsilateral to the side where the target appeared in the search display). To assess target N2pc onset latency differences between task conditions, a jackknife-based analysis method was employed, based on contralateral-ipsilateral N2pc difference waveforms, and using an absolute onset criterion of -0.5 μV (see Miller, Patterson, & Ulrich, 1998; Ulrich & Miller, 2001, for details).

*Results*

*Behavioral performance*

Figure 2 shows RTs and error rates for the sustained and transient tasks, as well as for sustained-color and transient-color targets in the mixed task. These data were analyzed with a 2 x 2 within-subjects Analysis of Variance (ANOVA) with the factors Template Type (transient versus sustained) and Task Context (blocked transient/sustained tasks versus mixed task). For RTs on trials with correct responses, there was no main effect of Template Type ($F(1,11) = 1.45$, $p = .26$), indicating that there was no overall RT difference between transient-color and sustained-color targets ($M$ = 603 versus 616 ms). A marginal main effect of Task Context ($F(1,11) = 4.69$, $p = .053$, $\eta_p^2 = .30$) indicated that RTs tended to be faster in the two blocked tasks relative to the mixed task ($M$ = 597 versus 622 ms). Critically, there was a highly significant interaction between both factors ($F(1,11) = 26.57$, $p < .001$, $\eta_p^2 = .71$). As shown in Figure 2, RT differences between targets that matched the transient versus sustained color template were observed between the two blocked tasks as well as between mixed-transient and mixed sustained targets, but in opposite directions. As expected, target RTs were faster in the blocked sustained task relative to the blocked transient task ($M$ = 578 versus 616 ms; $t(11) = 2.76$, $p = .019$). In contrast, RTs were substantially delayed for

sustained-color targets relative to transient-color targets in the mixed task (*M*= 590 versus 654 ms; $t(11) = 4.33$, p = .001).[1] For error rates, only a main effect of Template Type was found ($F(1,11) = 32.74$, $p < .001$, $\eta_p^2 = .75$), as errors were more frequent for transient-color targets relative to sustained-color targets (*M* = 12% versus 6%). There was no effect on Task Context ($F < 1$) and no two-way interaction ($F < 1.1$).

To determine whether the identity of the target on the preceding trial (sustained versus transient color) affected RTs to sustained-color and transient-color targets in the mixed task, an additional 2x2 ANOVA of RT data with the Factors Previous Target Color (Sustained, Transient), and Current Target Color (Sustained, Transient) was conducted. A main effect of Current Target Color ($F(1,11) = 18.71$, $p = .001$, $\eta_p^2 = .63$) reflected the RT costs for the sustained-color targets (see above). There was no main effect of Previous Target Color ($F(1,11) = 1.52$, $p = .24$), but an interaction between both factors was present ($F(1,11) = 6.41$, $p = .03$, $\eta_p^2 = .37$). RTs to sustained-color targets were faster when they were preceded by the same sustained-color target on the previous trial relative to when they were preceded by a transient-color target (*M* = 636 vs. 672 ms; $t(11) = 2.77$; $p = .018$). For RTs to transient-color targets, the color of the target on the previous trial (transient or sustained) had no significant effect (*M* = 580 vs. 603 ms; $t(11) = 1.84$; $p = .093$).

---

Insert Figure 2 about here

---

[1] When RT data were compared separately within each template type, RTs were significantly faster for sustained-color targets in the blocked relative to the mixed task ($t(11) = 4.04$, $p = .002$), while the opposite pattern (faster RTs for the mixed versus blocked task) was found for transient-color targets ($t(11) = 2.48$, $p = .03$).

*N2pc components*

Figure 3 (left panels) shows ERPs elicited by search displays at electrodes PO7/PO8 contralateral and ipsilateral to the side of target object in the 500 ms interval following display onset. ERPs are shown separately for the blocked sustained and transient tasks (top) and for sustained-color and transient-color targets in the mixed task (bottom). The corresponding contralateral-ipsilateral difference waveforms for these four conditions are shown in the right panel. Clear N2pc components were triggered by search targets in all tasks. Critically, the N2pc emerged later and was smaller in size for sustained-color targets in the mixed task relative to the other three conditions. This was confirmed by statistical analyses of N2pc mean amplitudes and onset latencies. Mean amplitudes obtained 200-300 ms after search display onset were entered into a 2x2x2 ANOVA with the factors Template Type, Task Context, and Laterality (electrode contralateral versus ipsilateral to target). A significant main effect of Laterality ($F(1,11) = 32.99$, $p < .001$, $\eta_p^2 = .75$) confirmed the reliable presence of target N2pc components. Importantly, there was also a three-way interaction ($F(1,11) = 12.88$, $p = .004$, $\eta_p^2 = .54$). As can be seen in Figure 3, N2pc components were smaller in size for sustained-color targets in the mixed task relative to all other types of targets (*M* diff = -.62 µV versus -1.27 µV, -1.07 µV, and -1.24 µV for targets in the sustained task, targets in the transient task, and transient-color targets in the mixed task, respectively; all $t$'s > 2.30, $p$'s < .05). There were no target N2pc amplitude differences between the other three task conditions (all $t$'s < 1.70, $p$'s > .11).

---

Insert Figure 3 about here

---

An analogous pattern was revealed by the jackknife-based N2pc onset latency analysis with the factors Template Type and Task Context. There was a main effect of Template Type ($F_c(1,11) = 7.60$, $p = .02$) that was qualified by a two-way interaction between both factors ($F_c(1,11) = 11.26$, $p = .006$). This interaction reflected the fact that N2pc

components emerged substantially later for sustained-color targets in the mixed task (M = 232 ms) relative to targets in the sustained task, the transient task, and transient-color targets in the mixed task *(M* = 193 ms, 196 ms, and 184 ms, respectively). Follow-up t-tests confirmed that the N2pc to sustained-color targets in the mixed task was reliably delayed relative to the N2pc onsets in the other three task conditions (all $t_c$'s > 2.31, $p$'s < .05), which did not differ from each other (all $t_c$'s < 1.49, $p$'s > .16).

*Discussion of Experiment 1*

In the two blocked transient and sustained tasks of Experiment 1, search was controlled by two color search templates that either had to be activated at the start of each trial, or remained constant throughout the entire task. RTs were faster in the sustained relative to the transient task, which could imply that the guidance of attention during two-color search is more effective when the same color templates can be maintained for extended periods. However, this conclusion was not supported by the N2pc components measured in the transient and sustained tasks. Target N2pcs emerged at the same time and were equal in size in these two tasks, demonstrating that transient and sustained target templates did not differ in their ability to control the allocation of attention to target objects. This pattern of behavioral costs for transient versus sustained search templates in a two-color search task without any corresponding costs for N2pc components perfectly matches the results of our lab's earlier study (Grubert et al., 2016). It suggests that these performance costs are generated at stages that follow the attentional selection of search targets. For example, it is possible that the identification of attended search target objects can be automatized and thus operate more rapidly under conditions where target-defining features remain constant than when they change on a trial-by-trial basis (see Shiffrin & Schneider, 1977, for an analogous suggestion that performance costs observed with variable target mappings are partially generated at the identification stage where perceptual signals are matched with stored representations of current target objects).

While transient and sustained color templates appear to be equally effective in guiding attention when two templates of the same type are activated together, marked

differences between them emerged in the mixed two-color search task of Experiment 1. Here, one sustained color template had to be maintained in parallel with a transient template that changed across successive trials. In this task, search performance showed the opposite pattern to what was observed in the two blocked tasks, with substantially delayed RTs for sustained-color targets relative to transient-color targets. Moreover, this behavioral difference was now also accompanied by a clear N2pc difference. N2pcs elicited by sustained-color targets in the mixed task were smaller and emerged later than N2pcs triggered by transient-color targets in this task, which did not differ from the N2pcs to both types of targets in the two blocked tasks. This suggests that the guidance of attention was specifically impaired for a sustained color template under conditions where this template was paired with another color template that was newly activated on a given trial.

Overall, the results of Experiment 1 suggest that there is a specific form of competition between two simultaneously active attentional templates that occurs when one of these templates is transiently activated while the other is held in a sustained fashion. Under these conditions, the newly activated template appears to interfere with the ability of the previously established template to guide attentional target selection. Notably, these costs for sustained-color targets in the mixed task were not mirrored by any corresponding benefits for transient-color targets in this task, as N2pcs to these targets did not differ from the N2pcs triggered by targets in the blocked transient and sustained tasks.

We suggest two possible explanations for the sustained-color costs in the mixed task. On the one hand, these costs could be a result of the fact that the two color templates in this task were held in different memory stores. Transient target colors were cued on a trial-by-trial basis and therefore had to be encoded into working memory. In contrast, because the sustained target color remained constant for several successive blocks, the corresponding attentional template may have been transferred to a long-term memory store. In order to affect on-line task performance, such a permanently stored memory representation may have to be retrieved from long-term memory and buffered within working memory (see Fukuda & Woodman, 2017, for a similar account). It is possible that the encoding of a new transient target color into working memory selectively interferes with the concurrent download of the other target color template from long-term memory, thereby reducing its ability to guide attention. This ‘download’ account can be contrasted with an alternative ‘upload’ account, which assumes that the encoding of a new attentional

template within working memory will interfere with any other already activated search template, regardless of whether this template is held in working memory or in a different long-term memory store.

The download account assumes that sustained-template costs will only emerge for target-defining features that have remained constant for an extended period and have therefore been transferred to long-term memory. In contrast, the upload account predicts that such costs are generated also for search templates that are still held in working memory whenever a new color template has to be activated. Because the same sustained-color template had to be maintained for several blocks in the mixed task of Experiment 1, these alternative predictions cannot be dissociated on the basis of the results of this experiment. Experiment 2 was designed to test them directly, with behavioral measures only. Here, participants again performed a mixed two-color search task where one target color was cued anew on each successive trial, while the other remained the same across trials. However, this sustained target color now stayed constant only for a run of eight trials. As in Experiment 1, each search display was preceded by a cue display that contained both possible target colors. Participants were informed that one of these colors would remain the same for eight successive trials, while the other would change on each trial. To indicate the start of a new run, the shape of the color cues (circles or squares) changed every eight trials. Search displays were equally likely to contain a transient-color or sustained-color target, and search performance was measured separately for these two types of targets.

The critical question addressed in Experiment 2 was whether and when performance costs for sustained-color targets would be observed within each run. Because the identity of the transient and sustained target color was not known on the first trial of each run, any such costs could only emerge from trial 2 onwards. According to the download account, sustained-template costs are the result of a transfer of these templates from working to long-term memory. Thus, the critical question is when such a transfer takes place. Previous electrophysiological studies (e.g., Carlisle et al., 2011) have used the contralateral delay activity (CDA) as an event-related potential (ERP) marker of the storage of search templates in working memory. The CDA is elicited in lateralized working memory tasks where observers have to retain memory sample stimuli on one side in order to compare them to a subsequent memory test display (e.g., Vogel & Machizawa, 2004). In such tasks, a CDA emerges contralateral to the task-relevant side of the sample display during the delay

period between sample and test displays. The amplitude of this component increases with the number of items that have to be memorized, indicating that it is an electrophysiological correlate of working memory maintenance. Importantly, a CDA is also elicited in response to lateralized cues that indicate the target-defining color for an upcoming search display, suggesting that it reflects the storage of color-specific attentional templates in working memory. Carlisle et al. (2011) demonstrated that when the cued target color remained constant for a run of successive trials, the CDA was reliably present only for the first four trials of each run, but not for subsequent trials. These results suggest that within approximately five trials, sustained search templates are no longer held in working memory, but have been transferred to a different long-term memory store (see Woodman et al., 2013, for further discussion). Based on these findings, the download account predicts that costs for sustained-color relative to transient-color targets in Experiment 2 should be absent or very small for the first four trials, and much larger for the final few trials within each run.

In contrast, the upload account assumes that the encoding of a new search template will interfere with any other search template that is already maintained in memory, even when this template has only been activated on the preceding trial. This account therefore predicts that costs for sustained-color targets will emerge early within each run, and will possibly already be evident on trial 2.

## EXPERIMENT 2

### *Participants*

Fourteen participants took part in Experiment 2. Of these, two participants were excluded due to error rates exceeding 3 SDs relative to the sample mean. The final sample size was therefore 12 participants (*M* age = 29 years, SD = 6; 6 male; all right-handed). All reported normal or corrected-to-normal vision.

The RT data from Experiment 1 was used to inform the desired sample size. As Experiment 2 investigated performance differences between target selection processes controlled by a sustained versus transient color templates in a mixed two-color search task, this power analysis was based on the observed RT difference between sustained-color and transient-color targets in the mixed task of Experiment 1 (*M* = 654 vs. 590 ms, SD = 106 vs.

69; $r$ = .915; $dz$ = 1.25). Analysis suggested a minimum sample size of 8 participants was required, assuming an alpha level of .05 and power of .80. To allow comparison across experiments, we retained the same sample size as in Experiment 1 (12 participants).

*Stimuli and Procedures*

These were similar to Experiment 1, with the following exceptions. Participants now completed only a version of the mixed task where one possible target color remained constant for a run of eight successive trials, while the other was determined randomly on each trial. Both target colors were again indicated by color cues at the start of each trial. Participants were informed that within each block, cue displays contained one color that would repeat for eight trials and another color that would randomly change across trials. To mark the transition between the separate eight-trial runs within a block, the shape of the cue stimuli changed from circle to square or vice versa) every eight trials. Thus, on the first trial within each new run, cue displays would contain two randomly selected colors. One of these (the sustained target color) would then be repeated on the remaining seven trials within the same run, while the other transient target color changed randomly across trials, with no transient color repetitions allowed across successive trials within the same run. Targets were equally likely to match either of these colors. Participants were instructed to notice which cue color was repeated within a given run, and were told that the change in cue shape indicated the start of a new run. They completed 8 experimental blocks of 96 trials each (i.e., each block containing 12 runs). In contrast to Experiment 1, no EEG was recorded during task performance.

*Results*

Figure 4 shows RTs in response to sustained-color and transient-color targets (left panel) and the resulting sustained-transient RT difference (right panel) for each successive trial within each run of eight trials. RTs were entered into a 2x8 ANOVA with the factors Template Type (Transient, Sustained) and Run Position (1-8). A significant main effect of Template Type ($F(1,11) = 24.56$, $p < .001$, $\eta_p^2 = .69$) reflected faster RTs for transient-color

relative to sustained-color targets (*M* = 599 vs. 656 ms). There was no main effect of Run Position ($F(7,77) = 1.74$, $p = .11$). Most importantly, a significant interaction between Template Type and Run Position was obtained ($F(7,77) = 5.08$, $p < .001$, $\eta_p^2 = .32$). As can be seen in Figure 4, there was no RT difference between transient-color and sustained-color targets on the first trial of each run (*M* diff = -1 ms; $t < 1$), as participants did not know the identity of the transient or sustained target color at this point. From trial 2 onwards, RTs were delayed in response to sustained-color relative to transient-color targets. This difference was only marginally significant for trial 2 (*M* diff = 39 ms; $t(11) = 2.16$, $p = .054$), but reliably present on trials 3-8 (*M* diff's > 58 ms; *t*'s > 3.05, *p*'s < .02). A matching analysis of error rate data showed no significant main effects or interactions (all *F*'s < 1). The overall error rate was 11%.

To assess whether the size of sustained-template costs on RTs increased across trials 3-8 within each run, an additional ANOVA was run for these trials only, with the factors Template Type and Run Position (3-8). There was no main effect of Run Position ($F < 1$), but a significant main effect of Template Type ($F(1,11) = 25.18$, $p < .001$, $\eta_p^2 = .70$), reflecting faster RTs for transient-color versus sustained-color targets. Critically, no interaction between factors was observed ($F < 1$), demonstrating that sustained-template costs remained constant across these trials. To investigate whether the presence or absence of a sustained-color RT cost on trial 2 was determined by whether the sustained target template was involved in the attentional selection of a target on trial 1, RTs on trial 2 were analyzed separately for runs where the target on trial 1 matched or did not match the sustained color template. A 2x2 ANOVA with the Factors Previous Target Color (Sustained, Transient), and Current Target Color (Sustained, Transient) confirmed the presence of a marginal sustained-color cost (main effect of Current Target Color: $F(1,11) = 4.67$, $p = .054$, $\eta_p^2 = .30$). There was no main effect of Previous Target Color and no interaction between both factors (both *F*'s < 1), indicating that the identity of the target on trial 1 had no effect on RTs to transient-color or sustained-color targets on trial 2. In particular, RTs to sustained-color targets on trial 2 were virtually identical on runs where the preceding first display contained a sustained-color or transient-target color target (*M* = 654 vs. 653 ms).

---

Insert Figure 4 about here

---

*Discussion of Experiment 2*

The existence of sustained-color target performance costs during two-color search found in the mixed task of Experiment 1 was confirmed in Experiment 2, in spite of the fact that the sustained search template was now only maintained for runs of eight trials, instead of several successive blocks. Importantly, these costs emerged rapidly within each run. There was already a marginal RT cost for sustained-color search targets relative to transient-color targets on trial 2, and these costs were reliably present from trial 3 onwards. Moreover, there was no change in the size of these costs across trials 1-8 within each run.[2] These observations provide strong support for an upload account, which assumes that the activation of a new attentional template interferes with the ability of any other search template currently held in working memory to guide attentional target selection. If such costs only arise for sustained search templates once they have been transferred to a long-term memory store, as proposed by the alternative download account, they should have been much larger once this transfer had been completed (from trial 5 onwards, as suggested by the CDA results by Carlisle et al., 2011), but small or absent during the first four trials when such templates are still maintained in working memory.

The fact that sustained-template costs were only marginally significant for trial 2 within each run precludes a clear answer to the question whether sustained-template costs occur immediately, even when a search template has only been activated on the preceding trial, or only when such a template has been maintained for at least two trials. The former would suggest that these costs are generated at a level of processing that may be relatively independent of top-down control, while the latter would point to an involvement of active search template consolidation mechanisms. Experiment 3 was conducted to obtain more definitive insights into the emergence of sustained-template costs across trials. Procedures were similar to Experiment 2, except that the length of each run of trials was reduced from

[2] Figure 2 (left panel) indicates that RTs to transient-color targets decreased across trials 2-8 within each run, while RTs to sustained-color targets remained constant. The fact that transient-target RTs became faster across successive trials of a given run might at least in part be due to template-unspecific short-term practice effects, and the apparent absence of such practice effects for sustained-colour targets could reflect the impact of additional sustained template costs, which were evident for the target N2pc components in Experiment 1.

eight to three. Thus, the shape of the color cues now changed every three trials, indicating the beginning of a new run where one target-defining color would remain constant. RT differences between targets in the sustained versus transient color were separately measured for trial 1 (where no such difference should be present) and for trials 2 and 3. Reducing run length from eight to three trials in Experiment 3 resulted in more trials per cell and greater experimental power to detect the presence of reliable RT differences between transient-color and sustained-color targets.

Reducing the number of successive trials with the same sustained target color to three in Experiment 3 also makes it possible to explore the role of top-down strategies for the emergence of sustained-template costs. Changing the sustained target color every three trials makes it less useful for participants to register the presence of color cue repetitions and to actively maintain a sustained color template across trials. If such intentional factors were involved, any sustained-template costs in Experiment 3 should be smaller than in Experiment 2, and possibly even entirely absent.

## EXPERIMENT 3

### *Participants*

Twelve participants took part in Experiment 3 (M age = 31 years, SD = 9; 4 male; 1 left-handed). All reported normal or corrected-to-normal vision.

### *Stimuli and Procedures*

These were similar to Experiment 2, with the following exceptions. Each cued run now only contained three trials instead of eight trials. As in Experiment 2, a new run was marked within a block by a change in cue shape (from circle to square, or vice versa). Participants completed 12 experimental blocks of 48 trials each (i.e., each block containing 16 three-trial runs).

### *Results*

Figure 5 shows RTs in response to sustained-color and transient-color targets on trials 1-3 within each run. RTs were entered into a 2x3 ANOVA with the factors Template Type (Transient, Sustained) and Run Position (1-3). There were no main effects of Template Type ($F(1,11) = 3.22$, $p = .10$) or Run Position ($F < 1$), but a significant interaction between both factors was present ($F(2,22) = 7.96$, $p = .003$, $\eta_p^2 = .42$). As shown in Figure 5, RTs did not differ between transient-color and sustained-color targets on trials 1 and 2 within each run (*M* diff = -2 ms and 5 ms; both $t < 1$). In contrast, a significant RT delay for sustained-color targets emerged on the third and final trial of each run (*M* diff = 38 ms; $t(11) = 3.92$, $p = .002$). For these targets, RTs were reliably slower on trial 3 relative to trial 2 within each run (*M* diff = 14 ms; $t(11) = 2.30$, $p = .04$). In contrast, RTs for transient-color targets was faster on trial 3 relative to trial 2 (M diff = -19 ms; t(11) = 3.34, p = .007). The overall error rate was 9% in Experiment 3. There were no main effects of Run Position ($F(2,22) = 1.11$, $p = .35$) or Template Type ($F < 1$) and no interaction between both factors ($F < 1$) for error rates.

To assess possible effects of the color of the target on the preceding trial on RTs for trials 2 and 3 within each run, two additional 2x2 ANOVAs were run with the Factors Previous Target Color (Sustained, Transient), and Current Target Color (Sustained, Transient). For trial 2, there were no main effects and no interaction between these two factors (all F's < 1). For trial 3, a main effect of Current Target Color (F(1,11) = 15.24, p = .002, $\eta_p^2 = .58$) reflected the presence of RT costs for sustained-color relative to transient-color targets (M = 593 vs. 555 ms). There was no main effect of Previous Target Color (F(1,11) = 2.27, p = .16) and no interaction between both factors (F < 1). Thus, and analogous to Experiment 2, RTs were unaffected by any intertrial target color priming.

---

Insert Figure 5 about here

---

*Discussion of Experiment 3*

Reducing the length of runs where one of the two target colors remained constant from eight to three trials did not eliminate the presence of sustained-template RT costs in Experiment 3. However, these costs only emerged on the third trial within each run, and were entirely absent on trial 2. In contrast, a tendency towards such costs was already observed in the second trial of each eight-trial run in Experiment 2. The lack of such an effect on trial 2 could suggest that the trend found in Experiment 2 was spurious. Alternatively, this difference between the two experiments could also be linked to differences in the incentive to encode and maintain a sustained color template across trials. When the constant target color changes every three trials, participants may not be motivated to notice any cue color repetitions, and therefore always treat both cued colors as new features that require the activation of new search templates. While this may have been the case for the second trial of each run, the presence of significant RT costs for sustained-color as compared to transient-color targets on trial 3 suggests that a sustained color template had been stored in working memory on this trial. This sustained template was then subject to interference by the activation of a new transient template, as predicted by the upload account. Thus, the results of Experiment 3 confirm that sustained-template costs emerge rapidly, even when target colors change frequently.

## GENERAL DISCUSSION

Previous research has shown that search templates for two target-defining colors can be activated simultaneously (Irons et al., 2012; Kerzel & Witzel, 2019), and that two parallel color templates are equally efficient in guiding attentional target selection, regardless of whether they remain constant for extended periods or are cued on a trial-by-trial basis (Grubert et al., 2016). Here we investigated the control of attentional target selection processes in two-color visual search tasks when a transient and a sustained color template had to be maintained simultaneously. In Experiment 1, such a mixed search task was run together with a blocked sustained and a blocked transient two-color search task. Template-guided target selection processes were assessed with behavioral measures and N2pc components, and the sustained target color remained the same for four successive blocks. In Experiments 2 and 3, performance was measured in mixed tasks where the

sustained target color remained constant for runs of eight trials (Experiment 2) or three trials (Experiment 3).

The major new finding of this study was the marked impairment of attentional guidance by a sustained color template in mixed tasks where this template was paired with a transient color template that had to be newly activated on each trial. In all three experiments, RTs to targets defined by the sustained color were delayed relative to transient-color targets, and this was mirrored by a delay and attenuation of N2pc components to sustained-color targets in Experiment 1. These observations demonstrate that sustained color templates were less efficient than transient templates in controlling the allocation of attention to search targets. Importantly, this differential effect was only observed in the mixed task. No N2pc differences between sustained-color and transient-color targets were observed in the two blocked task conditions of Experiment 1 (confirming previous observations, Grubert et al., 2016), and target RTs were even faster in the blocked sustained relative to the blocked transient task.

The differences in the speed of attentional target selection processes that are controlled by sustained versus transient color templates in the mixed task could be due to costs for the selection of sustained-color targets, benefits for the selection of transient-color targets, or a combination of both costs and benefits. A comparison of the results obtained in the mixed and the two blocked tasks of Experiment 1 suggests that these differential effects primarily reflect sustained-template costs. Responses to transient-color targets were faster in the mixed versus blocked task, indicative of a benefit when pairing a transient color template with a sustained template relative to pairing it with a second transient template. However, N2pc components to transient-color targets were virtually identical in mixed and blocked task contexts, suggesting that this relatively small RT benefit (26 ms) was generated at a post-selection stage of processing. In contrast, there were much larger RT costs (76 ms) for sustained-color targets in the mixed versus blocked task, and these costs were mirrored by a delay and attenuation of N2pc components. These observations demonstrate the existence of substantial costs for attentional guidance by a sustained color template that is paired with a newly activated transient template relative to a context where it is maintained together with another sustained template. Experiments 2 and 3 demonstrated that these sustained-color costs emerged rapidly within the first few trials after a new sustained target template had been established, and were reliably present from trial 3 onwards. This

suggests that these costs are not related to a transfer of a sustained search template from working memory into a different long-term memory store. Previous ERP results have shown that such templates are maintained in working memory for at least 4-5 trials before they become fully established in long-term memory (Carlisle et al., 2011; Woodman et al., 2013). In the current study, strong sustained-template costs emerged already on the third trial of each run, and did not increase in size for subsequent trials (Experiment 2), indicates that these costs are likely to reflect competitive interactions between two color templates that are both held in visual working memory.

Previous research demonstrating performance impairments and corresponding target N2pc delays during two-color versus one-color search (Grubert & Eimer, 2013; Grubert et al., 2016) suggests that while two feature templates can be maintained, there are competitive interactions between these templates which affect their ability to guide attentional target selection processes. The current results show that when a pre-existing and a new search template are held concurrently, the competition between them is strongly biased against the sustained template (see also Gunseli, Olivers, & Meeter, 2016, for corresponding evidence that newly encoded task-irrelevant working memory representations interfere with visual search when target templates remain constant across successive trials). This competitive disadvantage could be due to the fact that on any given trial, the active encoding of a transient template into working memory results in more processing resources being allocated to this template relative to a pre-existing sustained template. In line with this possibility, Kerzel and Witzel (2019) recently suggested that working memory representations which have the highest attentional priority will automatically act as search templates, while other less prioritized representations do not. Such a bias in the allocation of attentional resources could in principle account for the sustained-template costs observed for the mixed tasks in the current study. If this was the case, the bias in favor of transient templates should be larger in a mixed task where they compete with a sustained template than in the blocked transient task of Experiment 1 where two transient templates had to be activated concurrently, resulting in more efficient attentional guidance by transient templates in the mixed task. As mentioned earlier, N2pc components to transient-color targets were in fact identical in the mixed and blocked tasks. This is not consistent with a generic competitive prioritization account (Kerzel & Witzel,

2019), and more in line with a sustained-template cost that is the specific result of uploading a new attentional template.

The sustained-template cost uncovered in this study represents a new instance of the classic retroactive interference effects that are commonly observed in memory research (e.g., Underwood, 1957), now for the case of attentional target selection in visual search. This commonality highlights the close links between selection history and mechanisms of attentional control. However, the direction of these effects is unexpected, given previous suggestions that sustained attentional biases produced by earlier selection episodes can facilitate attentional allocation processes when these biases are congruent with current task sets (e.g., Awh et al., 2012). If this was the case, one would have expected to find benefits rather than costs for the selection of sustained-color targets in the mixed tasks of the present study. The existence of such costs is also remarkable because half of these trials were preceded by a trial where the same target was shown, which should have facilitated target selection (Awh et al., 2012). Such intertrial priming was indeed found in Experiment 1, where the sustained target color remained the same throughout, but the presence of this effect did not eliminate the robust sustained-template costs observed across all trials. No target-target intertrial priming effects were observed in Experiments 2 and 3, when the sustained target color was only kept constant for short runs of trials. Overall, our results demonstrate that while task history can sometimes produce benefits when targets are repeated across successive trials, it works in the opposite direction at the level of attentional control, with more recently established task settings producing retroactive interference for the guidance of attention by a pre-existing search template.

The costs that emerge when the activation of a new target template interferes with the guidance of attention by another previously stored template are similar to effects observed in previous research on attentional biases triggered by stimuli with long-term motivational relevance, such as angry or fearful faces. Involuntary attentional capture by such stimuli has been measured with the classic dot probe paradigm, where RTs to probes are faster when they appear at the location previously occupied by a threat-related object (e.g., MacLeod, Mathews, & Tata, 1986). Importantly, such sustained attentional biases can at times be eliminated or reversed when a short-term goal has been associated with a different object (Vogt et al., 2013; Moriya, Koster, & De Raedt, 2014). Along similar lines, benefits for the detection of threat-related objects during visual search often disappear

when a different top-down search template has been adopted and threat is made wholly task-irrelevant (e.g., Brown, Berggren, & Forster, in press; Everaert, Spruyt, & De Houwer, 2013; Lichtenstein-Vidne, Henik, & Safadi, 2012; Stein, Zwickel, Ritter, Kitzmantel, & Schneider, 2009; Vromen, Lipp, Remington, & Becker, 2016). In all of these cases, long-term attentional biases for motivationally salient stimuli are neutralized by activating a new short-term task set, which is analogous to the retroactive interference by new search goals on pre-existing target templates demonstrated in the current study. Whether this analogy reflects overlapping mechanisms remains open to debate. The sustained-template costs observed here are due to a competition between multiple task goals that are actively maintained in memory, whereas sustained threat- and/or reward-related attentional biases are often assumed to be stored in a different format that may be independent of top-down control (see Cisler & Koster, 2010; Anderson, Laurent, & Yantis, 2011; Purkis, Lester, & Field, 2011). Further research is required to determine whether the interactions between concurrently held sustained and transient search templates and the interactions between long-term attentional biases associated with affective and motivational relevance and short-term task goals are based on shared or functionally similar processes.

In summary, the present study has uncovered an important new constraint for the control of attention by attentional templates in visual search. The guidance of target selection processes by a previously stored search template is strongly impaired when an additional new search goal is activated, and this sustained-template cost emerges rapidly, within two or three trials. The existence of such retroactive interference effects in template-guided visual search highlights the similarities between the control of memory and attention, and may also provide further insights into interactions between attentional biases associated with long-term motivational relevance and short-term task goals.

*Context of the Research*

This research was inspired by the fact that certain classes of salient stimuli (such as motivationally-significant information like threat) are often believed to automatically capture attention, but do not always do so. Particularly, when participants adopt an alternative short-term goal during visual search, distraction by task-irrelevant threat stimuli may diminish. Because the tendency to attend to motivationally-relevant stimuli reflects a sustained long-term attentional bias, we became interested in the general question whether there are differences in the guidance of attention by top-down attentional control settings that have become habitual relative to newly established attentional templates. More specifically, we wanted to find out how long-term and short-term control settings interact when both are activated at the same time, and investigated this here with motivationally-neutral stimuli (colored bars). Our main finding that short-term task settings impair the ability of pre-existing and habitual task sets to guide attention suggests that the reduction of habitual threat biases in situations where a new short-term goal is adopted could reflect similar processes. This study forms part of all authors' ongoing research into how target templates guide visual search, and author NB's current research into the role of top-down attentional factors for anxiety-related symptomatology.

*Acknowledgements*

This work was supported by grants ES/L016400/1 and ES/R003459/1 from the Economic and Social Research Council (ESRC), UK. None of the data or interpretations in this paper have been previously disseminated, in whole or in part, elsewhere.

References

Anderson, B.A., Laurent, P.A., & Yantis, S. (2011). Value-driven attentional capture. *Proceedings of the National Academy of Sciences USA*, *108*, 10367-10371.

Awh, E., Belopolsky, A.V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in Cognitive Sciences*, *16*, 437-443.

Beck, V.M., Hollingworth, A., & Luck, S.J. (2012). Simultaneous control of attention by multiple working memory representations. *Psychological Science*, *23*, 887-898.

Berggren, N., Jenkins, M., McCants, C.W., & Eimer, M. (2017). The spatially global control of attentional target selection in visual search. *Visual Cognition*, *25*, 196-214.

Brown, C.R.H., Berggren, N., & Forster, S. (in press). Testing a goal-driven account of involuntary attentional capture by threat. *Emotion.*

Carlisle, N.B., Arita, J.T., Pardo, D., & Woodman, G.F. (2011). Attentional templates in visual working memory. *Journal of Neuroscience*, *31*, 9315-9322.

Cisler, J.M., Bacon, A.K., & Williams, N.L. (2009). Phenomenological characteristics of attentional biases towards threat: A critical review. *Cognitive Therapy and Research*, *33*, 221-234.

Cisler, J.M., & Koster, E.H. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review*, *30*, 203-216.

Duncan, J., & Humphreys, G. (1992). Beyond the search surface: Visual search and attentional engagement. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 578-588.

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology*, *99*, 225-234.

Eimer, M. (2014). The neural basis of attentional control in visual search. *Trends in Cognitive Sciences*, *18*, 526-535.

Eimer, M. (2015). EPS Mid-Career Awarded 2014: The control of attention in visual search: Cognitive and neural mechanisms. *The Quarterly Journal of Experimental Psychology*, *68*, 2437-2463.

Everaert, T., Spruyt, A., & De Houwer, J. (2013). On the malleability of automatic attentional biases: Effects of feature-specific attention allocation. *Cognition and Emotion*, *27*, 385-400.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191.

Folk, C.L., & Remington, R. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 847-858.

Folk, C.L., Remington, R.W., & Johnston, J.C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030-1044.

Fukuda, K., & Woodman, G.F. (2017). Visual working memory buffers information retrieved from visual long-term memory. *Proceedings of the National Academy of Sciences USA*, *114*, 5306-5311.

Grubert, A., & Eimer, M. (2013). Qualitative differences in the guidance of attention during single-colour and multiple-colour visual search: Behavioural and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*, *39*, 1433-1442.

Grubert, A., Carlisle, N.B., & Eimer, M. (2016). The control of single-colour and multiple-colour visual search by attentional templates in working memory and in long-term memory. *Journal of Cognitive Neuroscience*, *28*, 1947-1963.

Grubert, A., & Eimer, M. (2016). All set, indeed! N2pc components reveal simultaneous attentional control settings for multiple target colors. *Journal of Experimental Psychology: Human Perception and Performance*, *42*, 1215-1230.

Gunseli, E., Olivers, C.N.L., & Meeter, M. (2016). Task-irrelevant memories rapidly gain attentional control with learning. *Journal of Experimental Psychology: Human Perception and Performance*, *42*, 354-362.

Hickey, C., Chelazzi, L., & Theeuwes, J. (2010). Reward changes salience in human vision via the anterior cingulate. *Journal of Neuroscience*, *30*, 11096-11103.

Hopf, J.M., Luck, S.J., Girelli, M., Hagner, T., Mangun, G.R., Scheich, H., & Heinze, H.J. (2000). Neural sources of focused attention in visual search. *Cerebral Cortex*, *10*, 1233-1241.

Houtkamp, R., & Roelfsema, P.R. (2009). Matching of visual input to only one item at any one time. *Psychological Research*, *73*, 317-326.

Irons, J.L., Folk, C.L., & Remington, R.W. (2012). All set! Evidence for simultaneous attentional control settings for multiple target colors. *Journal of Experimental Psychology: Human Perception and Performance*, *38*, 758-775.

Kerzel, D., & Witzel, C. (2019). The allocation of resources in visual working memory and multiple attentional templates. *Journal of Experimental Psychology: Human Perception and Performance*, *45*, 645-658.

Lichtenstein-Vidne, L., Henik, A., & Safadi, Z. (2012). Task relevance modulates processing of distracting emotional stimuli. *Cognition and Emotion*, *26*, 42-52.

Luck, S.J., & Hillyard, S.A. (1994). Spatial filtering during visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1000-1014.

MacLeod, C., Mathews, A., & Tata, P. (1986). Attentional bias in emotional disorders. *Journal of Abnormal Psychology*, *95*, 15-20.

Moore, K.S., & Weissman, D.H. (2010). Involuntary transfer of a top-down attentional set into the focus of attention: Evidence from a contingent attentional capture paradigm. *Attention, Perception, & Psychophysics*, *72*, 1495-1509.

Miller, J., Patterson, T., & Ulrich, R. (1998). Jackknife-based method for measuring LRP onset latency differences. *Psychophysiology*, *35*, 99-115.

Moriya, J., Koster, E.H.W., & De Raedt, R. (2014). The influence of working memory on the anger superiority effect. *Cognition & Emotion*, *28*, 1449-1464.

Neisser, U., Novick, R., & Lazar, R. (1963). Searching for ten targets simultaneously. *Perceptual and Motor Skills*, *17*, 955-961.

Olivers, C.N.L., Peters, J., Houtkamp, R., & Roelfsema, P.R. (2011). Different states in visual working memory: When it guides attention and when it does not. *Trends in Cognitive Sciences*, *15*, 327-334.

Purkis, H.M., Lester, K.J., & Field, A.P. (2011). But what about the Empress of Racnoss? The allocation of attention to spiders and Doctor Who in a visual search task is predicted by fear and expertise. *Emotion*, *11*, 1484-1488.

Shiffrin, R.M., & Schneider, W. (1977). Controlled and automatic human information processing. II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, *84*, 127-190.

Stein, T., Zwickel, J., Ritter, J., Kitzmantel, M., & Schneider, W.X. (2009). The effect of fearful faces on the attentional blink is task dependent. *Psychonomic Bulletin & Review*, *16*, 104-109.

Stroud, M.J., Menneer, T., Cave, K.R., Donnelly, N., & Rayner, K. (2011). Search for multiple targets of different colours: Misguided eye movements reveal a reduction of colour sensitivity. *Applied Cognitive Psychology*, *25*, 971-982.

Ulrich, R., & Miller, J. (2001). Using the jackknife-based scoring method for measuring LRP onset effects in factorial designs. *Psychophysiology*, *38*, 816-827.

Underwood, B.J. (1957). Interference and forgetting. *Psychological Review*, *64*, 49-60.

Vogel, E.K., & Machizawa, M.G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature*, *428*, 748-751.

Vogt, J., De Houwer, J., Crombez, G., & Van Damme, S. (2013). Competing for attentional priority: Temporary goals versus threats. *Emotion*, *13*, 587-598.

Vromen, J.M., Lipp, O.V., Remington, R.W., & Becker, S.I. (2016). Threat captures attention, but not automatically: Top-down goals modulate attentional orienting to threat distractors. *Attention, Perception, & Psychophysics*, *78*, 2266-2279.

Wolfe, J.M. (2007). Guided search 4.0: Current progress with a model of visual search. In W. Gray (Ed.), *Integrated models of cognitive systems* (pp. 99-119). New York, NY: Oxford.

Wolfe, J.M., Yu, K.P., Stewart, M.I., Shorter, A.D., Friedman-Hill, S.R., & Cave, K.R. (1990). Limitations on the parallel guidance of visual search: Color x color and orientation x orientation conjunctions. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 879-892.

Woodman, G.F., Carlisle, N.B., & Reinhart, R.M.G. (2013). Where do we store the memory representations that guide attention? *Journal of Vision*, *13*, 1.

**Figure captions**

Figure 1: Example experimental trial sequence (not to scale). Search displays contained four vertical or horizontal colored bars. Targets were defined by one of two possible colors that were indicated at the start of each trial by a cue display that contained two colored circles. In the transient task, two new target-defining colors were cued at the start of each trial. In the sustained task, target colors remained constant throughout, and cue displays always contained the same two colors. In the mixed task, one target color remained constant while the other changed on a trial-by-trial basis.

Figure 2: Reaction times (top) and error rates (bottom) measured in Experiment 1 in response to sustained-color targets (black bars) and transient-color targets (grey bars) in the two blocked tasks (left) and in the mixed task (right). Error bars denote ± 1 standard error.

Figure 3: (Left panels) Grand averaged ERPs elicited in Experiment 1 by search displays at posterior electrodes PO7/8 contralateral and ipsilateral to a target item, shown separately for displays with sustained-color targets and transient-color targets in the blocked sustained and transient tasks (top) and in the mixed task (bottom). (Right panel) N2pc difference waveforms obtained by subtracting ipsilateral from contralateral ERPs, shown separately for sustained-color and transient-color targets in the blocked and mixed tasks.

Figure 4: Reaction times measured in Experiment 2 in response to sustained-color and transient-color targets, for each position within in the eight-trial runs (left panel), and the corresponding RT difference for each run position (right panel). Error bars denote ± 1 standard error.

Figure 5: Reaction times measured in Experiment 3 in response to sustained-color and transient-color targets, for each position within in the three-trial runs. Error bars denote ± 1 standard error.

Figure 1

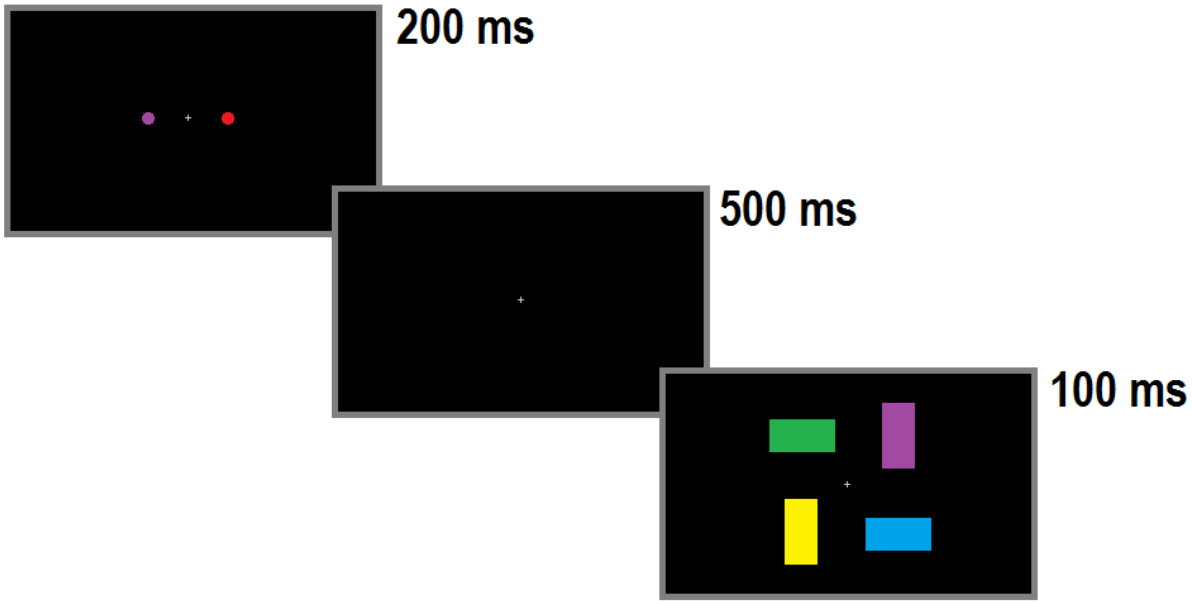
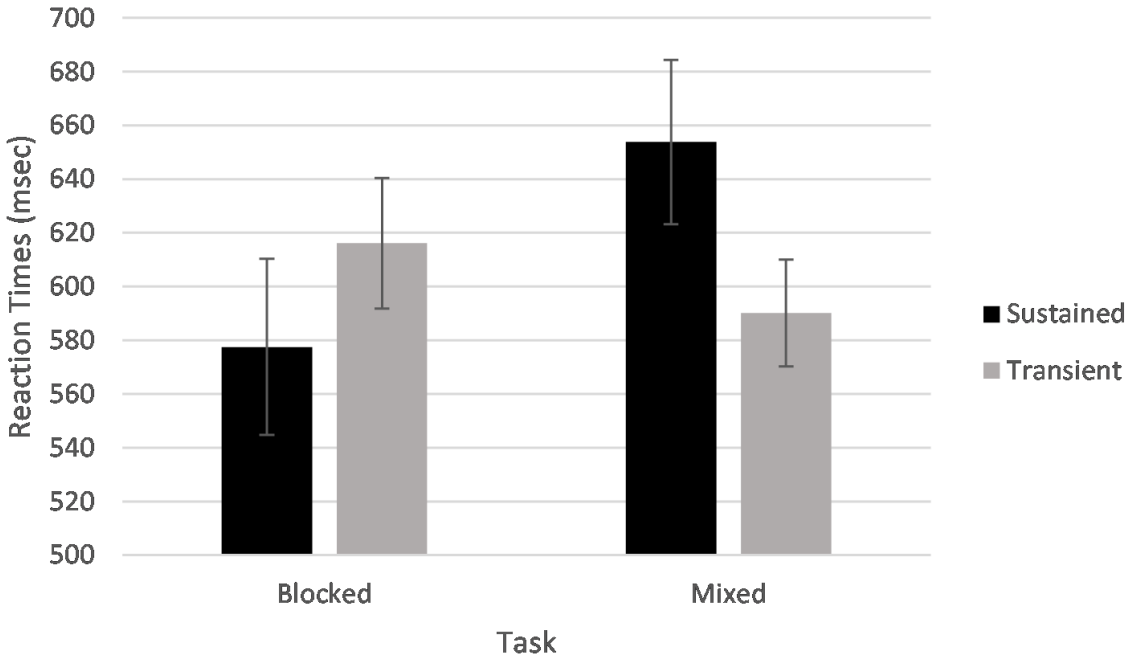


Figure 2


700
680
660
640
620
600
580
560
540
520
500
Reaction Times (msec)
Blocked
Mixed
Task
Sustained
Transient

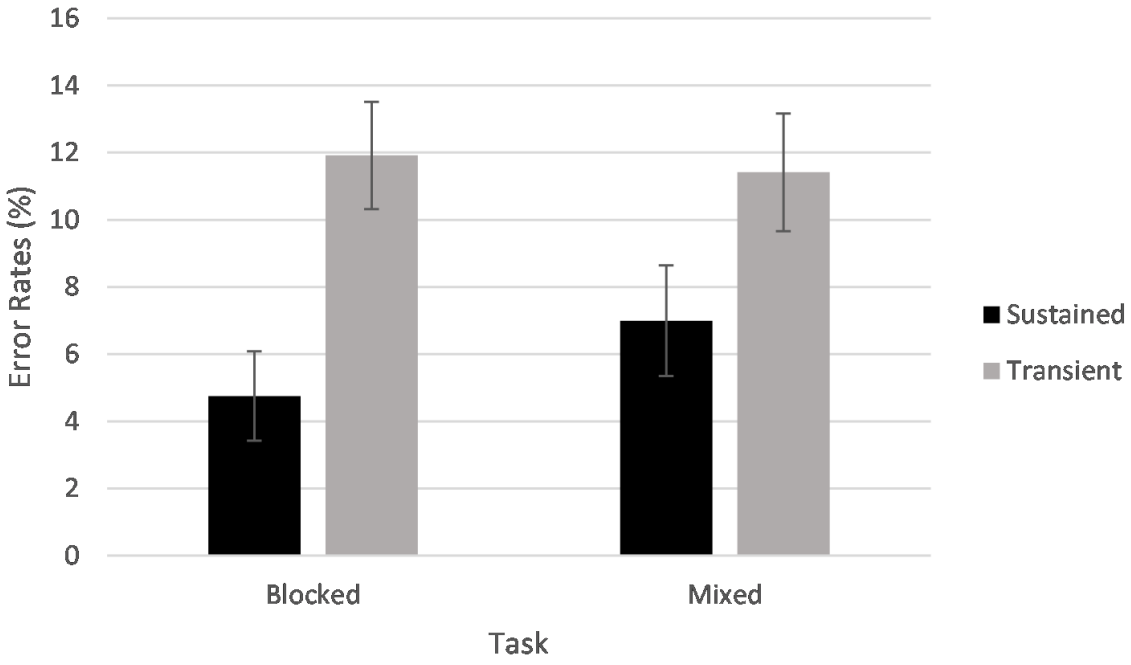

16
14
12
10
8
6
4
2
0
Error Rates (%)
Blocked
Mixed
Task
Sustained
Transient

Figure 3

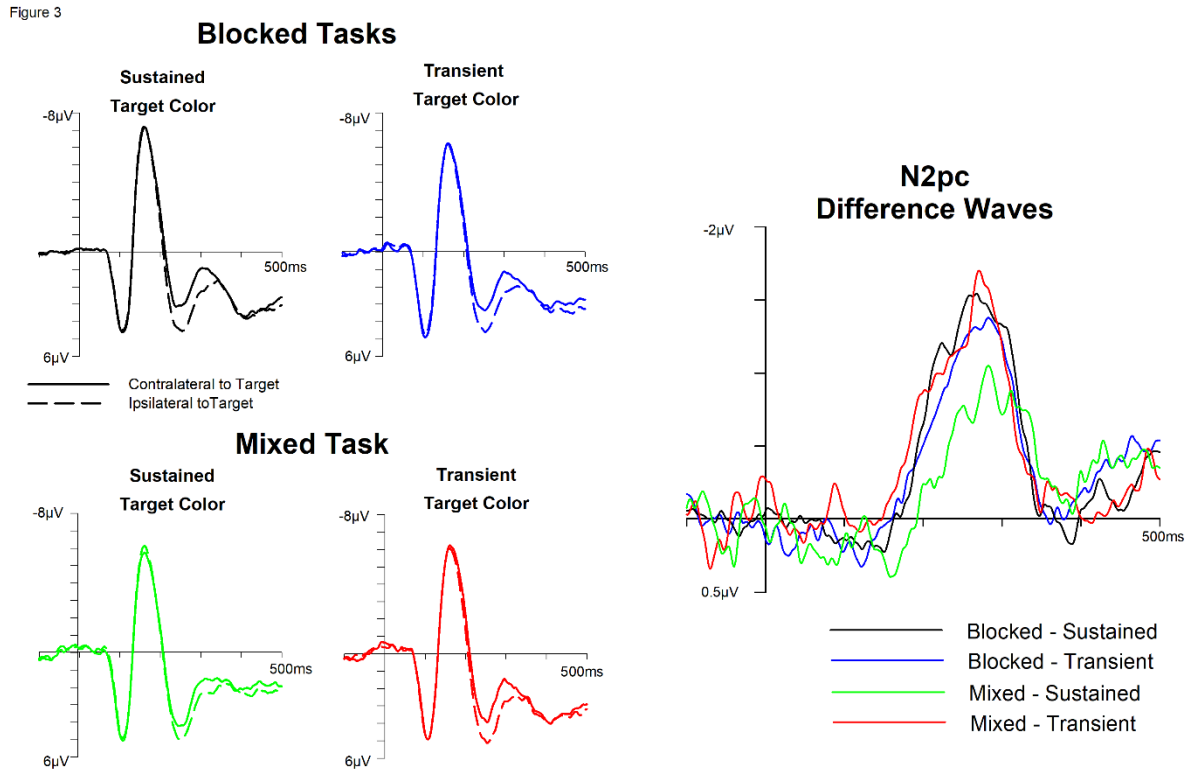
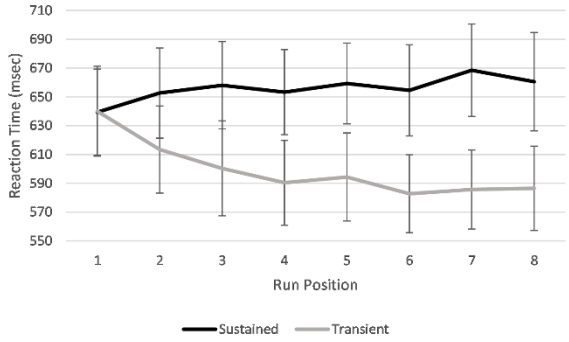


Figure 3
Blocked Tasks
Sustained
Target Color
Transient
Target Color
-8μV
6μV
500ms
Contralateral to Target
Ipsilateral toTarget
Mixed Task
Sustained
Target Color
Transient
Target Color
N2pc
Difference Waves
-2μV
0.5μV
Blocked - Sustained
Blocked - Transient
Mixed - Sustained
Mixed - Transient

Figure 4


710
690
670
650
630
610
590
570
550
Reaction Time (msec)
1
2
3
4
5
6
7
8
Run Position
Sustained
Transient

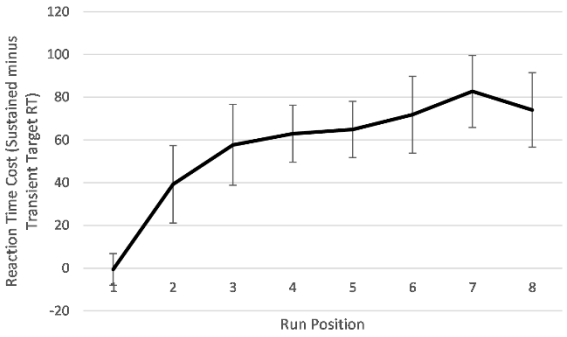
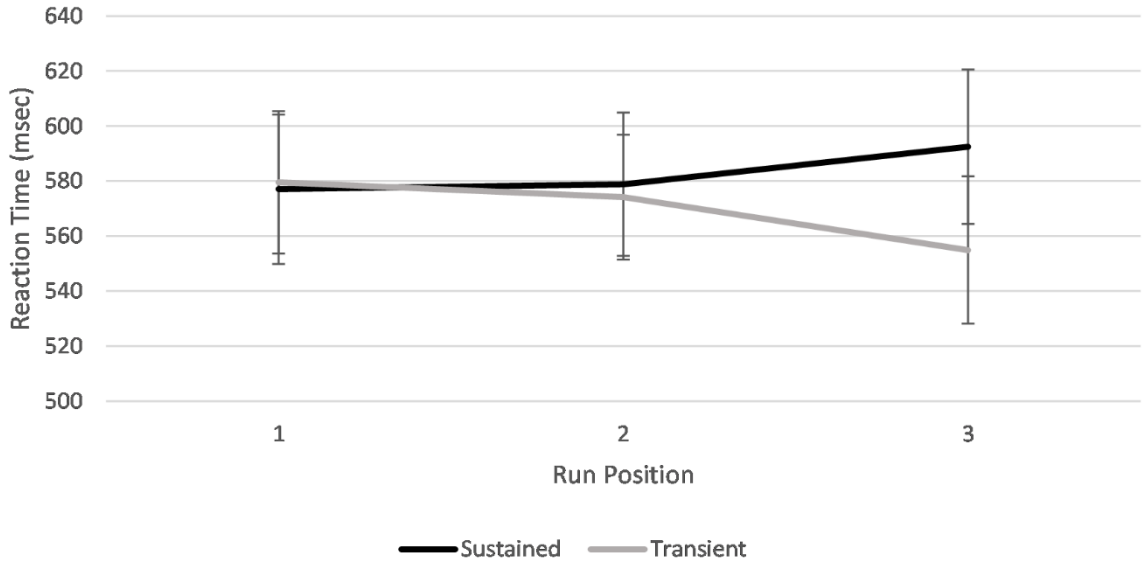

120
100
80
60
40
20
0
-20
Reaction Time Cost (Sustained minus Transient Target RT)
1
2
3
4
5
6
7
8
Run Position

Figure 5


640
620
600
580
560
540
520
500
Reaction Time (msec)
1
2
3
Run Position
Sustained
Transient