PROACTIVE CONTROL OF SELECTIVE ATTENTION

PROACTIVE CONTROL OF SELECTIVE ATTENTION: ENDOGENOUS CUEING EFFECTS IN A TWO-TARGET ATTENTIONAL BLINK TASK

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Abstract

Our study investigated the effect of preparatory selective attention on encoding two target items (T1 and T2), causing an attentional blink effect (AB), as observed in previous studies. We altered participants' readiness state on a trial-to-trial basis using informative or uninformative cues for selective attention. Additionally, we varied their overall state of readiness by randomly mixing cue types (mixed cue-context) or presenting them in separate blocks (blocked cue-context). Our findings demonstrated a clear advantage in performance when participants received informative cues compared to uninformative ones in the mixed cue-condition, regardless of the lag between T1 and T2. Notably, in the blocked cue-context condition, cueing benefits were limited to the shortest T1-T2 lag. This suggests that participants proactively prepared to focus on T1 when anticipating conflict, but the extent of this preparation varied between cue-contexts. A heightened state of preparation led to an overinvestment of resources to T1 encoding, which negatively affected T2 encoding.

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Mean T1 and T2|T1 accuracy for participants in the mixed cue-context group (top panel) and participants in the blocked cue-context group (bottom panel) as a function of cue type (informative/uninformative), trial type (selection/no-selection), and SOA (233/467/700 ms). The error bars represent the standard error of the mean (SEM) corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008), calculated with the Superb package (Cousineau, Goulet, Harding, 2021).

Introduction

Human sensory systems process vastly more information than can be analyzed meaningfully. Research on attention aims to understand how this sensory input is processed selectively. Attentional conflicts arise when goal-irrelevant information competes with goal-relevant information for attentional priority. For example, notifications on mobile devices may cause attentional conflicts, and distract people from achieving a behavioural goal such as studying or driving. From a scientific perspective, uncovering how the human cognitive system adjusts attention in pursuit of goal-directed behaviour is a major challenge.

The biased competition account points to a potential mechanism in the visual system that manages this challenge (Desimone & Duncan 1995; Kastner & Ungerleider, 2001). According to this account, competition between multiple stimuli in the visual field can be biased by bottom-up sensory-driven factors (e.g., stimulus salience), or by top-down influences that control selective attention (Kastner & Ungerleider, 2001). The latter of the two processes utilize internal goals and ongoing context to generate a task-set that biases information processing in service of behavioural goals (Miller & Cohen, 2001; Egner, 2017). For example, task-sets might describe a mental representation of task-relevant stimuli, responses, and their corresponding stimulus-response mappings, all of which facilitate selection of an appropriate action in response to a stimulus (Monsell, 2003). This form of cognitive control thus grants us considerable behavioural flexibility; but how is such flexibility regulated? That is, how does the brain determine when and how much attentional control to apply?

The dual mechanism of control (DMC) framework operationalizes one way in which such control could be instantiated (Braver, 2012). According to this framework, cognitive control dynamically shifts between proactive and reactive control settings in response to changing

environments or goals (Braver, 2012). Proactive control involves the active maintenance of internal goals and prepares the appropriate task-set in anticipation of upcoming attentional conflict (Braver et al., 2007; Shenav et al., 2013; Egner, 2014; Jiang et al., 2014; Abrahamse et al., 2016). In contrast, reactive control is more transient in nature, and resolves attentional conflict on an as-needed basis with minimal demand on mental resources. Thus, while proactive control grants us more behavioural efficiency, it does so at the cost of being slow and effortful.

Of interest in the present study is the degree to which selective attention can indeed depend on proactive control processes. In particular, we were interested in whether people can utilize explicit cues that signal forthcoming conflict and adjust control proactively to minimize interference. Though this issue has been previously studied, most notably in the colour Stroop task (e.g., Bugg & Smallwood, 2016; Logan & Zbrodoff, 1982; see also Gratton et al., 1992), here we address this issue using an attentional blink paradigm (AB; Raymond, Shapiro, & Arnell., 1992). The AB refers to a decrement in identification of a second target (T2) when it is paired closely in time to the presentation of a first target (T1). This second target decrement is thought to capture the temporal limits of the deployment of selective attention (Dux & Marois, 2009). Before introducing the AB method used in the present study, we provide a brief overview of the broader topic of contextual control of selective attention, and then summarize prior research on endogenous cueing effects on selective attention efficiency.

Contextual control of selective attention

Contextual control of selective attention refers to the idea that selective attention efficiency depends on the context in which a selective attention task is presented to participants. Findings that align with this idea are well-documented in the literature, and particularly so for the classic Stroop task (Stroop, 1935). In this task, colour naming responses are slower and less

accurate when the print colour and meaning of colour words mismatch (incongruent trials; e.g., RED printed in blue) compared to when they match (congruent trials; e.g., RED printed in red). This difference in performance is a highly robust finding known as the Stroop congruency effect, and it is attributed to limitations in the ability to selectively attend to the task-relevant stimulus feature (i.e., print colour of the word) due to interference from the task-irrelevant stimulus feature (i.e., meaning of the word). By probing factors that systematically alter the magnitude of the Stroop congruency effect, we can then make inferences about processes that control selective attention. The widest known example is perhaps the list-wide proportion congruency effect (LWPCE).

The LWPCE refers to the finding that the Stroop congruency effect is smaller when items are presented in a mostly incongruent relative to mostly congruent list or block (Logan and Zbrodoff, 1979; Lowe and Mitterer, 1982; Lindsay and Jacoby, 1994; Kane and Engle, 2003; Bugg et al., 2011; for a review see Bugg & Crump, 2012). Similarly, a LWPCE manipulation has also been shown to attenuate the congruency effect in the Erikson flanker task (Bugg & Gonthier, 2020). Although there has been debate about the precise mechanisms underlying the LWPCE, there is clear evidence for a cognitive control account, which posits that the degree to which task-relevant information (e.g., target colour) and task-irrelevant information (e.g., distractor word) are processed is adjusted based on the overall likelihood of encountering conflict (Suh & Bugg, 2021). Thus, in a mostly incongruent condition, the word dimension is processed to a lesser degree than in a mostly congruent condition (Melara & Algom, 2003). Yet the mechanisms that bring about different levels of attentional control in the different task contexts remain the target of rich theoretical debate.

One possible mechanism relies on list-level information such as the likelihood of occurrence of trial types. According to this expectancy-driven mechanism, participants completing trials in a mostly congruent or incongruent block develop explicit knowledge of the likelihood of conflict on incongruent trials, which leads them to strategically alter attention in advance of stimulus presentation (Lindsay & Jacoby, 1994; Lowe & Mitterer, 1982; Suh & Bugg, 2021). Therefore, in a mostly incongruent block, where incongruent trials are expected, participants may proactively filter out word information to minimize interference, whereas in a mostly congruent list, they may bias attention to the word as an effective strategy for the expected congruent trial. This idea that participants adapt attentional control explicitly and strategically in response to the task context aligns well with a proactive account of control (Braver et al., 2007).

Although a strategic explanation seems both parsimonious and intuitive, there are other competing accounts for the LWPCE. One particularly impactful idea is the conflict adaptation or conflict monitoring account which attributes the LWPCE, at least in part, to a reactive control mechanism (Botvinick et al., 2001). According to this model, in addition to strategic adjustments of attention at the start of the experiment in order to achieve task goals, the cognitive system continues to dynamically adapt attentional control on a trial-to-trial basis throughout a task. To this end, conflict monitoring is thought to be triggered in reaction to previous conflict, consistent with reactive control of attention as described under the DMC framework. This account is substantiated by the finding of sequential effects in conflict tasks wherein congruency effects are reduced following incongruent compared to congruent trials (for reviews see Duthoo et al., 2014; Egner, 2007).

The possibility that LWPCE manipulations produce effects that are caused by local trial-to-trial adaptive control mechanisms is supported by the fact that LWPCE manipulations introduce local trial sequence differences across conditions. Specifically, for mostly incongruent lists, incongruent trials more often follow incongruent trials than congruent trials. Similarly, for mostly congruent blocks, incongruent trials more often follow congruent trials than incongruent trials. If these differences in local trial sequences impact performance, and if these impacts on processing are unrelated to proactive shifts in strategies, then smaller congruency effects for mostly incongruent than for mostly congruent blocks does not necessarily require an interpretation in terms of proactive control.

Another finding that points to a form of reactive rather than proactive control is the context specific proportion congruency effect (CSPCE; Crump et al., 2006). The CSPCE is the observation that congruency effects are still reduced when mostly congruent and mostly incongruent trials are randomly intermixed and only distinguished by a secondary contextual cue. For example, Crump et al. (2006; Experiment 2A) used a prime-probe version of the Stroop task, whereby a color-word (prime) was presented briefly in black and was followed by a colored rectangle (probe) that appeared randomly either above or below fixation. On each trial, the probe was shown in one of two screen locations and, unbeknownst to the participants, location was predictive of the proportion of incongruent trials (or conflict-likelihood). Across trials, probe location was randomized, therefore participants could not form accurate expectations for likelihood of probe congruency. Despite this, the congruency effect was smaller for items in the mostly incongruent location (25% congruent trials) compared to items in the mostly congruent location (75% congruent trials). Parallel findings of this nature have been observed in the more conventional Stroop paradigm (Bugg et al., 2008), and in the flanker task using different types of

contextual cues (Corballis & Gratton, 2003; Wendt et al., 2008; Lehle & Hübner, 2008). A key contribution of these studies is that they rule out the possibility that this type of contextual control is mediated by explicit expectancies (i.e., proactive control).

They key takeaway from this section is that, although LWPCE manipulations could possibly index proactive control, they are confounded by the presence of congruency sequence effects. This allows for the possibility of other control mechanisms; most viable of which include adaptive reactive control processes that accounted for the CSPCE to also contribute to the LWPCE. These issues highlight the need for methods other than those used to study the LWPCE to investigate the degree to which expectancy-based proactive control processes contribute to cognitive control over attentional conflict.

Endogenous Cueing of Congruency

An alternative approach to exploring the role of proactive control in selective attention is to manipulate participants' expectation of conflict without altering the balance of congruent and incongruent trials within a list. For example, using Stroop stimuli, Entel et al. (2014; see also Bugg et al., 2015) instructed participants that they would be completing a mostly congruent or mostly incongruent list of trials while keeping conflict experience constant; that is, proportion congruency was .50 for both lists. Here a LWPCE-like pattern was found, wherein Stroop interference was reduced under high conflict probability instructions compared to low conflict probability instructions. A similar false instruction effect has been observed in a Simon interference task (Desender, 2018).

These list-wide instructional effects on cognitive control suggest that one might also find evidence for trial-to-trial cueing effects on cognitive control. Do trial-to-trial pre-cues that signal whether the upcoming item will be congruent or incongruent modulate congruency effects? To

date, only a handful of studies have employed this approach, with most being limited to a variant of the Stroop paradigm (Bugg & Smallwood, 2016; Chao, 2011; Correa et al., 2014; Lamers & Roelofs, 2011). In Bugg and Smallwood's (2016) procedure, congruent and incongruent Stroop trials were pre-cued informatively with the words "CONFLICTING" for incongruent trials and "MATCHING" for incongruent trials, or uninformatively with a row of Xs (i.e., "XXXXXXXXX"). A pronounced pre-cue benefit was observed on congruent trials when the cues were 100% valid, as had been reported in prior studies that used other conflict tasks (Correa et al., 2009; Gratton et al., 1992; Logan & Zbrodoff, 1982). Although this is an interesting result, it can be explained by an attention switching strategy rather than an up-regulation in cognitive control in response to the pre-cue—participants may switch their attention to the nominally irrelevant (and faster to process) stimulus dimension when they know in advance that the trial will be congruent. More important, there was also a pre-cue benefit for incongruent trials; participants responded more quickly to incongruent trials following a valid and informative cue than following an uninformative cue. However, it was notable that this pre-cue effect for incongruent trials was found only for a relatively long cue-to-stimulus interval (CSI; 2000 ms), and only when informative cues were 100% valid.

A detailed review of the literature on congruency pre-cues suggests that there are indeed some nuances to the conditions that produce pre-cue benefits for incongruent trials. This issue was pursued by Jiménez et al. (2021) in an extensive series of experiments that explored factors that affect participants' use of congruency cues to prepare for conflict. Their findings highlight important boundary conditions that suggest that proactive preparation in response to trial-by-trial cues is limited to conditions in which: (a) participants have sufficient time to prepare for conflict following cues; (b) the cues are 100% valid; (c) the cues are presented between trials, rather than

embedded in a stimulus/response property of the prior trial; (d) the task to which the cues are applied involves a nonarbitrary stimulus-response mapping. Together with previous cueing studies, these results demonstrate that although endogenous cueing of congruency can produce a proactive control effect in the Stroop and flanker tasks, such effects are often small in size and limited to particular methods.

Contextual control of selective attention in an AB method

In the present study, we aimed to study a related set of issues using a method that produces an AB effect. The AB is generally studied by embedding two visual targets (T1 and T2) in a stream of rapidly displayed stimuli, one after the other in the same spatial location, a technique known as rapid serial visual presentation (RSVP; Broadbent & Broadbent 1987). Under these conditions, identification accuracy is quite good for T1, but poor for T2 when the temporal lag between the two targets is short (100-300 ms). T2 performance then improves progressively as the lag is increased to about 700 ms (Raymond et al., 1992).

The AB effect appears to be sensitive to selective attention demands. Raymond et al. (1992; Experiment 3) presented participants with an RSVP stream of letters on each trial and asked them to respond selectively to two targets that could appear in each stream. The first target (T1) was a white letter, and participants were to report its identity. The second target (T2) was a black "X" that appeared on some trials and not on others; participants were to report its presence or absence. Importantly, on some trials T1 was followed by a blank 90 ms interval, while on other trials no such interval was present. The key result was that the magnitude of the two-target deficit was significantly reduced when T1 was followed by a blank interval. This result is consistent with the idea that the T1+1 item holds the potential to interfere with T1 encoding, and

that selective attention to T1 is needed to prevent that interference. However, selective attention to T1 renders attention temporarily unavailable for T2 encoding, which causes the AB effect.

It is noteworthy for our purpose that the AB effect does not require use of an RSVP method. Duncan et al. (1994) developed a skeletal method to measure the AB effect. In this method, a red letter (T1) and a green digit (T2) were presented rapidly, sequentially, and masked. When the task was to identify both items, T2 identification was poor when the interval between T1 and T2 was short but improved as this temporal interval increased. This pattern of results closely resembles the AB in studies that use the RSVP method and suggests that as long as T1 and T2 are pattern masked the rest of the distractors in the RSVP stream are not necessary to measure an AB effect.

An alternative skeletal method was developed recently that points directly at the role of selective attention in the AB effect (MacLellan et al., 2015). On any given trial there were two events: T1 was a red word, and T2 was a white word that followed T1 after a blank interval of varying duration. Participants were to report the identity of T1 and T2 at the end of each trial. T1 was interleaved with a green distractor word (selection trials) or presented on its own (no-selection trials). T2 accuracy was nearly perfect on no-selection trials irrespective of the T1-T2 interval. However, T2 accuracy for selection trials was quite poor at the shortest T1-T2 interval, but improved as this interval was extended—that is, an AB effect was observed.

More important, this AB effect was sensitive to the task context in which trials were presented. T2 performance for selection trials was substantially worse when selection and no-selection trials were randomly intermixed in the same block than when these two trial types were presented in separate blocks. T2 performance for selection trials also varied in accord with the relative proportions of selection and no-selection trials, with better T2 performance in contexts in

which selection trials were frequent. These list-wide context effects are reminiscent of the LWPCE observed in numerous conflict tasks. MacLellan et al. (2015) also reported the presence of sequence effects, such that selection performance was better following a sequence of two consecutive selection trials than following a sequence of two consecutive no-selection trials.

As with the earlier summarized findings, the list-wide context effects reported by MacLellan et al. (2015) are consistent with a proactive control interpretation—participants may have adapted control processes proactively and strategically to mitigate interference during T1 encoding, which in turn improved T2 performance. However, these results do not necessarily require a proactive control interpretation. As noted above, reactive control mechanisms can result in trial-to-trial adaptations of cognitive control that produce effects which are easily mistaken to be markers of proactive control. In this case, T2 performance may have been better for the blocked condition than the mixed condition because attentional control processes are adapted reactively and carry over from one trial to the next automatically (Botvinick et al., 2001). What is needed to establish that proactive control processes can modulate the AB effect is a method that unambiguously measures proactive control, rather than a method that it ambiguous about whether it measures reactive control, proactive control, or both.

The present study

To address this issue, we used an endogenous cueing manipulation wherein a cue presented prior to T1 indicated whether or not T1 would be presented with or without a competing distractor. Participants were instructed to use these informative cues to prepare to selectively attend accordingly. Performance for informative cue trials was compared to performance on trials in which the cues were uninformative.

Whether an endogenous cueing effect would occur in the skeletal AB task described above was of interest for two reasons. First, prior studies of endogenous cueing of congruency effects have centered on the Stroop and Eriksen flanker paradigms (Bugg & Smallwood, 2016; Jiménez et al., 2021; add other citations here; but see Wühr & Kunde, 2008 for a study of Simon interference), and it would be useful to determine whether such effects generalize beyond these well-studied task domains. This issue of generalization to other tasks is particularly important given the restricted set of conditions in which such effects appear to occur (Bugg & Smallwood, 2016; Jiménez et al., 2021).

Second, generalization of cueing effects to an AB task would be particularly interesting in light of one particular theory of the AB effect: the overinvestment hypothesis (Olivers and Nieuwenhuis, 2005, 2006). According to this theory, the AB occurs because participants often devote too many attentional resources to T1 encoding, which inadvertently results in substantial encoding of one or more distractors that follow T1. Resolution of the resulting conflict then triggers processes that hurt T2 encoding. Indeed, several methods aimed at reducing attentional allocation to T1 have produced smaller AB effects: (1) instruction to think about leisure activities while completing the AB task; (2) a concurrent short-term memory task; (3) viewing pictures associated with positive affect prior to AB trials; and (4) instruction to concentrate less while completing the AB task (Olivers & Nieuwenhuis, 2005; 2006). In line with this view, it was not immediately clear whether an endogenous cueing of conflict effect in an AB task would improve or hurt T2 performance.

To summarize, the research question addressed here concerned cueing effects on T2 performance and centered on trials in which T1 required selection between a target and distractor: Would selective attention to T1—and subsequent T2 identification—depend on

whether cues informatively signalled the selective attention demand of T1? And if so, would the cueing of impending T1 conflict improve T2 performance, or would it trigger an overinvestment in T1 encoding and hurt T2 performance?

Experiment 1

As mentioned, cognitive control can be triggered in reaction to previous conflict (reactive control), as assumed under the conflict monitoring account and supported by the finding of sequential effects in conflict tasks (Gratton, Coles, & Donchin, 1992). However, can control also be triggered in a strategic manner in anticipation of conflict (proactive control)? The purpose of Experiment 1 was to address this question by adding an endogenous cuing method to our skeletal AB task. In the informative cue condition, we used 100% valid cues in this and subsequent experiments, as pilot work in our lab and other published studies indicate that use of 100% valid cues may be critical to measure a reliable cuing effect (Jiménez et al., 2021; Bugg and Smallwood, 2016; Luks, Simpson, Dale, & Hough, 2007; van Driel et al., 2015). Performance in this informative cue condition was compared with performance in an uninformative cue condition. In both cue conditions, the cues preceded each trial in a session that included randomly intermixed selection and no-selection trials. If participants can capitalize on the informative cues to adjust their attention on a trial-by-trial basis, a smaller AB may occur for selection trials preceded by informative cues than for selection cues preceded by uninformative cues. Conversely, if use of informative cues leads participants to overinvest attention resources in T1 encoding, then the opposite pattern of results may occur.

Methods

Participants

A power analysis was conducted to estimate the appropriate sample size for this experiment using G*Power version 3.1.9.7 (Faul, Erdfelder, Lang, & Buchner, 2007). As no prior studies had examined endogenous cueing effects with this method, we used what may be a related effect as a starting point. MacLellan et al. (2015; Experiment 1; $N = 24$) reported superior T2 performance for blocked selection trials relative to selection trials that were randomly intermixed with no-selection trials, with a large effect size *f* of .675. Under the assumption that this effect may have both proactive and reactive control components, we reasoned that we might expect a proactive control (endogenous cueing) effect half this size. Using this estimate of effect size, we determined that a sample of 16 participants would be sufficient to detect such an effect with power = .80. Therefore, we recruited 16 participants (XX males, M_{age} = XX, range XX–XX) from the introductory psychology undergraduate participant pool at McMaster University in exchange for partial course credit. All participants in this and subsequent experiments reported normal or corrected-to-normal visual acuity. All procedures reported in this article were approved by the McMaster Research Ethics Board (MREB).

Apparatus and Stimuli

The experiment was designed using Micro Experimental Laboratory (MEL2) software (Schneider, 1988), and presented in graphics mode on a Sony SVGA CRT color monitor that was connected to a Pentium 1 microcomputer. Target stimuli were presented against a black uniform background and were drawn from the stimulus set used by MacLellan et al. (2015). An endogenous cue was presented prior to the onset of T1 on all trials.

The stimulus set consisted of the following eight words presented in capital letters: BREAD, PLACE, CHIEF, RIGHT, STICK, DREAM, FLUTE, and GRAIN. On each trial three different words were randomly chosen from the eight-word set and assigned the roles of T1, T1 distractor, and T2, with the condition that no word be assigned to more than one role within a single trial. On no-selection trials T1 consisted of a single target word displayed in red, whereas on selection trials T1 consisted of a red target word interleaved with a green distractor word. The green T1 distractor was slightly brighter than the red T1 target, as judged by the authors. Examples of the two trial types are presented in Figure 1. On selection trials, the T1 distractor had an equal likelihood of appearing either slightly above or below the T1 target. T2 was always a single word displayed in white. A pattern mask that followed T2 consisted of the symbols ‘‘X’’, ‘‘O’’, and ‘‘&’’ superimposed on each other to ensure the spatial locations occupied by T2 were fully masked.

The informative cue for a no-selection trial was a single row of Xs (i.e., X X X X X), printed in white and presented at the center of the screen. The informative cue for a selection trial consisted of two rows of Xs printed in white and interleaved at spatial locations at which the T1 target and distractor appeared. The uninformative cue was a single question mark, printed in white at the center of the screen (see Figure 1). All characters subtended approximately 0.5 degrees of visual angle in height and 0.9 degrees of visual angle in width. Each character was separated by approximately one degree of visual angle.

At the end of each trial, participants were asked to report the identity of the T1 and T2 target words in the order they appeared on screen. Numbers 1-8 on the number keypad were labelled with the eight possible response options, and participants responded by pressing one of these keys for each of T1 and T2.

Design & Procedure

Upon arrival in the lab, participants were asked to sign the informed consent form, and then seated at a table at approximately 57 cm from a computer screen. Participants received task instructions that informed them to report, to the best of their ability, the identity of the T1 and T2 targets with key presses at the end of each trial. To improve their response accuracy, participants were encouraged to make use of informative cues when available to prepare for the more difficult selection trials.

Each trial began with a white fixation cross at the center of a black screen. The subject initiated a trial when ready by pressing the space bar, upon which the white fixation cross was replaced by a blank screen. The blank screen remained for 100 ms and was followed by presentation of the cue for 500 ms. The cue was followed by a blank interval of 1500 ms, producing a cue-to-stimulus interval (CSI) of 2000 ms. Next, the T1 item appeared for 117 ms followed by a blank interval that preceded onset of T2, and that produced a T1–T2 stimulus onset asynchrony (SOA) of 233, 467 or 700 ms. T2 was presented for 100 ms and followed by a pattern mask that remained on screen until the participant reported the identity of the T1 and T2 word targets at the end of the trial. The design of Experiment 1 included three within-subject variables: cue-type (informative/uninformative), trial-type (selection/no selection), and SOA (233/467/700 ms). Participants completed 4 blocks of 72 trials, totaling 288 experimental trials, with 2-3 min breaks between each block. Each block contained an equal number of trials in each condition and trial order was randomized within each block. Prior to starting the experimental trials, participants completed a practice block of 12 trials; with trials in each of the conditions defined by the cue-type, trial-type, and SOA variables. Performance on these practice trials were excluded from all analyses.

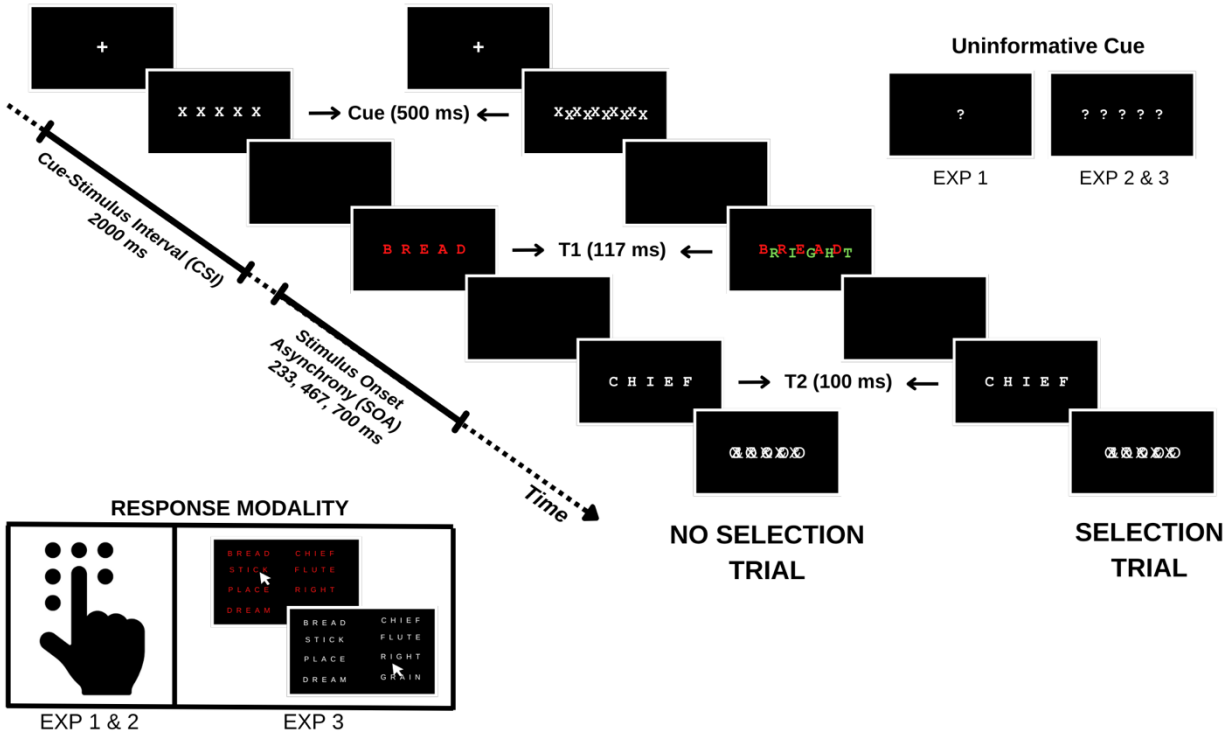

Figure 1. Event structure for trials in all experiments. Cue-to-stimulus interval (CSI) consists of the 2000 ms interval from onset of the cue event (an informative or uninformative cue that appeared for 500 ms) to the onset of T1. Stimulus onset asynchrony (SOA) consists of the interval between onset of T1 (117 ms duration) and onset of T2 following a blank interval of varying duration (116 ms, 350 ms, and 583 ms).

Results

There were two primary dependent measures for this and all subsequent experiments in this article: (1) the percentage of correctly identified T1 items; and (2) the percentage of correctly identified T2 items given that T1 was accurately identified (T2|T1). Two criteria were established to determine whether data from any given participant were included in the analyses. These criteria were intended to be inclusive, identifying participants as outliers only if they did not understand the task, did not attempt to perform the task accurately, or found the task

prohibitively difficult. In line with this aim, we computed a single accuracy measure per participant separately for each trial-type by averaging across their T1 and T2|T1 identification accuracies. We excluded data from anyone whose average performance on no-selection trials fell below 60% correct (about 9.62 standard deviations below mean T1 and T2|T1 performance), or whose mean selection trial performance was less than 20% correct (slightly better than chance performance of 12.5% correct, and approximately 2.78 standard deviations below the mean T1 and T2|T1 performance). For this experiment, the data from all participants satisfied these criteria and were included in analyses.

T1 and T2|T1 accuracy were submitted to separate analyses of variance (ANOVA) with an alpha criterion of .05 to determine statistical significance in these primary analyses. Effect sizes were approximated using both partial eta squared (η^2_P) and generalized eta squared (η^2_G) to facilitate cumulative science based on the guidelines recommended by Lakens (2013) on reporting effect size. An alpha level of .05 was used to determine statistical significance unless otherwise noted. Mean T1 and T2|T1 accuracy rates, collapsed across participants for Experiment 1 are depicted in Figure 2.

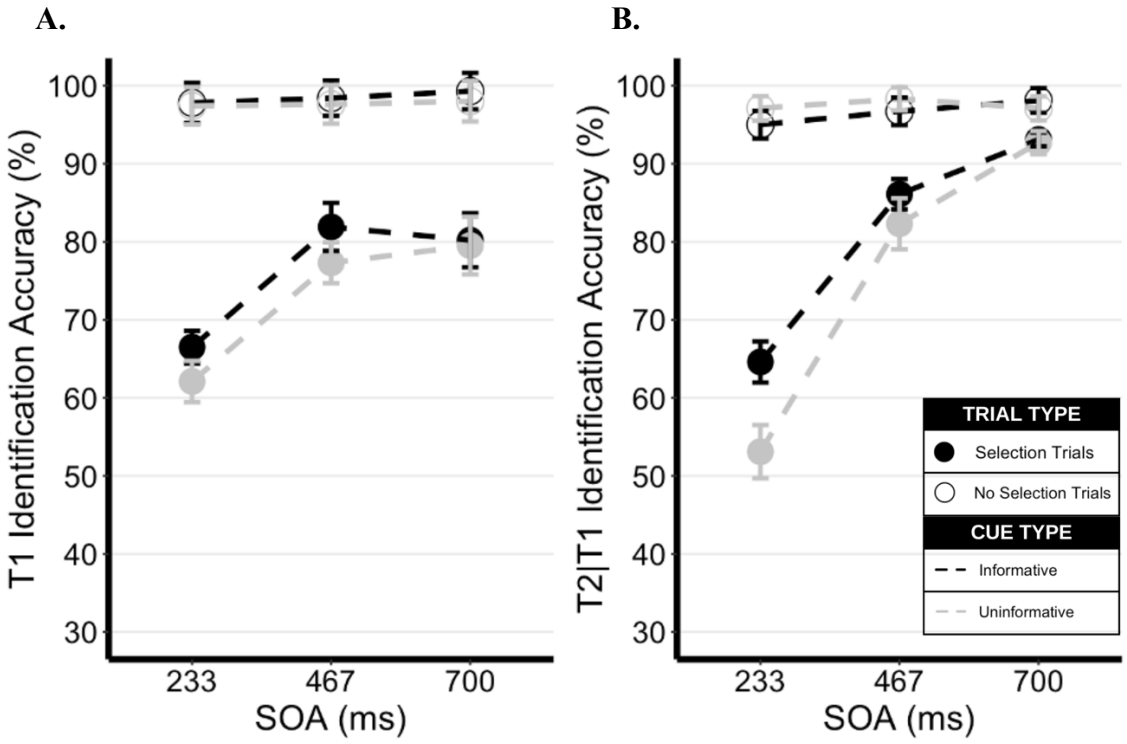

Figure 2. Percent correct T1 and T2|T1 averaged across participants in Experiment 1 as a function of cue type (informative/uninformative), trial-type (selection/no-selection), and SOA (233/467/700 ms). Error bars reflect the standard error of the mean corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008), calculated with the Superb package (Cousineau, Goulet, Harding, 2021).

T1 Analysis.

The percentage of correct responses to T1 were submitted to a three-way ANOVA with cue-type (informative/uninformative), trial-type (selection/no selection), and SOA (233/467/700 ms) as within-subject factors. In general, mean T1 accuracy in the left panel of Figure 2 shows near ceiling performance for no selection trials across all SOAs. In contrast, T1 accuracy is substantially below ceiling performance for selection trials; performance is worst at the shortest SOA and recovers somewhat at the two longer SOAs. These observations are supported by the significant main effects of trial-type $F(1, 15) = 26.5$, $MSE = 997.7$, $p < .001$, $\eta^2_P = .639$, $\eta^2_G =$

.426, and SOA F(2, 30) = 27.0, MSE =80.6, $p < .001$, $\eta^2_P = .643$, $\eta^2_G = .073$, as well as a significant interaction between trial-type and SOA F(2, 30) = 28.0, MSE = 60.5, $p < .001$, $\eta^2_P = .651$, $\eta^2_G = .061$. These findings replicate effects observed in prior studies with this skeletal two-target method (MacLellan et al., 2015), and occur in all experiments reported in this paper.

More important, selection trial performance appears to be more accurate on informative cue trials than on uninformative cue trials (see left panel of Figure 2). This observation was supported by a significant main effect of cue-type, F(1, 15) = 12.9, MSE = 15.7, $p = .003$, $\eta^2_P = .462$, $\eta^2_G = .006$, and an interaction between cue-type and trial-type that approached significance F(1,15) = 3.1, MSE = 22.1, $p = .099$, $\eta^2_P = .171$, $\eta^2_G = .002$. This interaction was probed further by conducting separate two-way ANOVAs for each trial-type that treated cue-type and SOA as within-subject factors. For selection trials, there was a significant main effect of SOA F(2, 30) = 28.7, MSE = 137.5, $p < .001$, $\eta^2_P = .657$, $\eta^2_G = .127$, as well as a significant main effect of cue-type F(1, 15) = 7.5, MSE = 33.8, $p = .015$, $\eta^2_P = .334$, $\eta^2_G = .007$, with more accurate T1 responses on informative cue trials (76.2%) than on uninformative cue trials (73.0%). For no-selection trials, only the main effect of cue-type approached significance [F(1, 15) = 4.4, MSE = 4.1, $p = .054$, $\eta^2_P = .226$, $\eta^2_G = .022$].

T2 Analysis.

The percentage of correct responses to T2 provided that T1 was also correctly identified served as the dependent measure in this analysis. These data were submitted to the same ANOVA as the corresponding T1 data. The mean percent correct T2|T1 are plotted in the right panel of Figure 2. Performance for no-selection trials was near ceiling, while performance for selection trials was sensitive to SOA. The results of the main analysis supported this interpretation, again producing significant main effects of trial-type F(1, 15) = 51.3, MSE =

315.9, $p < .001$, $\eta^2_P = .774$, $\eta^2_G = .463$, and SOA $F(2, 30) = 69.2$, MSE =79.5, $p < .001$, $\eta^2_P = .822$, $\eta^2_G = .369$, as well as a significant interaction between trial-type and SOA $F(2, 30) = 65.1$, MSE =69.6, $p < .001$, $\eta^2_P = .813$, $\eta^2_G = .325$.

More important, the analysis reported a significant main effect of cue-type, $F(1,15) = 14.1$, MSE = 15.9, $p = .002$, $\eta^2_P = .485$, $\eta^2_G = .012$, as well as a significant two-way interaction between cue-type and trial-type, $F(1,15) = 20.5$, MSE = 22.2, $p < .001$, $\eta^2_P = .578$, $\eta^2_G = .024$, and a cue-type by SOA interaction that only approached significance, $F(2,30) = 2.76$, MSE = 28.8, $p = .078$, $\eta^2_P = .155$, $\eta^2_G = .008$. Nevertheless, the key result from the analysis was the significant three-way interaction between trial-type, cue-type, and SOA, $F(2,30) = 7.9$, MSE =25.6, $p = .002$, $\eta^2_P = .344$, $\eta^2_G = .021$. As is evident in the right panel of Figure 2, this interaction appears to be driven by a cueing effect that is sensitive to SOA and that occurs only for selection trials. This interpretation was supported by the separate two-way ANOVAs conducted for each trial-type that treated cue-type and SOA as within-participants variables.

Separate analysis of the no-selection trials revealed no significant effects. For selection trials, there was a significant main effect of cue-type, $F(1, 15) = 23.2$, MSE = 28.5, $p < .001$, $\eta^2_P = .608$, $\eta^2_G = .038$, and main effect of SOA, $F(2, 30) = 77.9$, MSE = 128.4, $p < .001$, $\eta^2_P = .838$, $\eta^2_G = .543$, qualified by a significant cue-type by SOA interaction, $F(2,30) = 6.0$, MSE =43.3, $p = .006$, $\eta^2_P = .286$, $\eta^2_G = .030$. Post hoc analysis with a Holm-Bonferroni adjustment revealed that, at the shortest SOA, T2 performance was about 11.5% more accurate for informative cue trials than for uninformative cue trials, $t(15)=4.36$, $p <.001$. This cueing benefit was about 3.9% and approached significance at the 467 ms SOA, $t(15) =1.97$, $p = .068$. The cueing benefit (0.4%) was clearly not significant at the 700 ms SOA, $t(15) =.190$, $p = .852$.

Discussion

The key finding of Experiment 1 was an endogenous cueing benefit for selection trials in a two-target AB task. The AB effect in the selection trials was smaller for informative cue trials than for uninformative cue trials. To our knowledge, the results constitute the first evidence of an endogenous cueing effect in a two-target AB task.

Though the cueing effect was significant in Experiment 1, the effect size of this cueing effect was much smaller than the blocked/mixed context effect reported by MacLellan et al. (2015). The different size of these two effects suggests that proactive control may be only partial responsible for the blocked/mixed context effect, but there are perhaps other reasons for the small size of the cueing effect observed here. One factor that may have worked against observing a larger cueing effect in Experiment 1 is that we presented informative and uninformative cue trials intermixed at random. Doing so may have dissuaded the participants from relying on the cues, as cues were informative on a random half of the trials. A more sustained and efficient use of cues may occur if all cues within a block are informative. Indeed, cueing studies using the Stroop method indicated that cueing effects were more reliable when informative cue trials were all presented in the same block, rather than intermixed with other control (non-cued) trials (Jiménez et al., 2021; Bugg & Smallwood, 2016).

Experiment 2

In this experiment, we investigated whether the context in which informative and uninformative cues are presented influences endogenous cueing effects. In the mixed cue-context condition, informative and uninformative cue trials were randomly intermixed within blocks of trials, as in Experiment 1. In the blocked cue-context condition, informative and uninformative cue trials were presented in separate blocks to help foster a more efficient cue-based control strategy. In brief, we expected the results of the mixed cue-context condition to replicate the results of Experiment 1, and we predicted that the blocked cue-context condition would produce a larger cueing effect than the mixed cue-context condition.

Methods

Participants

Thirty-two students were recruited from the introductory psychology undergraduate participant pool at McMaster University in exchange for course credit. Half of these participants were randomly assigned to the blocked cue-context condition (3 males; M_{age} = 18.0, range 17–20), and the other half were assigned to the mixed cue-context condition (3 males; M_{age} = 18.1, range 17–19).

Apparatus and stimuli

The apparatus and stimuli were the same as in Experiment 1, with the exception that the uninformative cue was now a single row of question marks.

Design & Procedure

Task, timing, and structure of a trial were identical to Experiment 1 with the following exceptions. The design for this experiment included a between-subject variable—informative and uninformative cue trials were randomly intermixed for one group and presented in separate

blocks for the other group. The mixed cue-context group served as a built-in replication of Experiment 1. For the blocked cue-context group, there were two consecutive blocks of 72 trials in which all cues were informative, and two consecutive blocks of 72 trials in which all cues were uninformative, with the order of the two cue-types counterbalanced across participants. As in Experiment 1, each block contained an equal number of trials in each condition defined by the factorial combination of trial-type and SOA variables, and these trials were randomized within each block. At the end of the experiment, participants completed a questionnaire in which they were asked to indicate, with a yes or no answer, whether they used the cue to help them prepare for the difficult selection trials. If they answered yes to this question, they were then asked to estimate the percentage (0-100%) of trials in which they used the cue to help them prepare.

Results

The exclusion criteria were the same as in Experiment 1. We again aimed to exclude data from anyone whose average performance on no-selection trials fell below 60% correct (about 8.37 standard deviations below mean T1 and T2|T1 performance), or whose mean selection trial performance was less than 20% correct (approximately 2.65 standard deviations below the mean T1 and T2|T1 performance). For this experiment, the data from all participants satisfied these criteria and were included in the analyses. Participants' performance on the no-selection trials was again near ceiling. In the interest of simplifying our analyses, and because our primary interest was in performance for selection trials, we report analyses here that included data from selection trials only. Full analyses that include the no-selection trials are included in the Appendix A for the interested reader. The means of percent correct T1 and T2|T1 data, collapsed across participants for each cue context group, are depicted in Figure 3.

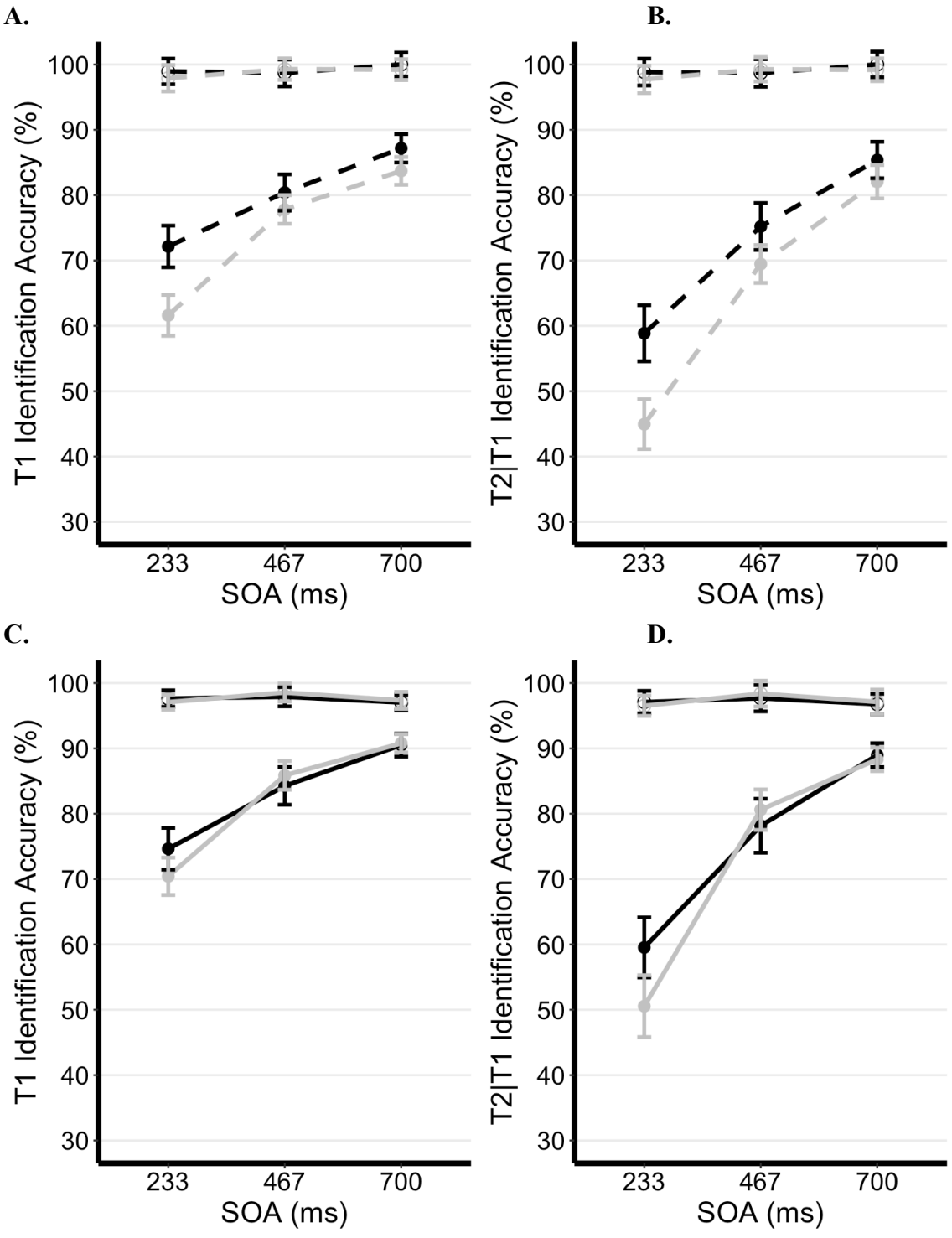
A.
B.
C.
D.
T1 Identification Accuracy (%)
T2|T1 Identification Accuracy (%)
SOA (ms)
233
467
700
100
90
80
70
60
50
40
30
CUE CONTEXT
TRIAL TYPE
CUE TYPE
Mixed
Blocked
Selection Trials
No Selection Trials
Informative
Uninformative

Figure 3. Mean T1 and T2|T1 accuracy for participants in the mixed cue context group (top panel) and participants in the blocked cue context group (bottom panel) as a function of cue type (informative/uninformative), trial type (selection/no-selection), and SOA (233/467/700 ms). The error bars represent the standard error of the mean (SEM) corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008), calculated with the Superb package (Cousineau, Goulet, Harding, 2021).

T1 Analysis.

The percentage of correct T1 responses, for selection trials only, served as the dependent measure in this analysis. These percentages were submitted to a mixed ANOVA that treated cue-type (informative/uninformative) and SOA (233/467/700 ms) as within-subject factors, and cue-context (blocked/mixed) as a between-subject factor. As in prior studies using this method, the analysis revealed a significant main effect of SOA, $F(2, 60) = 87.0$, $MSE = 64.4$, $p < .001$, $\eta^2_P = .744$, $\eta^2_G = .214$, with T1 performance generally improving across SOA (see Figure 3). More important, there was a significant main effect of cue-type, $F(1, 30) = 5.55$, $MSE = 86.0$, $p = .025$, $\eta^2_P = .156$, $\eta^2_G = .011$, with more accurate T1 performance for informative cues (81.4%) than for uninformative cues (78.4%). Also important, the interaction between cue-context and cue-type did not reach significance, $F(1, 30) = 3.16$, $MSE = 86.0$, $p = .086$, $\eta^2_P = .095$, $\eta^2_G = .007$, and indeed the data in Figure 3 offer no evidence for the predicted larger effect of cue-type for blocked than mixed cue-context—if anything, the trend was for a larger cue-type effect for the mixed cue-context. The only other effect in this analysis that approached significance was the cue-type by SOA interaction, $F(1, 30) = 2.75$, $MSE = 105.9$, $p = .089$, $\eta^2_P = .084$, $\eta^2_G = .010$.

To facilitate comparison between the results of Experiments 1 and 2, separate two-way ANOVAs were conducted for the blocked and the mixed cue-contexts that treated cue-type and

SOA as within-participant factors. As anticipated, the analysis for the mixed cue-context showed a significant main effect of SOA, $F(2, 30) = 43.9$, $MSE = 65.0$, $p < .001$, $\eta^2_P = .745$, $\eta^2_G = .204$, and a significant main effect of cue-type, $F(1, 15) = 16.8$, $MSE = 43.6$, $p < .001$, $\eta^2_P = .529$, $\eta^2_G = .032$, with higher accuracy for informative cues (79.9%) than uninformative cues (74.4%). This finding replicates the cueing effect reported in Experiment 1. Surprisingly, analysis of the blocked cue-context group showed only a significant main effect of SOA, $F(2, 30) = 43.2$, $MSE = 63.7$, $p < .001$, $\eta^2_P = .742$, $\eta^2_G = .224$. The main effect of cue-type was clearly not significant, $F(1, 15) = .113$, $MSE = 128.3$, $p = .742$, $\eta^2_P = .007$, $\eta^2_G = .001$.

T2 Analysis.

The percentages of correct T2|T1 responses, for selection trials only, served as the dependent measure in this analysis, and were submitted to the same mixed ANOVA as the corresponding T1 data. Once again, there was a significant main effect of SOA, $F(2, 60) = 118.3$, $MSE = 151.1$, $p < .001$, $\eta^2_P = .798$, $\eta^2_G = .343$, with T2|T1 accuracy increasing across SOA (see Figure 4). As in the T1 analysis, one key result was a significant main effect of cue-type, $F(1, 30) = 7.45$, $MSE = 162.9$, $p = .011$, $\eta^2_P = .199$, $\eta^2_G = .017$, wherein T2|T1 accuracy was greater for informative cues (74.4%) than for uninformative cues (69.3%). The other key result was a non-significant interaction between cue-context and cue-type $F(1, 30) = 2.05$, $MSE = 162.9$, $p = .163$, $\eta^2_P = .064$, $\eta^2_G = .005$, which does not support our prediction of a larger effect of cue-type for the blocked than the mixed cue-context. If anything, the trend was opposite to that predicted (see right panels of Figure 3). As in the T1 analysis, the cue-type by SOA interaction approached significance $F(1, 30) = 3.15$, $MSE = 218.3$, $p = .068$, $\eta^2_P = .095$, $\eta^2_G = .014$.

Next, to compare the results of this experiment to the results observed in Experiment 1, we submitted the T2|T1 performance for selection trials in each cue-context group to separate

two-way ANOVAs with cue-type and SOA as within-participant factors. Analysis of the mixed cue-context found significant main effects of SOA $F(2, 30) = 56.2$, $MSE = 148.0$, $p = .086$, $\eta^2_P = .789$, $\eta^2_G = .356$, and cue-type $F(1, 15) = 28.7$, $MSE = 49.1$, $p < .001$, $\eta^2_P = .657$, $\eta^2_G = .045$, with higher T2|T1 accuracy for informative cues (73.1%) than uninformative cues (65.5%). This finding replicates the cue-type effect in Experiment 1. Separate analysis of the blocked cue-context found only a significant main effect of SOA, $F(2, 30) = 62.4$, $MSE = 154.4$, $p < .001$, $\eta^2_P = .806$, $\eta^2_G = .333$. Importantly, the main effect of cue-type was not significant, $F(1, 15) = .497$, $MSE = 276.8$, $p = .492$, $\eta^2_P = .032$, $\eta^2_G = .004$.

In summary, the analysis of T2|T1 performance revealed higher accuracy on informative than uninformative cue trials, but counterintuitively this cue-type effect was observed only for the mixed cue-context condition. The null effect of cue-type for the blocked cue-context condition was surprising in that we presumed that this condition would be optimal for strategic endogenous control processes to produce a cueing effect.

Post-Experiment Questionnaire.

Participants in the mixed cue-context condition reported that they used the informative cues to prepare for the difficult selection trials on about 65% of the trials (median = 70%). The blocked cue-context group reported that they used the informative cues to prepare on about 72% of the trials (median = 78%). It should be noted that this estimate included the response from one participant in the blocked cue-context condition who responded “No” (0% of trials) to using the cues to prepare.

Discussion

The purpose of Experiment 2 was to determine whether the cueing benefit observed in Experiment 1 would be larger when informative and uninformative cues are blocked rather than intermixed. Blocking informative cues seems like it ought to be optimal for the adoption of proactive control in response to the cue. To start, the results from the mixed cue-context condition replicated the finding from Experiment 1—the AB was smaller for informatively cued trials than for uninformatively cued trials. However, counter to our prediction, the cueing effect was not larger in the blocked cue-context condition than in the mixed cue-context condition. In fact, the cueing effect in the blocked cue-context condition was not significant.

The absence of cueing effect in the blocked cue-context condition is surprising, given that (a) participants were explicitly instructed to use the informative cues to improve performance, (b) the informative cues predicted the selective attention demand of the upcoming trial with 100% validity, (c) the CSI used here was equal to that used in other studies reporting reliable demonstrations of cueing effects (2,000 ms in Bugg & Smallwood, 2016), and (d) participants were demonstrably paying attention to the cues, as they responded in the post-experiment questionnaire. Therefore, we felt that a replication of these surprising results was necessary prior to reaching any theoretical conclusions.

Experiment 3

To recap, the results from the first two experiments indicate that participants can engage in proactive control in response to an informative cue in a two-target AB task. However, somewhat counter to intuition, this cueing effect was observed when informative cues were mixed randomly with uninformative cues, but not when informative and uninformative cues were presented in separate blocks. This pattern of results is surprising given that the blocked design would appear to foster more consistent proactive use of informative cues than the mixed design (see Bugg & Smallwood, 2016, Jiménez et al., 2021). The only hint of a cueing benefit in the blocked cue-context group was at the shortest SOA (see Figure 3), where T2 accuracy was about 9% more accurate for informative selection trials (59.5%) than for uninformative selection trials (50.5%)—but Experiment 2 had insufficient power to determine whether this effect was reliable. To address this issue, and to determine whether the unexpected results of Experiment 2 were reliable, Experiment 3 replicated the method of Experiment 2 but with additional power.

Methods

Participants

A power analysis to determine appropriate sample size for this experiment was conducted using G*Power (Faul et al., 2007). This analysis was based on the mean effect size of cueing effects observed in Experiment 2 (partial eta-squared. = .345, f = .8726). This analysis determined that a sample size of 24 in each group was needed to detect a cueing effect of this size with power of .80. As data were collected online in this experiment, and we anticipated that some data would have to be excluded, data from one-hundred and four students from the introductory psychology undergraduate participant pool at McMaster University were recruited as participants in exchange for partial course credit.

Participants were randomly assigned to either the blocked or mixed cue-context condition. We again aimed to exclude data from anyone whose average performance on no-selection trials fell below 60% correct (about 1.15 standard deviations below mean T1 and T2|T1 performance), or whose mean selection trial performance was less than 20% correct (approximately 1.58 standard deviations below the mean T1 and T2|T1 performance). This resulted in the exclusion of data from analyses for eight participants from the blocked cue-context condition, and fifteen participants from the mixed cue-context condition. We analyzed data from the first collected 36 of the remaining 43 blocked cue-context participants (6 males; 1 non-binary; M_{age} = 18.5, range 17–24), and the first collected 36 of the remaining 38 mixed cue-context participants (5 males; 1 non-binary; M_{age} = 18.5, range 17–27) with the aim of arriving a final sample sizes for the two groups that were equal and that constituted a properly counterbalanced design.

Apparatus and stimuli

This experiment was programmed using PsychoPy Builder (Peirce et al., 2019). Virtual data collection was hosted through PsychoPy's open science platform Pavlovia.org due to COVID19 restrictions on indoor activities. The sizing of stimuli in PsychoPy were specified in 'height units' which are scaled to the height of participants' computer screen while the ratio of the height to width of the stimuli remains absolute. The use of this unit in PsychoPy ensured that stimuli were presented consistently without restricting participation based on screen-size or operating system requirements. In PsychoPy, the width of the stimuli is also defined by the font. All stimuli were presented in Courier New, a fixed-width font, to ensure that all letters in a single word took up the same amount of space. In the following description, we report the size of the

stimuli in terms of height units, but for the sake of clarity, we also report stimulus dimensions in terms of centimeters (cm) based on a 13-inch widescreen display.

The stimuli were analogous to those described for Experiment 2, with the only difference being changes in stimulus dimensions, and that responses were reported using the mouse cursor, rather than being made manually on a set of labelled keys on a keyboard. The fixation cross at the center of the screen measured .01 units (1.05 cm) both horizontally and vertically. Each word from the eight-word stimulus set measured .01 units (1.05 cm) tall and .1 units (9.5 cm) wide. The same dimensions were used for the T2 pattern mask, as well as the single row of Xs and question marks that made up the cue displays.

At the end of each trial, participants were shown the eight-word set in red, which remained on screen until the participant used their mouse cursor to report the identity of T1. Right after report of T1, a similar procedure was followed for the report of T2, with the words now appearing in white. Locations of the eight words on these response screens were kept constant across trials (see Figure 1).

Design & Procedure

The design and procedure were identical to that described for Experiment 2, with the following exceptions. The duration of events in each trial were not changed from the previous two experiments, but defined in PsychoPy by specifying the number of frames the event was presented for based on 60 frames per second (Hz), which is the standard for most laptop screens and laboratories. Therefore, for the sake of clarity we will report the trial events again but report all timing parameters both in millisecond (ms) units and their corresponding Hz unit.

Each trial began with the presentation of a white fixation cross at the centre of a black screen, that remained on screen until the participant initiated the trial by pressing the space bar.

Upon initiation of a trial, T1 appeared for about 117 ms (7 Hz) and was followed by a blank interval of either 117 ms (7 Hz), 350 ms (21 Hz), or 583 ms (35 Hz). These blank intervals created a T1-to-T2 stimulus onset asynchrony (SOA) of 233, 467 or 700 ms. T2 was presented for 100 ms (6 Hz) and replaced by a pattern mask that appeared for 500 ms (30 Hz). Each trial ended with presentation of the T1 response page, that remained on screen until a valid mouse click (word click) was made. This process was repeated immediately after for the T2 response page.

Participants completed a fully remote session at some point during the months of November and December 2022. Participants were asked to complete the experiment in a quiet area, with a stable internet connection, and no distractors. Participants were also asked to be seated about an arm's length away from their computer screen and to ensure that their screen brightness was at the maximum setting (100% screen brightness). This procedure was followed so that contrast of T1 and T1 distractor would be as consistent as possible across unavoidable variation associated with remote data collection. We collected information on the type of operating system (Windows, MacOS, or Linux) used to complete the experiment. We confirmed the validity of these online methods by conducting an initial pilot study, which replicated effects typically observed with this two-target task in a laboratory setting. For this experiment, we dropped the post-experiment questionnaire.

Results

We adopted the same analysis strategy as described for Experiment 2. Mean T1 and T2|T1 performance for each condition in both groups are displayed in Figure 4. Full analyses that include the no-selection trials are included in the Appendix B for the interested reader.

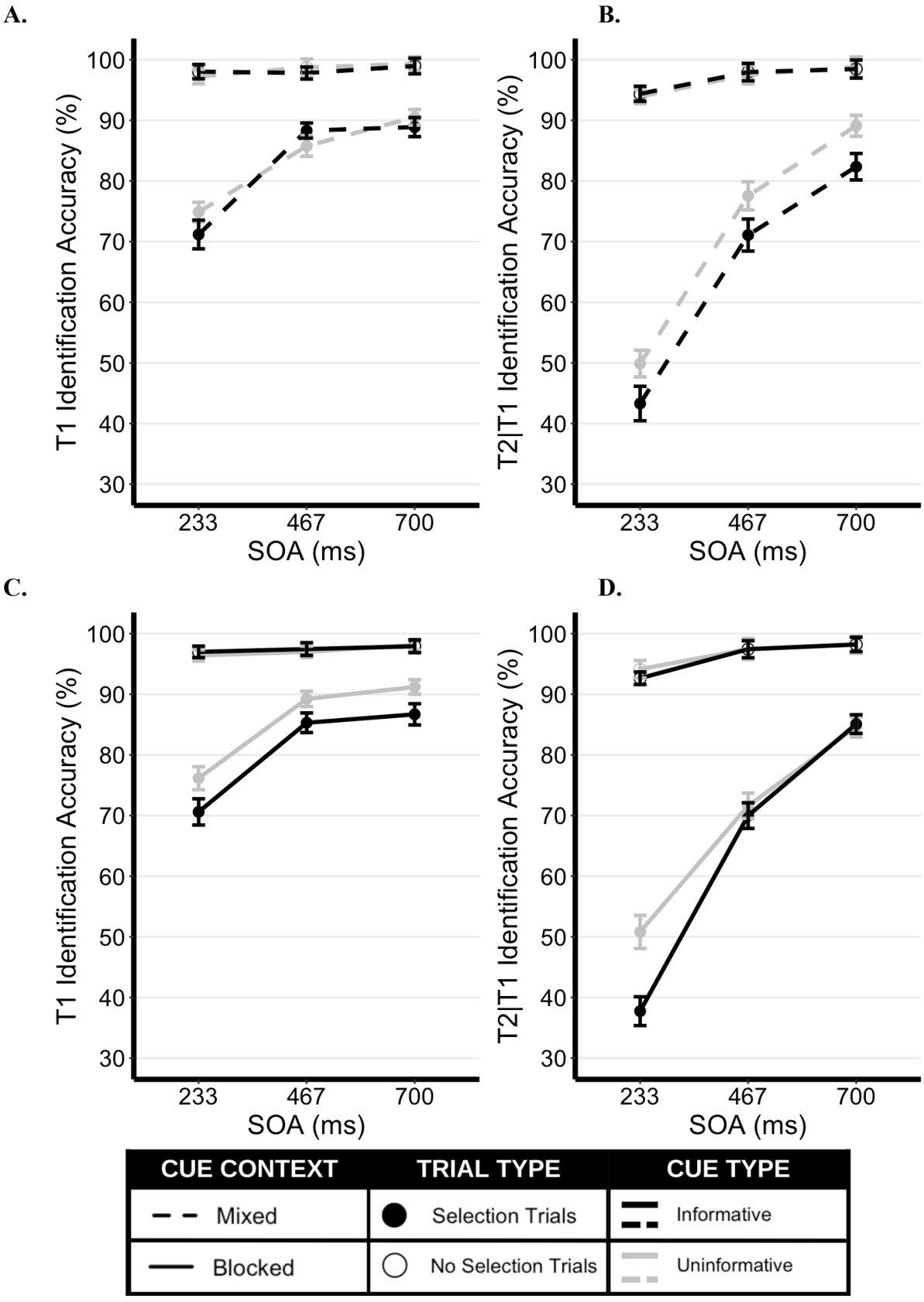
A.
B.
C.
D.
T1 Identification Accuracy (%)
T2|T1 Identification Accuracy (%)
SOA (ms)
233
467
700
100
90
80
70
60
50
40
30
CUE CONTEXT
TRIAL TYPE
CUE TYPE
Mixed
Blocked
Selection Trials
No Selection Trials
Informative
Uninformative

Figure 4. Mean T1 and T2|T1 accuracy for participants in the mixed cue-context group (top panel) and participants in the blocked cue-context group (bottom panel) as a function of cue type (informative/uninformative), trial type (selection/no-selection), and SOA (233/467/700 ms). The error bars represent the standard error of the mean (SEM) corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008), calculated with the Superb package (Cousineau, Goulet, Harding, 2021).

T1 Analysis.

Percent correct T1 responses for selection trials were submitted to a mixed ANOVA that treated cue-type (informative/uninformative) and SOA (233/467/700 ms) as within-subject factors, and cue-context as a between-subject factor. Findings of note include the cue-context by cue-type interaction that approached significance, $F(1, 70) = 3.31$, $MSE = 114.3$, $p = .073$, $\eta^2_P = .045$, $\eta^2_G = .004$. This two-way interaction was probed further by conducting separate ANOVAs for each cue-context condition, with cue-type and SOA as within-subject factors.

For the mixed cue-context condition, there was a significant interaction between cue-type and SOA $F(2, 70) = 3.68$, $MSE = 49.6$, $p = .030$, $\eta^2_P = .095$, $\eta^2_G = .007$, but the main effect of cue-type was not significant, $F(1, 35) = 1.18$, $MSE = 39.4$, $p = .285$, $\eta^2_P = .033$, $\eta^2_G = .00087$. Post-hoc analysis with a Holm-Bonferroni adjustment revealed that the cueing effect was not significant for any of the SOAs (233 ms SOA, +3.7%, $t(35) = 1.79$, $p = .082$; 467 ms SOA, -2.5%, $t(35) = -2.12$, $p = .041$; 700 ms SOA, +1.6%, $t(35) = 1.16$, $p = .255$). Thus, the interaction between cue-type and SOA owes to small shifts in the sign of non-significant cueing effects across SOAs. For the blocked cue-context group, there was a significant main effect of cue-type, $F(1, 35) = 6.22$, $MSE = 189.3$, $p = .018$, $\eta^2_P = .151$, $\eta^2_G = .028$, with more accurate T1 performance for informative cues (85.5%) than for uninformative cues (80.9%).

Other significant effects in the overall three-way ANOVA included a significant main effect of SOA, $F(2, 70) = 62.3$, $MSE = 109.2$, $p < .001$, $\eta^2_P = .640$, $\eta^2_G = .205$, which captures the increase in T1 performance with increasing SOA. There was also a significant interaction between cue type and SOA, $F(2, 140) = 3.38$, $MSE = 41.9$, $p = .037$, $\eta^2_P = .046$, $\eta^2_G = .003$. As for the cue-type by SOA interaction for the mixed cue-context group, this interaction appears to reflect subtle changes in the cueing effect across SOAs (see left panel of Figure 4).

T2 Analysis.

Percent correct T2|T1 for selection trials only were submitted to the same ANOVA as the corresponding T1 data. The mean percent correct for each condition, collapsed across participants, are depicted in the right panels of Figure 4. The data in Figure 4 show that T2 performance increases across SOAs, that both conditions show a cueing benefit, but that cueing benefit itself differs across SOA for the two cue-context conditions. These observations were supported by the results of the main analysis, which revealed significant main effects of SOA, $F(2, 140) = 316.0$, $MSE = 216.2$, $p < .001$, $\eta^2_P = .819$, $\eta^2_G = .434$, and cue-type, $F(1, 70) = 26.1$, $MSE = 133.0$, $p < .001$, $\eta^2_P = .271$, $\eta^2_G = 0.022$, but also significant interactions between cue-type and SOA, $F(2, 140) = 4.86$, $MSE = 97.6$, $p = .009$, $\eta^2_P = .0650$, $\eta^2_G = .006$, and most importantly between cue-context, cue-type, and SOA, $F(2, 140) = 4.96$, $MSE = 97.6$, $p = .008$, $\eta^2_P = .0661$, $\eta^2_G = 0.006$. This three-way interaction was examined further with separate ANOVAs for each cue-context condition that treated cue-type and SOA as within-participant factors.

For the mixed cue-context condition, there was a significant main effect of SOA, $F(2, 70) = 129.9$, $MSE = 271.6$, $p < .001$, $\eta^2_P = .788$, $\eta^2_G = .401$, and more important, a significant main effect of cue-type, $F(1, 35) = 24.3$, $MSE = 96.8$, $p < .001$, $\eta^2_P = .410$, $\eta^2_G = 0.026$. T2

performance was more accurate on informative cue trials (72.2%) than on uninformative cue trials (65.6%).

For the blocked cue-context condition, the key result was a significant two-way interaction between cue-type and SOA, $F(2, 70) = 11.5$, $MSE = 103.9$, $p < .001$, $\eta^2_P = .248$, $\eta^2_G = .027$. Post hoc analysis with a Holm-Bonferroni adjustment revealed that at the shortest SOA, T2 performance was about 13.1% better on informative cue trials than on uninformative cue trials $t(35) = 4.29$, $p < .001$. No such cueing benefit was observed for the two longer SOAs (467 ms SOA, 1.6%, $t(35) = .739$, $p = .465$; 700 ms SOA, -0.5%, $t(35) = -0.231$, $p = .818$).

Discussion

The key finding in Experiment 3 was the demonstration of a significant cueing effect in both the mixed and blocked cue-context conditions, which provides the strongest demonstration yet of cue-based control (i.e., proactive control) in this AB task. Interestingly, this cueing effect appeared only for the shortest SOA in the blocked cue-context condition, whereas it was observed reliably across SOAs in the mixed cue-context condition. The implications of these different patterns of cueing effects are discussed in more detail in the General Discussion.

General Discussion

Many cognitive control theories converge on the idea that when presented with cues warning us of forthcoming conflict, we can prepare our attentional task sets accordingly. However, to date, evidence showing that proactive control modulates conflict processing has been scarce and largely confined to the Stroop task; even so proactive control effects are most often masked by modulatory effects caused by reactive control (sequence effects), with any pure isolations of this effect in cueing studies producing effects of modest size at best, and only under strict boundary conditions. The present set of experiments contribute to this ongoing literature by presenting unequivocal evidence showing that participants capitalized on informative cues to proactively prepare to attend in a two-target AB task.

The first key evidence was found in Experiment 1, where performance on difficult selection trials was significantly improved when they were followed by informative cues versus uninformative cues. This cueing effect was replicated in Experiment 2 and demonstrated again more clearly in Experiment 3 using a high-powered design. Across all three experiments, we observed this cueing benefit for informative cue trials when these cues were presented randomly intermixed with uninformative cue trials. Moreover, across these experiments, the mixed cue context condition produced cueing effects that differed in their temporal course. Specifically, in Experiment 1, a cueing benefit was observed only at the shortest SOA. In Experiment 2, while the effect of SOA on cue-type was not significant, the pattern of data did show the greatest benefit of cueing at the shortest SOA, that did appear to diminish at the longer SOAs (see Figure 3B). Conversely, in Experiment 3, the cueing effect persisted across all three levels of the SOA manipulation. We consider these conflicting findings in light of the concern that they may have been reported under artificial constraints imposed by the 100% limit of the response scale.

In Experiment 1, it is immediately obvious that the AB functions in Figure 2B converge towards a high level of T2 accuracy at the longer SOAs. These converging functions for informatively cued and uninformatively cued selection trials in Experiment 1 create the impression that the cues were not beneficial to performance at the longer SOAs. But this conclusion is erroneous because the two functions are constrained by the ceiling imposed by the 100% limit of the response scale (see Figure 2B). However, ceiling effects in Experiment 2 are more apparent in the blocked cue-condition than in the mixed (see right panel of Figure 2). The data for the mixed condition summarized in Figure 2B show that the two functions for selection trials begin to run parallel at the two shortest SOAs, but still converged to some degree at the longest SOA to a common level nearing ceiling (see Figure 2B). Nevertheless, we cannot completely rule out ceiling effects in Experiment 2, which paired with the concern of an underpowered design imposed a constrain on the data.

Notably, with remote experiments, the data are typically noisy with worse performance compared to data collected in-person under controlled lab conditions. To our advantage, this removed ceiling constraint in Experiment 3, which showed functions of T2 accuracy over SOA that were nowhere near the 100% limit of the T2 response scale (see right panel of Figure 4). Here, for the mixed cue-context condition we saw parallel AB functions, with performance being better overall for the informatively cued selection trials compared to uninformatively cued selection trials. However, the cueing effect found in the mixed cue-context condition, upon its first demonstration in Experiment 1, was modest in size at best, and even in its subsequent replications did not produce an effect size comparable to that previously reported for the LWPCE. This finding opposes the view that the LWPCE is a direct result of purely proactive control mechanisms. To that end, we attempted to produce a cueing effect by presenting

informatively cued trials separate from uninformatively cued trials. The rationale behind this design was that it would heighten proactive control in a sustained fashion across the course of a block of informative trials. Therefore, for the blocked cue context we expected a cueing effect greater in magnitude than that observed under a mixed cue-context.

Critically, this effect was not observed when the informative cues were presented in a separate block on their own. In Experiment 2, by adopting the blocked design, an atypical cueing pattern emerged that had a distinct temporal signature. When equipped with enough power to detect such an effect in Experiment 3 we saw that the cueing effect was impacted by SOA, wherein a cueing benefit was found only at the shortest SOA. The different time course of the cueing effects across the two designs implicates different mechanisms for resource allocation to T1 processing. We account for the different cue effects across the two cue-context conditions as follows.

In the blocked design, when completing an informatively cued block of trials, participants consistently engaged in proactive control processes to create and maintain an attentional filter for minimizing conflict on a selection T1 trial type. This preparation allowed for the effective encoding of T1 and the discarding of the green distractor word (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998). However, preparation to attend selectively to T1 at the outset of all trials resulted in the over-investment of encoding resources to T1, which was detrimental to T2 processing. Supporting this account are the differential pattern of cueing benefits for T1 and T2|T1 data in the blocked design for Experiment 3. On selection trials, T1 accuracy is consistently better independent of the SOA factor when the trials are informatively cued compared to control (uninformatively cued trials). This result suggests that when participants were presented with an informative cue signalling a selection trial, they readily deployed

resources for T1 processing. This overinvestment of resources improved T1 accuracy, but impaired T2 accuracy, critically at the two longer SOAs, but not at the shortest SOA.

The critical claim of the over-investment hypothesis is that the AB is a direct consequence of devoting too many attentional resources to encoding T1, leading to the inadvertent processing of trailing distractors in an RSVP stream, which interferes with T2 processing (Olivers and Nieuwenhuis, 2006). However, in the current study we employed a two-target design, wherein a distractor was paired with T1, rather than trailing it as in an RSVP stream. Therefore, the only item trailing T1, at variable intervals is T2. Therefore, we posit that at the shortest SOA, over-investment of resources for T1 processing led to subsequent entry and processing of T2, which did not occur at the two longer SOAs.

Conversely, in the mixed cue-context condition, it is not always beneficial to pay attention to the cues, since informative and uninformative cues were equally likely to occur. Therefore, we assume that participants prepared less than optimally for the informative cues, and as a result asserted a more passive control over selective attention than participants in the blocked cue-context condition. This passive approach precluded over-investment of resources to T1 processing, resulting in an intermediate level of attention, which according to the over-investment hypothesis, is more beneficial for performance in an AB task.

Cognitive Control Requires Effort

According to the DMC account, the process of proactively preparing and maintaining task sets is an effortful but potentially performance-enhancing process. So then how might we decide on whether it is worth investing resources in such effortful control processes or how much should be invested? The expected value of control (EVC) theory posits that the amount of effort and mental resources we voluntarily invest in a task is influenced by the payoff we can expect if

we perform that task effectively (Shenhav, Botvinick, & Cohen, 2013). Therefore, the extent to which participants utilize informative cues depends on the estimated value of the cues, including the cost of cognitive control. In other words, cues will lead to adjustments in control demands, as long as they allow for a cost-efficient regulation of behavior. This idea helps explain some of the strict boundary conditions alluded to in the literature for exploiting cues, most notably that of cue validity, wherein participants appear to readily make use of deterministic cues (signaling conflict with 100% validity) over probabilistic cues (signaling conflict with less than 100% validity).

Moreover, it may have been the case that the EVC was different across the two cue-context conditions. In the mixed cue-context condition, it may have been costly to consistently engage in proactive control, since not all cues were informative, and when a random uninformative cue appeared, the cost of maintaining a task set was no longer justified by the expected payoff (e.g., performance gain). Conversely, in the blocked cue-context, while the expected benefit of engaging in proactive control is not different, the expected cost of such processes is lower compared to the mixed condition. Since every trial is informatively cued, it is always beneficial to pay attention to the cues. Therefore, the weight assigned to the informative cues is likely lower in the mixed compared to the blocked cue-context condition. This is somewhat reflected numerically in the post-experiment questionnaire from Experiment 2, where participants in the mixed condition reported that they made use of informative cues on about 65% of the trials, while the blocked group reported that they made use of the cues on 72% of the trials. While the difference between these two scores was not significant, future work should implement a much more direct and standardized approach to indexing the expected efficacy of cues across these two conditions.

Conclusion

To summarize, the current study provided novel and theoretically important evidence supporting the view that explicit, trial-by-trial cues influence cognitive control in a two-target AB task. This proactive cognitive control effect was reflected in improved accuracy on selection trials that were cued informatively than uninformatively. This finding lends credence to the DMC framework proposed by Braver et al. (2007), as it demonstrates that control adaptations are not solely reactive responses to conflict (as seen in Botvinick et al., 2001), but can also take place proactively in anticipation of stimulus or conflict. Intriguingly, informative cues produced different effects on the AB when they were presented in a separate block than when they were randomly intermixed with uninformative cues. It appears that when participants were certain that an informative cue would occur (i.e., in the blocked cue-context condition), proactive cue-based control may lead to an overinvestment of resources to T1 processing, which limited the cueing benefit to the shortest SOA. Nevertheless, the results do endorse the perspective that when the type of conflict (or stimulus) is foreseeable, mental processes can be prearranged in advance, as exemplified by participants' utilization of endogenous cues in this skeletal AB task.

References

Abrahamse, E., Braem, S., Notebaert, W., & Verguts, T. (2016). Grounding cognitive control in associative learning. *Psychological Bulletin*, 142, 693–728. http://dx.doi.org/10.1037/bul0000047

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, 108, 624–652. http://dx.doi.org/10.1037/0033-295X.108.3.624

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16*(2), 106–113. doi:10.1016/j.tics.2011.12.010.

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in Working Memory* (pp. 76–106). Oxford University Press.

Broadbent, D. E., & Broadbent, M. H. P. (1987). From detection to identification: Response to multiple targets in rapid serial visual presentation. *Perception & Psychophysics*, 42, 105–113.

Bugg, J. M., & Crump, M. J. (2012). In support of a distinction between voluntary and stimulus-driven control: A review of the literature on proportion congruent effects. *Frontiers in Psychology*, 3, 367.

Bugg, J. M., & Gonthier, C. (2020). List-level control in the flanker task. *Quarterly Journal of Experimental Psychology*, 73(9), 1444–1459. https://doi.org/10.1177/1747021820912477

Bugg, J. M., Jacoby, L. L., & Toth, J. P. (2008). Multiple levels of control in the Stroop task. *Memory & Cognition*, 36, 1484–1494. http://dx.doi.org/10.3758/MC.36.8.1484

Bugg, J. M., & Smallwood, A. (2016). The next trial will be conflicting! Effects of explicit congruency pre-cues on cognitive control. *Psychological Research*, 80, 16–33. http://dx.doi.org/10.1007/s00426-014-0638-5

Chao, H. F. (2011). Active inhibition of a distractor word: The distractor precue benefit in the Stroop color-naming task. *Journal of Experimental Psychology: Human Perception and Performance*, 37(3), 799–812. http://dx.doi.org/10.1037/a0022191

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, 21, 109–127.

Corballis, P. M., & Gratton, G. (2003). Independent control of processing strategies for different locations in the visual field. *Biological Psychology*, 64, 191–209. http://dx.doi.org/10.1016/S0301-0511(03)00109-1

Correa, Á., Rao, A., & Nobre, A. C. (2009). Anticipating conflict facilitates controlled stimulus–response selection. *Journal of Cognitive Neuroscience*, 21, 1461–1472. http://dx.doi.org/10.1162/jocn.2009.21136

Cousineau, D., Goulet, M.-A., & Harding, B. (2021). Summary plots with adjusted error bars: The superb framework with an implementation in R. *Advances in Methods and Practices in Psychological Science*, 4(3), Article 25152459211035109. https://doi.org/10.1177/25152459211035109.

Crump, M., Gong, Z., & Milliken, B. (2006). The context specific proportion congruent Stroop effect: Location as a contextual cue. *Psychonomic Bulletin & Review*, 13, 316–321.

Desender, K. (2018). Different mechanisms can account for the instruction induced proportion congruency effect. *Acta Psychologica*, 184(3), 39–45. http://dx.doi.org/10.1016/j.actpsy.2017.03.011

Duncan, J., Ward, R., & Shapiro, K. (1994). Direct measurement of attentional dwell time in human vision. *Nature*, 369(6478), 313–315.

Dux, P. E., & Marois, R. (2009). The attentional blink: A review of data and theory. *Attention, Perception, & Psychophysics*, 71, 1683–1700.

Duthoo, W., Abrahamse, E. L., Braem, S., Boehler, C. N., & Notebaert, W. (2014). The congruency sequence effect 3.0: A critical test of conflict adaptation. *PLoS ONE*, 9(10), e110462. https://doi.org/10.1371/journal.pone.0110462

Egner, T. (2007). Congruency sequence effects and cognitive control. *Cognitive, Affective, & Behavioral Neuroscience*, 7, 380–390.

Egner, T. (2014). Creatures of habit (and control): A multi-level learning perspective on the modulation of congruency effects. *Frontiers in Psychology*, 5, 1247.

Entel, O., Tzelgov, J., & Bereby-Meyer, Y. (2014). Proportion congruency effects: Instructions may be enough. *Frontiers in Psychology*, 5.

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

Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General*, 121(4), 480–506.

Jiang, J., Heller, K., & Egner, T. (2014). Bayesian modeling of flexible cognitive control. *Neuroscience & Biobehavioral Reviews*, 46, 30–43.

Jiménez, L., Méndez, C., Abrahamse, E., & Braem, S. (2021). It is harder than you think: On the boundary conditions of exploiting congruency cues. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 47(10), 1686–1704. https://doi.org/10.1037/xlm0000844

Jolicoeur, P., & Dell'Acqua, R. (1998). The demonstration of short-term consolidation. *Cognitive Psychology*, 36, 138–202.

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General*, 132, 47–70.

Kastner, S., & Ungerleider, L. G. (2001). The neural basis of biased competition in human visual cortex. *Neuropsychologia*, 39(12), 1263–1276.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology, 4*, 863. https://doi.org/10.3389/fpsyg.2013.00863

Lehle, C., & Hübner, R. (2008). On-the-fly adaptation of selectivity in the flanker task. *Psychonomic Bulletin & Review*, 15(4), 814–818.

Lindsay, D. S., & Jacoby, L. L. (1994). Stroop process dissociations: The relationship between facilitation and interference. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 219–234.

Lowe, D. G., & Mitterer, J. O. (1982). Selective and divided attention in a Stroop task. *Canadian Journal of Psychology*, 36, 684–700.

Luks, T. L., Simpson, G. V., Dale, C. L., & Hough, M. G. (2007). Preparatory allocation of attention and adjustments in conflict processing. *NeuroImage*, 35, 949–958.

MacLellan, E., Shore, D. I., & Milliken, B. (2015). Contextual control over selective attention: Evidence from a two-target method. *Psychological Research*, 79(4), 556–569.

Melara, R. D., & Algom, D. (2003). Driven by information: A tectonic theory of Stroop effects. *Psychological Review*, 110, 422–471.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience,* 24, 167–202.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, 7, 134–140.

Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *Reason*, 4, 61–64.

Olivers, C. N., & Nieuwenhuis, S. (2006). The beneficial effects of additional task load, positive affect, and instruction on the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, 32, 364–379.

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods, 51*(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, 18(3), 849–860.

Schneider, W. (1988). Micro Experimental Laboratory: An integrated system for IBM PC compatibles. *Behavior Research Methods, Instruments, & Computers*, 20, 206–217.

Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: An integrative theory of anterior cingulate cortex function. *Neuron*, 79, 217–240.

Suh, J., & Bugg, J. M. (2021). The shaping of cognitive control based on the adaptive weighting of expectations and experience. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 47(10), 1563–1584. https://doi.org/10.1037/xlm0001056

van Driel, J., Swart, J. C., Egner, T., Ridderinkhof, K. R., & Cohen, M. X. (2015). (No) time for control: Frontal theta dynamics reveal the cost of temporally guided conflict anticipation. *Cognitive, Affective, & Behavioral Neuroscience*, 15, 787–807.

Wendt, M., & Kiesel, A. (2011). Conflict adaptation in time: Foreperiods as contextual cues for attentional adjustment. *Psychonomic Bulletin & Review*, 18, 910–916.

Wühr, P., & Kunde, W. (2008). Precueing spatial S–R correspondence: Is there regulation of expected response conflict? *Journal of Experimental Psychology: Human Perception and Performance*, 34(4), 872–883.

Appendix A

Table 1.

Experiment 2 Mixed Four-Way ANOVA for T1 and T2|T1 Data

		T1 Accuracy								T2|T1 Accuracy							
	Effect	DFn	DFd	F	MSE	p	sig	η2P	η2G	DFn	DFd	F	MSE	p	sig	η2P	η2G
2	CUE_CONTEXT	1.00	30.00	0.6	680.5	0.437		0.020	0.009	1.00	30.00	0.3	1050.8	0.617		0.008	0.004
3	CUE_TYPE	1.00	30.00	5.7	45.7	0.024	*	0.159	0.006	1.00	30.00	7.2	88.7	0.012	*	0.194	0.009
4	TRIAL_TYPE	1.00	30.00	80.4	402.4	0.000	*	0.728	0.421	1.00	30.00	116.1	570.3	0.000	*	0.795	0.476
5	SOA	2.00	60.00	92.9	32.2	0.000	*	0.756	0.118	2.00	60.00	120.1	78.4	0.000	*	0.800	0.205
6	CUE_CONTEXT:CUE_TYPE	1.00	30.00	3.7	45.7	0.064		0.110	0.004	1.00	30.00	2.3	88.7	0.136		0.072	0.003
7	CUE_CONTEXT:TRIAL_TYPE	1.00	30.00	2.9	402.4	0.097		0.089	0.026	1.00	30.00	1.9	570.3	0.177		0.060	0.015
8	CUE_CONTEXT:SOA	2.00	60.00	0.4	32.2	0.678		0.013	0.001	2.00	60.00	0.6	78.4	0.557		0.019	0.001
9	CUE_TYPE:TRIAL_TYPE	1.00	30.00	4.8	45.8	0.037	*	0.137	0.005	1.00	30.00	7.1	80.1	0.012	*	0.192	0.008
10	CUE_TYPE:SOA	1.56	46.80	3.7	52.2	0.043	*	0.110	0.007	1.48	44.26	3.8	110.4	0.043	*	0.112	0.008
11	TRIAL_TYPE:SOA	2.00	60.00	69.6	37.7	0.000	*	0.699	0.106	2.00	60.00	106.7	79.6	0.000	*	0.781	0.189
12	CUE_CONTEXT:CUE_TYPE:TRIAL_TYPE	1.00	30.00	2.3	45.8	0.139		0.071	0.002	1.00	30.00	1.6	80.1	0.213		0.051	0.002
13	CUE_CONTEXT:CUE_TYPE:SOA	1.56	46.80	0.1	52.2	0.870		0.003	0.000	1.48	44.26	0.1	110.4	0.817		0.004	0.000
14	CUE_CONTEXT:TRIAL_TYPE:SOA	2.00	60.00	0.1	37.7	0.944		0.002	0.000	2.00	60.00	0.3	79.6	0.710		0.011	0.001
15	CUE_TYPE:TRIAL_TYPE:SOA	1.45	43.54	1.7	60.3	0.192		0.055	0.003	1.41	42.43	2.4	114.5	0.115		0.075	0.005
16	CUE_CONTEXT:CUE_TYPE:TRIAL_TYPE:SOA	1.45	43.54	0.1	60.3	0.824		0.004	0.000	1.41	42.43	0.3	114.5	0.690		0.009	0.001

[a] Correction: Greenhouse Geisser

Note. This table provides the full analysis for Experiment 2 including data from no-selection trials. The mixed four-way ANOVA includes cue-context as a between-participants variable, and cue-type, trial-type, and SOA as within-participant variables.

Table 2.

Experiment 2 Separate Three-Way ANOVA on T1 Data for each Cue-Context Condition

		MIXED GROUP								BLOCKED GROUP							
	Effect	DFn	DFd	F	MSE	p	sig	η2P	η2G	DFn	DFd	F	MSE	p	sig	η2P	η2G
2	CUE_TYPE	1.00	15.00	20.5	20.7	4.01e-04	*	0.577	0.018	1	15	0.1	70.7	7.99e-01		0.004	0.000
3	TRIAL_TYPE	1.00	15.00	40.5	567.0	1.28e-05	*	0.730	0.503	1	15	44.5	237.8	7.50e-06	*	0.748	0.326
4	SOA	2.00	30.00	55.1	29.2	0.00e+00	*	0.786	0.124	2	30	39.7	35.1	0.00e+00	*	0.726	0.113
5	CUE_TYPE:TRIAL_TYPE	1.00	15.00	11.8	26.7	4.00e-03	*	0.440	0.014	1	15	0.2	64.8	6.97e-01		0.010	0.000
6	CUE_TYPE:SOA	1.33	19.91	2.5	61.2	1.25e-01		0.141	0.009	2	30	1.3	40.7	2.83e-01		0.081	0.005
7	TRIAL_TYPE:SOA	2.00	30.00	29.9	42.0	1.00e-07	*	0.666	0.100	2	30	41.1	33.4	0.00e+00	*	0.733	0.112
8	CUE_TYPE:TRIAL_TYPE:SOA	1.30	19.52	1.4	62.3	2.55e-01		0.087	0.005	2	30	0.5	47.1	6.08e-01		0.033	0.002

[a] Correction: Greenhouse Geisser

Note. This table provides the separate analyses on T1 data in each cue-context group for Experiment 2 including data from no-selection trials. The three-way ANOVA includes cue-type, trial-type, and SOA as within-participant variables.

Table 3.

Experiment 2 Separate Three-Way ANOVA on T2|T1 Data for each Cue-Context Condition

		MIXED GROUP								BLOCKED GROUP							
	Effect	DFn	DFd	F	MSE	p	sig	η2P	η2G	DFn	DFd	F	MSE	p	sig	η2P	η2G
2	CUE_TYPE	1.00	15.00	32.6	24.3	4.16e-05	*	0.685	0.025	1	15	0.4	153.2	5.42e-01		0.025	0.001
3	TRIAL_TYPE	1.00	15.00	65.9	639.3	7.00e-07	*	0.815	0.580	1	15	50.2	501.4	3.70e-06	*	0.770	0.372
4	SOA	1.36	20.39	61.0	108.6	0.00e+00	*	0.803	0.228	2	30	59.8	82.9	0.00e+00	*	0.799	0.189
5	CUE_TYPE:TRIAL_TYPE	1.00	15.00	21.8	28.7	3.04e-04	*	0.592	0.020	1	15	0.6	131.6	4.52e-01		0.038	0.002
6	CUE_TYPE:SOA	1.29	19.32	1.7	130.7	2.08e-01		0.103	0.009	2	30	2.2	78.7	1.28e-01		0.128	0.008
7	TRIAL_TYPE:SOA	2.00	30.00	46.8	81.7	0.00e+00	*	0.757	0.201	2	30	60.6	77.5	0.00e+00	*	0.802	0.181
8	CUE_TYPE:TRIAL_TYPE:SOA	1.26	18.93	1.2	141.4	2.97e-01		0.075	0.007	2	30	1.5	72.8	2.35e-01		0.092	0.005

[a] Correction: Greenhouse Geisser

Note. This table provides the separate analyses on T2|T1 data in each cue-context group for Experiment 2 including data from no-selection trials. The three-way ANOVA includes cue-type, trial-type, and SOA as within-participant variables.

Appendix B

Table 4.

Experiment 3 Mixed Four-Way ANOVA for T1 and T2|T1 Data

		T1 Accuracy								T2|T1 Accuracy							
	Effect	DFn	DFd	F	MSE	p	sig	η2P	η2G	DFn	DFd	F	MSE	p	sig	η2P	η2G
2	CUE_CONTEXT	1.00	70.00	0.1	692.9	0.764		0.001	0.001	1.00	70.00	0.4	1044.1	5.35e-01		0.006	0.002
3	CUE_TYPE	1.00	70.00	5.6	72.8	0.021	*	0.074	0.004	1.00	70.00	23.1	79.3	8.60e-06	*	0.248	0.011
4	TRIAL_TYPE	1.00	70.00	120.4	382.6	0.000	*	0.632	0.306	1.00	70.00	313.0	573.7	0.00e+00	*	0.817	0.514
5	SOA	1.61	112.52	134.2	58.7	0.000	*	0.657	0.108	1.67	116.88	344.4	130.2	0.00e+00	*	0.831	0.306
6	CUE_CONTEXT:CUE_TYPE	1.00	70.00	2.0	72.8	0.158		0.028	0.001	1.00	70.00	0.2	79.3	6.22e-01		0.003	0.000
7	CUE_CONTEXT:TRIAL_TYPE	1.00	70.00	0.1	382.6	0.718		0.002	0.000	1.00	70.00	0.3	573.7	5.96e-01		0.004	0.001
8	CUE_CONTEXT:SOA	1.61	112.52	0.2	58.7	0.792		0.003	0.000	1.67	116.88	0.3	130.2	7.24e-01		0.004	0.000
9	CUE_TYPE:TRIAL_TYPE	1.00	70.00	8.5	51.7	0.005	*	0.108	0.004	1.00	70.00	23.6	69.6	7.10e-06	*	0.252	0.010
10	CUE_TYPE:SOA	1.65	115.31	1.9	29.3	0.161		0.026	0.001	2.00	140.00	4.7	58.6	1.00e-02	*	0.063	0.003
11	TRIAL_TYPE:SOA	1.49	104.31	97.8	65.3	0.000	*	0.583	0.084	1.73	121.09	202.4	131.9	0.00e+00	*	0.743	0.214
12	CUE_CONTEXT:CUE_TYPE:TRIAL_TYPE	1.00	70.00	4.5	51.7	0.037	*	0.061	0.002	1.00	70.00	1.3	69.6	2.66e-01		0.018	0.001
13	CUE_CONTEXT:CUE_TYPE:SOA	1.65	115.31	0.5	29.3	0.593		0.007	0.000	2.00	140.00	5.5	58.6	5.00e-03	*	0.073	0.004
14	CUE_CONTEXT:TRIAL_TYPE:SOA	1.49	104.31	0.1	65.3	0.842		0.002	0.000	1.73	121.09	0.3	131.9	7.03e-01		0.004	0.000
15	CUE_TYPE:TRIAL_TYPE:SOA	2.00	140.00	4.2	25.6	0.018	*	0.056	0.002	1.77	123.90	4.0	56.3	2.40e-02	*	0.055	0.002
16	CUE_CONTEXT:CUE_TYPE:TRIAL_TYPE:SOA	2.00	140.00	1.9	25.6	0.154		0.026	0.001	1.77	123.90	3.5	56.3	4.00e-02	*	0.047	0.002

[a] Correction: Greenhouse Geisser

Note. This table provides the full analysis for Experiment 3 including data from no-selection trials. The mixed four-way ANOVA includes cue-context as a between-participants variable, and cue-type, trial-type, and SOA as within-participant variables.

Table 5.

Experiment 3 Separate Three-Way ANOVA on T1 Data for each Cue-Context Condition

		MIXED GROUP								BLOCKED GROUP							
	Effect	DFn	DFd	F	MSE	p	sig	η2P	η2G	DFn	DFd	F	MSE	p	sig	η2P	η2G
2	CUE_TYPE	1.00	35.00	23.3	47.8	2.71e-05	*	0.400	0.012	1.00	35.00	6.6	110.8	1.40e-02	*	0.159	0.010
3	TRIAL_TYPE	1.00	35.00	130.9	645.2	0.00e+00	*	0.789	0.474	1.00	35.00	189.7	502.2	0.00e+00	*	0.844	0.555
4	SOA	2.00	70.00	149.0	122.1	0.00e+00	*	0.810	0.280	1.59	55.58	202.2	120.0	0.00e+00	*	0.852	0.336
5	CUE_TYPE:TRIAL_TYPE	1.00	35.00	21.8	57.0	4.34e-05	*	0.384	0.013	1.00	35.00	5.9	82.2	2.00e-02	*	0.144	0.006
6	CUE_TYPE:SOA	2.00	70.00	0.0	70.3	9.57e-01		0.001	0.000	1.72	60.27	12.8	54.5	5.69e-05	*	0.267	0.015
7	TRIAL_TYPE:SOA	1.49	52.23	88.8	171.6	0.00e+00	*	0.717	0.195	2.00	70.00	117.4	100.1	0.00e+00	*	0.770	0.236
8	CUE_TYPE:TRIAL_TYPE:SOA	2.00	70.00	0.0	54.5	9.82e-01		0.001	0.000	1.45	50.82	8.2	62.2	2.00e-03	*	0.191	0.010

[a] Correction: Greenhouse Geisser

Note. This table provides the separate analyses on T1 data in each cue-context group for Experiment 3 including data from no-selection trials. The three-way ANOVA includes cue-type, trial-type, and SOA as within-participant variables.

Table 6.

Experiment 3 Separate Three-Way ANOVA on T2|T1 Data for each Cue-Context Condition

		MIXED GROUP							BLOCKED GROUP						
	Effect	DFn	DFd	F	MSE	p	sig	η2P	η2G	DFn	DFd	F	MSE	p	sig	η2P	η2G
2	CUE_TYPE	1.00	35.00	1.2	25.5	0.274		0.034	0.001	1.00	35.00	4.3	120.2	0.044	*	0.110	0.011
3	TRIAL_TYPE	1.00	35.00	49.6	495.0	0.000	*	0.587	0.306	1.00	35.00	79.7	270.2	0.000	*	0.695	0.307
4	SOA	1.55	54.26	65.8	65.5	0.000	*	0.653	0.107	1.67	58.53	68.7	52.2	0.000	*	0.663	0.110
5	CUE_TYPE:TRIAL_TYPE	1.00	35.00	0.8	19.3	0.368		0.023	0.000	1.00	35.00	7.8	84.2	0.008	*	0.183	0.013
6	CUE_TYPE:SOA	1.66	58.05	1.8	34.5	0.182		0.049	0.002	1.62	56.61	0.3	24.2	0.694		0.009	0.000
7	TRIAL_TYPE:SOA	1.43	50.13	55.9	61.8	0.000	*	0.615	0.082	1.54	53.82	43.2	69.0	0.000	*	0.553	0.086
8	CUE_TYPE:TRIAL_TYPE:SOA	2.00	70.00	4.9	29.7	0.010	*	0.122	0.005	2.00	70.00	0.5	21.4	0.638		0.013	0.000

[a] Correction: Greenhouse Geisser

Note. This table provides the separate analyses on T2|T1 data in each cue-context group for Experiment 3 including data from no-selection trials. The three-way ANOVA includes cue-type, trial-type, and SOA as within-participant variables.