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Reward Favors the Prepared: Incentive and Task-Informative Cues Interact to Enhance Attentional Control

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The dual mechanisms of control account suggests that cognitive control may be implemented through relatively proactive mechanisms in anticipation of stimulus onset, or through reactive mechanisms, triggered in response to changing stimulus demands. Reward incentives and task-informative cues (signaling the presence/absence of upcoming cognitive demand) have both been found to influence cognitive control in a proactive or preparatory fashion; yet, it is currently unclear whether and how such cue effects interact. We investigated this in 2 experiments using an adapted flanker paradigm, where task-informative and reward incentive cues were orthogonally manipulated on a trial-by-trial basis. In Experiment 1, results indicated that incentives not only speed reaction times, but specifically reduce both interference and facilitation effects when combined with task-informative cues, suggesting enhanced proactive attentional control. Experiment 2 manipulated the timing of incentive cue information, demonstrating that such proactive control effects were only replicated with sufficient time to process the incentive cue (early incentive); when incentive signals were presented close to target onset (late incentive) the primary effect was a speed–accuracy trade-off. Together, results suggest that advance cueing may trigger differing control strategies, and that these strategies may critically depend on both the timing—and the motivational incentive—to use such cues.

Keywords: cognitive control, incentive, preparation, informative cueing, flanker

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A remarkable feature of human nature is the ability to organize cognitive and behavioral activity in a goal-directed manner. This ability encompasses a wide range of mechanistic processes, broadly termed *cognitive control*, that include selective attention to goal-relevant information and inhibition of goal-irrelevant information, detection of conflict, active maintenance, and updating of goal-relevant information over time (Braver, Barch, & Cohen, 2002). Recently, the influence of motivational factors on cognitive control has arisen as a major topic within the field (Braver et al., 2014; Chiew & Braver, 2013; Engelmann, Damaraju, Padmala, & Pessoa, 2009; Krebs, Boehler, Appelbaum, & Woldorff, 2013; Krebs, Boehler, & Woldorff, 2010; Locke & Braver, 2008; Small et al., 2005; Taylor et al., 2004). The organization of behavior toward optimal goal pursuit necessarily requires that some goals are prioritized over others, and that this prioritization is adaptive to changes in an individual's internal and external environment; such prioritization and adaptation may thus be a primary function of the motivational system. It is now relatively well-established that when this system is manipulated via performance-contingent incentives, robust changes in behavioral performance, as well as control and reward-related brain regions, are observed (Botvinick & Braver, 2015; Braver et al., 2014). Notably, control-related cortical areas and reward-related areas including the ventral striatum and dopaminergic (DA) midbrain have been implicated, fruitfully extending theoretical frameworks explicitly attributing cognitive control mechanisms to DA innervation of cortical areas (Braver & Cohen, 2000).

A critical question within this literature concerns the temporal dynamics of control processes and how they may change when modulated by motivational incentives. The dual mechanisms of control framework has been useful in providing a unifying account of not only the effects of motivation on cognitive control dynamics (Chiew & Braver, 2013), but also other experimental, individual difference and population group factors (Braver, 2012). The dual mechanisms of control framework posits that cognitive control may be understood as operating within two primary modes: *proactive control*, which is characterized by advance maintenance of goal information, and *reactive control*, which is characterized by flexible adjustment of control (i.e., in response to performance monitoring). Consistent with the idea of reward as critical to goal selection and maintenance, evidence suggests that incentives may specifically enhance proactive control, using behavioral, psychophysiological, and neuroimaging measures. Task performance

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with reward incentives shows a shift toward stronger context maintenance versus nonincentive (or punishment) conditions (Braver, Paxton, Locke, & Barch, 2009; Locke & Braver, 2008). Pupillometric evidence has indicated increased preparatory effort following encoding of contextual information when paired with reward cues (Chiew & Braver, 2013, 2014). Likewise, neuroimaging evidence suggests that control-related cortical regions, such as the lateral prefrontal cortex, may exhibit increased sustained as well as transient anticipatory brain activity as a function of rewarding task contexts (Jimura, Locke, & Braver, 2010).

These investigations suggest that incentives may modulate cognitive control in a proactive or preparatory manner. However, it is not currently well-understood how incentive effects interact with other aspects of preparatory processing. Cueing paradigms permit examination of task anticipation and preparation processes: these include task-switching paradigms, where cues on each trial specify a task to be performed on a subsequent stimulus (Karayanidis, Coltheart, Michie, & Murphy, 2003; Kiesel et al., 2010; Meiran, 1996), and cued conflict paradigms where advance cues signal the relevant stimulus modality (Stern, Wager, Egner, Hirsch, & Mangels, 2007) or the presence/absence of upcoming conflict (Aarts & Roelofs, 2011; Aarts, Roelofs, & van Turennout, 2008; Luks, Simpson, Dale, & Hough, 2007). Informative cues regarding upcoming conflict or the lack thereof have been associated with reaction time (RT) speeding and modulations of event-related potential (ERP) activity (Correa, Rao, & Nobre, 2009; Czernochowski, 2015), as well as with anticipatory activity in control regions including dorsolateral prefrontal cortex (Luks et al., 2007) and anterior cingulate cortex (Aarts et al., 2008). These modulations of task and neural activity under advance cueing have been interpreted as indicative of increased proactive control (Correa et al., 2009; Czernochowski, 2015).

Given evidence that both incentive and advance task-informative cueing may enhance proactive control, it is important to clarify how these manipulations may interact with one another in terms of modulating performance. For example, do incentive and task-informative cueing manipulations lead to similar increases in proactive control? Do they combine together in an additive fashion? Or are both manipulations associated with increased proactive control individually, but without further benefit when combined (i.e., a ceiling effect; subadditive interaction)? A third possibility is that incentive anticipation enhances the utilization of task-informative cues, leading to a (superadditive) interactive increase in proactive control. Investigating the effect of these experimental factors in combination allows testing of the principle of additive factors theory (Pieters, 1983; Sternberg, 1969): this predicts that factors that impact the same stage of cognitive processing should have an interactive (i.e., sub or superadditive) on overt behaviors such as RT, while factors impacting different stages of processing should lead to additive effects on performance. Given that both incentive and task-informative cues have been postulated to impact proactive control, examining these influences using the principle of additive factors could help shed light on whether control at the preparatory stage should be considered a unified construct or can be further fractionated. Given that the extent to which the construct of cognitive control should be considered unified versus multicomponent is a central problem in cognitive psychology (Banich, 2009), the present investigation could be helpful in characterizing the nature of preparatory control may be more broadly.

Two recent studies by Soutschek and colleagues (Soutschek, Stelzel, Paschke, Walter, & Schubert, 2015; Soutschek, Strobach, & Schubert, 2014) have begun to address the question of whether incentive and expectancy interact. The experimental approach was to investigate how reward incentives modulated cognitive control under conditions that independently manipulated the emphasis on proactive control. Specifically, a Stroop-like conflict task was studied, where proactive control was manipulated in terms of conflict expectancy: some task blocks had frequent conflict trials (high conflict expectancy) whereas in others, conflict trials were infrequent (low conflict expectancy). The first study indicated that high conflict expectancy (vs. low) *and* the presence of reward incentives (high vs. low motivation) were each individually associated with improved control (i.e., reduced interference costs in RT), but combining the two manipulations together in a blocked fashion offered no additional performance benefit. A follow-up neuroimaging study revealed that dorsal anterior cingulate cortex was sensitive to the interaction of motivation and conflict expectancy on congruency-related activation, such that the conflict-related increase in activation was reduced by conflict expectancy, but only under high-motivation conditions. However, behavioral effects were similar to the first study in showing independent effects of reward and conflict expectancy on interference without a significant interaction.

These studies thus provide mixed evidence regarding whether motivation and proactive control manipulation interact to modulate cognitive performance. Experimental design and timing may critically determine the effect of these two factors. In particular, Soutschek and colleagues (Soutschek et al., 2014; Soutschek et al., 2015) used a design where both incentive and conflict expectancy (i.e., proportion of conflict trials) were blocked. Manipulations of control level, including incentive and expectancy status, may be implemented on different timescales: ranging from relatively sustained to a more transient, trial-by-trial modulation (i.e., through cue signals indicating changing control demands). Further, manipulating control demands on a trial-by-trial basis may be especially useful in clarifying the nature of their effects, given tighter experimental control and more clearly defined temporal windows of influence versus block manipulations. To our knowledge, the interaction between reward incentives and other signals of control demands, such as expectancy/informative cues, have not been investigated on a trial-by-trial basis, nor have such interactions been investigated using a mixed design (i.e., with effects on both relatively sustained and transient timescales).

The present study sought to clarify these issues through two behavioral experiments probing the influence of incentive and task-informative cues and their interaction on performance over multiple timescales. We examined cognitive performance using a variant of the well-established flanker paradigm (which requires processing of a central target on each trial while ignoring distracting flankers; (Eriksen & Eriksen, 1974) under different manipulations of incentive and task-informative cue. Experiment 1 employed fully crossed incentive (vs. no-incentive) and task-informative (vs. uninformative) cue manipulations to examine how these cues influence task performance separately and in combination. In Experiment 2, we varied the timing of incentive and

task-informative cues prior to target to further probe the dynamic nature of this interaction.

We hypothesized that reward incentives would be associated with a shift toward proactive control, leading to faster performance and decreased interference costs. However, from the prior literature, two opposing predictions are possible regarding the impact of task-informative cueing and its interaction with incentive on performance. It is possible that under incentive, proactive control may increase to such a degree that no further benefit is obtained from informative cueing (in line with observations reported by Soutschek and colleagues; Soutschek et al., 2014; Soutschek et al., 2015). Conversely, incentives may enhance the utilization of task-informative cues, increasing proactive control in a paradigm such as the flanker task, where otherwise all of the task-relevant information for a given trial is present only at target. A similar possibility was alluded to by Czernochowski (2015), where an informatively cued task-switching paradigm was used to investigate ERP correlates of proactive control specifically because such cueing was thought to promote such processes.

Additionally, we employed a mixed block/event experimental design including both trial-by-trial and block-based (contextual) incentive manipulations. This design has proved fruitful in characterizing incentive effects on cognitive control in previous investigations, providing evidence for both relatively transient and sustained incentive effects on behavior and physiological correlates (i.e., high-resolution pupillometry; Chiew & Braver, 2013, 2014). The present study was also unique in employing primary, rather than monetary, incentives (i.e., pleasant liquids delivered orally at the end of each rewarded incentive trial). A majority of studies examining the effects of reward incentives on cognition have utilized monetary rewards but, as recently noted (Krug & Braver, 2014), primary incentives may offer experimental advantages in terms of temporal precision (i.e., they are consumed immediately within the context of the experiment), reduced reliance on symbolic or conceptual processing, and more biologically hard-wired appetitive/aversive value relative to monetary incentives. Moreover, prior work has suggested that although primary and monetary rewards produce similar effects on behavior, primary rewards may produce relatively more transient modulations of brain activity, versus more sustained effects observed with monetary rewards (Beck, Locke, Savine, Jimura, & Braver, 2010). Thus, we predicted liquid reward incentives in the current study would primarily increase the utility of information cues, but in a trial-by-trial, rather than a block-based, contextual manner.

Experiment 1

In this experiment, we sought to examine how combining incentive cues and task-informative cues at the preparation stage may modulate cognitive control performance using the Eriksen flanker task. Specifically, given prior evidence that both incentive and task-informative cues may enhance preparatory control, we investigated whether the presence of both cues at once would be associated with (a) no enhancement in control above that associated with a single cue (subadditive effect), (b) an additive increase in control, and (c) an interactive increase in control (superadditive effect). Both types of cues were administered on a trial-by-trial basis: incentive (vs. nonincentive) cues indicated the possibility of receiving a performance-contingent reward, while task-informative (vs. uninformative) cues signaled whether the upcoming flanker array was incongruent, neutral, or congruent. Interference (incongruent minus neutral trial RTs) and facilitation (neutral minus congruent trial RTs) were used as performance measures, with reduced interference effects being indicative of enhanced cognitive control (consistent with more constricted attention to the center target in the presence of conflict), and reduced facilitation effects indicating a global attentional filtering strategy (i.e., attention being constricted to the center target even on congruent trials).

Method

Participants. Twenty-four healthy young adults participated (11 male, 13 female; mean age 19.5 years +/− *SE* 0.35). Participants were recruited from participant pools maintained by the Department of Psychology at Washington University in St. Louis. All participants provided written informed consent as outlined by the Washington University Human Studies Committee and received either course credit or $10/hr for their participation. Participants were required to be able to refrain from drinking liquids for 3 hr prior to the experiment without any adverse health effects or excessive discomfort, and were evaluated for their adherence to this requirement prior to the experiment. Also, participants were required to be free from food allergies to apple juice. All participants were right-handed, had corrected-to-normal vision, and were free from psychiatric or neurological disorders.

Task design. Participants engaged in an adapted arrow version of the Eriksen flanker task (Eriksen & Eriksen, 1974) requiring identification of the direction of the center arrow while it was surrounded by response compatible arrows (i.e., > > > > >; congruent trials), response incompatible arrows (i.e., < < > < <; incongruent trials), or neutral stimuli (i.e., X X > X X; neutral trials). The task was presented on a Windows PC using E-Prime software (Psychology Software Tools, Pittsburgh, PA) using white text on a black background. Pointed brackets (e.g., ">" "<") in Arial font size 36 were used as arrows.

On each trial of the task, participants first viewed a cue (a centrally presented rectangular box) for 800 ms. The cue was presented as either white or green (50% each); in the baseline block participants were instructed to ignore the colors, while in the subsequent incentive blocks they were instructed that the color indicated the incentive status of each trial (white and green were nonincentive and incentive, respectively[1]). Four shapes, one on each side, accompanied the centrally presented rectangular box. These shapes were either task-informative or uninformative (50% in each condition; fully crossed with incentive status as indicated by color) in predicting the upcoming array of arrows. On informative trials, these shapes were either circles (predicting congruent trials), squares (predicting neutral trials), or triangles (predicting

[1] Color was not counterbalanced between nonincentive and incentive cues. Given that green has been typically associated with "go" actions, we examined cue color as an effect in the baseline block (where participants were explicitly told to disregard cue color) for both Experiment 1 and 2. In Experiment 1, participants actually made more errors, $F(1, 23) = 7.271$, $p = .013$, and slower RTs, $F(1, 23) = 23.727$, $p < .001$, on green cues than white (no significant cue color effects at baseline in Experiment 2). While this result was surprising, it actually makes performance enhancement in the reward blocks more striking, given that incentive cues were green and nonincentive cues were white.

incongruent trials). On uninformative trials, these shapes were question marks ("?") in Arial font size 48. All shapes were either green or white to match the rectangular box cue and predicted the upcoming array with 100% validity.

Following cue presentation, the flanker array appeared for 200 ms within the cue box (which remained on the screen). Stimulus presentation was followed by a 800 ms interstimulus interval, permitting a 1,000 ms response window, and then by a feedback screen that appeared for 1,500 ms. If participants made an error, a red triangle was displayed. If participants answered correctly, the feedback screen displayed the message "Next Trial"; on reward blocks, visual feedback additionally varied according to whether performance was above or below criterion, and was accompanied by liquid delivery (details follow). Trials were separated by an intertrial interval of 2,000 ms. Task trial structure is illustrated in Figure 1.

Liquid administration equipment. Liquid feedback was delivered using digital infusion pumps (model SP200i, made by World Precision Instruments, Sarasota, FL), which permitted adjustable delivery of an exact amount of liquid. Each pump operated two 60-mL syringes (BD 60-mL syringe with Luer-Lok tip, Fisher Scientific, Waltham, MA) filled with liquid. Liquids were delivered through a length of Tygon food-grade tubing, which delivered liquid from the syringes in the pump setup to the participant's mouth. The pumps were connected to and triggered by E-Prime via a digital in-line port. Apple juice was used as the reward liquid, whereas a neutral isotonic solution (similar in chemical concentration to saliva, 25 mM KCl and 2.5 mM $NaHCO_3$; O'Doherty, Deichmann, Critchley, & Dolan, 2002) was used as nonreward feedback. Liquids were administered in 0.75-mL portions.

Experiment procedure. Participants were asked to refrain from drinking any liquids for 3 hr prior to experiment onset, so that they would be thirsty and motivated to perform for liquid rewards. All participants were questioned to ensure they had been able to adhere to this requirement prior to beginning the experiment.

Task performance was examined under two blocked-incentive conditions: baseline (144 trials) and reward (288 trials). Before the task, participants were informed regarding the predictive value of the shapes accompanying each cue and instructed to consider this information prior to array presentation on each trial. They then completed a practice block, followed by a brief quiz that verified that they were aware of the mapping between each informative shape (circle, square, triangle) and the array it predicted (congruent, neutral, incongruent, respectively). Next, participants completed the baseline block, where no liquid incentives were provided. Although green and white reward cues were presented along with task-informative cues in this block, participants were told that cue color was inconsequential during this block. Following completion of the baseline block, block performance was used to calculate a RT criterion for each participant. This criterion was defined as the RT at the 30th percentile of correct baseline RTs (ordered from fastest to slowest) and used in the reward block of the task, as will be described.

Participants completed the reward block after the baseline block. The reward block contained 50% incentive trials and 50% nonincentive trials, indicated by cue color, fully crossed with task-informative status (50% each uninformative and informative trials; 25% in each Incentive × Informative cue condition). On incentive trials within the reward block, participants received reward feedback both visually and in the form of a drop of liquid delivered to their mouth. If performance was accurate and faster than RT criterion, participants received apple juice and visual feedback indicating "You Won a Bonus!", whereas slow or incorrect responses received neutral solution as feedback, accompanied by visual feedback indicating "Next Trial" or displaying a red triangle, respectively. On nonincentive trials no liquids were delivered;

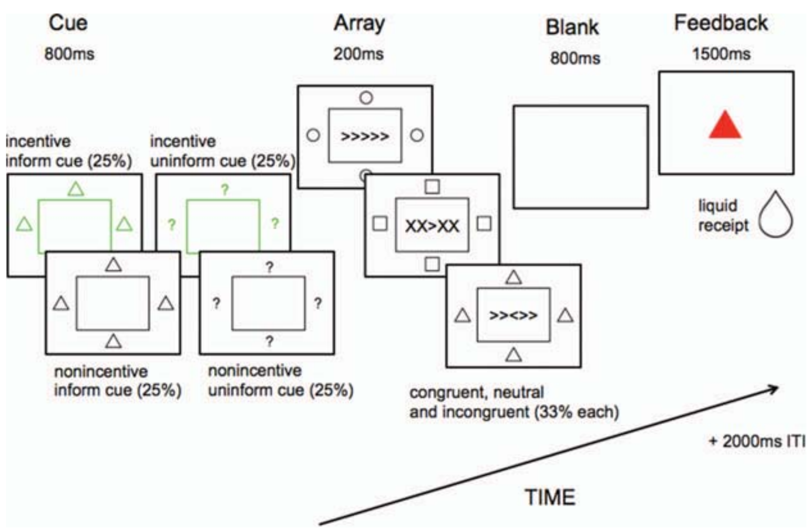

Figure 1. Trial structure for Experiment 1. Each trial began with a cue that was either white or green (indicating nonincentive and incentive trials in the reward block, respectively) and either informative or uninformative regarding conflict in the upcoming array (in informative trials, circles, squares, and triangles predicted congruent, neutral and incongruent flanker arrays respectively; in uninformative trials question marks were shown). Following the array presentation (200 ms with a 1,000 ms total response window), participants received feedback. See the online article for the color version of this figure.

visual feedback indicated whether the response was correct or not ("Next Trial" or a red triangle, respectively). Following completion of the experimental task blocks, participants were again quizzed to verify their knowledge of the shapes' predictions. All participants ($N = 24$) were successful on both pre- and posttest quizzes, indicating that they understood the task-informative cues while completing the task.

Results

After briefly summarizing global experimental effects, we focus the results on interference (incongruent minus neutral trial RTs) and facilitation (neutral minus congruent trial RTs) scores as dependent measures. Both interference and facilitation have been found to decrease with greater cognitive control (i.e., leading to greater selective attention on the central target and decreased processing of distractors, both incongruent and congruent; (Padmala & Pessoa, 2011) in the flanker task: thus, our analyses examine whether they change as a function of incentive condition.

The mixed block/event nature of the experimental design, with both block and trial-by-trial manipulations of incentive, allowed us to analyze effects of incentive on both timescales. Specifically, block-based incentive effects were examined by comparing performance in the baseline block versus nonincentive trials in the reward block, and trial-based incentive effects were examined by comparing performance in nonincentive versus incentive trials within the reward block.

Global effects. Descriptive data for RT and accuracy for all cell means are provided in Tables 1 and 2. In general, the data replicated well-established effects of flanker trial type, with slower and more error-prone performance on incongruent trials, and faster, more accurate performance on congruent trials, relative to neutral. Significant main effects of trial type were present both in the block-based incentive contrast, errors: $F(2, 46) = 20.007$, $p < .001$; RTs: $F(2, 46) = 59.324$, $p < .001$, and in the trial-based incentive contrast, errors: $F(2, 46) = 29.252$, $p < .001$; RTs: $F(2, 46) = 40.600$, $p < .001$.

Likewise, the incentive manipulation was successful in improving performance, as participants achieved above-criteria (i.e., rewarded) performance on 71% of incentive trials (range: 34%–89.5%), versus the expected rate of 30% reward if performance had remained at baseline levels. This occurred through a significant speed up in the reward block relative to baseline, $F(1, 23) = 39.635$, $p < .001$, although this was accompanied by an increase in errors, $F(1, 23) = 28.851$, $p < .001$.[2] When examining general trial-by-trial incentive effects (i.e., collapsed across trial type and task-informative cues), the effects were uniformly positive, with faster RTs, $t(23) = 10.704$, $p < .001$, and a trend toward higher accuracy, $t(23) = 1.791$, $p = .087$, on incentive versus nonincentive trials. Additionally, RTs were faster in task-informed versus uninformed trials for both the block incentive contrast, $F(1, 23) = 16.777$, $p < .001$, and the trial incentive contrast, $F(1, 23) = 62.426$, $p < .001$, without any significant change in errors (all ps $> .15$).

Block-based effects. Block-based (i.e., contextual) effects were examined in both interference and facilitation via 2 × 2 ANOVAs, which contrasted these measures as a function of block (baseline vs. nonincentive within reward blocks) and task information (uninformative, informative). Using error measures, analysis of interference costs revealed a significant main effect of block, $F(1, 23) = 11.133$, $p = .003$, but no other significant effects, task information: $F(1, 23) = .047$, $p = .831$; Block × Task Information: $F(1, 23) = .226$, $p = .639$; higher interference was observed in nonincentive versus baseline trials, suggesting that block-based increases in errors may have specifically impacted incongruent trials, leading to an increase in interference. Error-based measures of facilitation revealed no significant effects, block: $F(1, 23) = 1.640$, $p = .213$; task information: $F(1, 23) = .035$, $p = .852$; Block × Task Information: $F(1, 23) = .005$, $p = .945$. Using RT measures, no effects were significant in interference costs, block: $F(1, 23) = 1.268$, $p = .272$; task information: $F(1, 23) = .008$, $p = .931$; Block × Task Information: $F(1, 23) = .002$, $p = .962$, or facilitation costs, block: $F(1, 23) = 2.505$, $p = .127$; task information: $F(1, 23) = 2.769$, $p = .110$; Block × Task Information: $F(1, 23) = 1.424$, $p = .245$. This suggests that incentive-related modulation of attention was not present at a blockwise (contextual) level, while general RT speeding at the block level was associated with an increase in error-based interference, potentially reflecting a speed–accuracy trade-off.[3]

Interference effects. The primary goal of the study was to examine whether reward incentive and task-informative cues have combined or independent effects on cognitive control. To investigate this, a 2 × 2 ANOVA examined trial-by-trial influences of task information (uninformative, informative) and reward cues (incentive, nonincentive) on cognitive control within the reward block, using interference (incongruent—neutral) as the dependent measure. In error rates, none of the effects were significant, incentive: $F(1, 23) = .340$, $p = .566$; task information: $F(1, 23) = .289$, $p = .596$; Incentive × Task Information: $F(1, 23) = .049$, $p = .827$. However, for RTs, the ANOVA (results shown in Figure 2) revealed significant main effects of incentive, $F(1, 23) = 11.564$, $p = .002$, and task information, $F(1, 23) = 4.953$, $p = .036$, due to lower interference in incentive (vs. nonincentive) and informed (vs. uninformed) trials. Critically, the Incentive × Task-Informative Cue interaction was also significant, $F(1, 23) = 6.927$, $p = .015$. This interaction indicates that interference was selectively lowest in the presence of *both* incentive and task-informative cues. Post hoc simple effects analyses indicated that the task-informative cueing effect was significant in reducing interference on incentive trials, $t(23) = 4.110$, $p < .001$, but was not significant on nonincentive trials, $t(23) = .079$, $p = .938$. This

[2] While RTs decreased and error rates increased in the reward block compared to baseline, correlating changes in RT versus changes in error rate (for baseline trials vs. nonincentive trials in the reward block, separately for each task information condition) across participants did not reveal any significant correlations, uninform: $r(24) = -.345$, $p = .099$; inform: $r(24) = -.213$, $p = .318$, suggesting that a systematic speed–accuracy trade-off was not present. However, to probe this possibility further, we conducted additional analyses investigating the possibility of speed–accuracy trade-off, included in the Supplementary Material.

[3] As noted under global effects, RTs decreased and errors increased from the baseline block to the reward block; this effect disproportionately affected incongruent trials, leading specifically to this increase in error interference across the block-based incentive contrast. However, differences in error rates and RTs across this contrast (incongruent trials in baseline vs. nonincentive within the reward block) were not significantly correlated, uninform: $r(24) = -.218$, $p = .307$; inform: $r(24) = -.178$, $p = .405$. These analyses are not consistent with the presence of a speed–accuracy trade-off, but do not conclusively rule it out.

Table 1
Experiment 1 Error Rates (Group Means, With Standard Deviations Shown in Parentheses) as a Function of Condition

	Congruent		Neutral		Incongruent	
	Uninform	Inform	Uninform	Inform	Uninform	Inform
Baseline block	.0451 (.0990)	.0417 (.0975)	.033 (.0388)	.0313 (.0525)	.1354 (.1627)	.1267 (.1507)
Nonincentive trials (reward block)	.0938 (.1516)	.0712 (.1017)	.1007 (.1056)	.0816 (.0864)	.2778 (.1968)	.2726 (.1707)
Incentive trials (reward block)	.0434 (.1002)	.0486 (.1090)	.0434 (.0528)	.0503 (.0727)	.2413 (.1505)	.2535 (.1789)

suggests that reward incentives were able to enhance the utilization of task-informative cues: that is, increased utilization of proactive control as the primary mechanism of reward-based performance enhancement.

Facilitation effects. In addition to examining effects on interference, we tested the hypothesis that reward incentives would lead to reduced facilitation effects, via increased attention toward the task-relevant central stimulus. To test this, another 2 × 2 ANOVA was conducted, again with task information (uninformative, informative) and reward cues (incentive, nonincentive) as factors, but facilitation (neutral–congruent) as the dependent measure. As with interference, there were no effects in error rates, incentive: $F(1, 23) = .169$, $p = .685$; task information: $F(1, 23) = .053$, $p = .820$; Incentive × Task Information: $F(1, 23) = .004$, $p = .947$, while an Incentive × Task-Informative Cue interaction was observed for RTs, $F(1, 23) = 7.507$, $p = .012$; results shown in Figure 3. This interaction was due to the fact that task-informative cueing increased facilitation effects on nonincentive trials at a trend level, versus incentive, $t(23) = -2.009$, $p = .056$, while, in contrast, on incentive trials task-informative cueing significantly decreased the presence of facilitation, $t(23) = 2.142$, $p = .043$. The implication of this finding will be discussed further.

Discussion

In Experiment 1, we investigated how incentive and advance task information may interact to influence cognitive control performance at the preparatory stage. Toward this goal, we examined flanker performance under fully crossed manipulations of incentive and task-relevant advance information. Given that both types of cues have been associated with enhanced proactive control, we tested whether incentive and task-informative cues would lead to a subadditive, additive, or superadditive effect when combined. Observed results in Experiment 1 supported this last hypothesis. When examining the effects of trial-based incentive, we observed a significant Incentive × Task Information interaction driven specifically by lower interference costs in informed, incentive trials relative to all other conditions. Trial-based effects of incentive on facilitation effects revealed a similar Incentive × Task Information interaction driven by lower facilitation specifically in incentivized, informed trials. Interpreted through additive factors theory (Pieters, 1983), this pattern of findings indicates that both incentive and task-informative cues may be influencing a unitary construct of proactive control, possibly by enhanced use of informative cues under incentive.

Further, these results are somewhat consistent with prior work (Padmala & Pessoa, 2011), where motivational incentives were associated with decreased interference and facilitation in a Stroop-like conflict task; Padmala and Pessoa interpreted this as resulting from enhanced attentional filtering. Significant Incentive × Task Information interactions in both interference and facilitation measures suggest that participants may have used a global attentional filtering strategy on informed, incentivized trials regardless of congruency, but may not have consistently implemented attentional filtering on congruent trials in the presence of incentive or informative cue alone.

A notable, and potentially surprising feature of the current results is that task-informative cues alone did not lead to significantly decreased interference. Although informative cues have generally been associated with increased proactive control (Correa et al., 2009; Czernochowski, 2015), recent evidence suggests that cueing effects on subsequent performance may be variable (Bugg & Smallwood, 2014), and may be altered by rewarding contexts such that unrewarded cues in this context are relatively devalued as control signals (Braem, Verguts, Roggeman, & Notebaert, 2012; Muhle-Karbe & Krebs, 2012). Other studies suggest that informative cues predicting conflict may have mixed results (Aarts et al., 2008) and/or lead to faster RTs without specifically decreasing interference (Luks et al., 2007).

Additionally, while both interference and facilitation were sensitive to an Incentive × Task Information interaction, a significant

Table 2
Experiment 1 Median Correct Reaction Times (Group Means, With Standard Deviations Shown in Parentheses) as a Function of Condition

	Congruent		Neutral		Incongruent	
	Uninform	Inform	Uninform	Inform	Uninform	Inform
Baseline block	478.9792 (72.7025)	466.0104 (79.4130)	491.9583 (75.2510)	485.0417 (74.9128)	573.8958 (71.3797)	566.7917 (77.7413)
Nonincentive trials (reward block)	447.125 (65.961)	417.25 (58.8628)	444.2292 (56.9176)	433.2083 (51.7931)	518.7083 (65.6665)	506.9375 (69.4186)
Incentive trials (reward block)	378.5208 (46.6906)	369.7083 (51.9640)	387.8125 (41.8298)	370.125 (43.0145)	454.5833 (55.8869)	408.8958 (48.8701)

main effect of incentive was observed in interference costs but not in facilitation. It is possible that incentive effects on facilitation were smaller due to a strategy where attentional filtering was increased on incongruent but not congruent trials, given that filtering on congruent trials is effortful and unnecessary to the task (i.e., the distractors were associated with the same response as the target). Use of such a strategy would predict a decrease in interference, but not facilitation, under incentive and informative cue. To clarify these issues further, we conducted a second experiment where timing of incentive and task-informative cues was manipulated on a within-subjects basis, allowing us to examine with more precision the conditions under which informative and incentive cues may or may not interact to enhance cognitive control.

Experiment 2

In Experiment 2, we sought to clarify the observation that simultaneous presentation of both incentive and advance information was associated with a larger decrease in interference costs (i.e., greater enhancement in cognitive control) than either incentive or task-informative cue alone. This observation is consistent with the hypothesis that reward incentives can selectively enhance preparatory control processes, specifically benefiting performance the most when informative cues are available to be used in advance of the target stimulus—that is, that incentive and informative cues have an interactive effect at the preparatory stage. Here, we probed the temporal dynamics of this interaction—testing the extent to which this interaction effect requires time for proactive control to emerge versus acting rapidly—by investigating whether varying cue timing would influence performance benefit in Experiment 2.

The key modification was to separate the presentation of incentive and trial information cues in time (vs. Experiment 1 where both incentive status and trial information were presented simultaneously during the entire cue stage). Cue presentation timing was manipulated in a blocked, within-subjects fashion, that is, all participants completed the flanker task under both presentation timings: (a) in the *early incentive* condition, the incentive cue was presented prior to the task information cue, and long before the flanker array; (b) in the *late incentive* condition, the incentive cue was presented after the task information cue, shortly before the flanker array. Specifically, cue timing was set such that in the early incentive condition, the incentive and task-informative cues were present together for a relatively long duration (1,700 ms), similar to the Experiment 1 design. In contrast, in the late incentive condition, the task information cue was presented alone for a relatively long time (1,700 ms) and the incentive and task information cue were only present together for a short period of time (300 ms).[4] This design permitted us to examine with greater temporal precision how incentive cue timing modulated usage of the information cue.

We hypothesized that effects in the early incentive condition would largely replicate those in Experiment 1 (i.e., decreased interference and facilitation would be observed specifically in informed, incentivized trials), given the similarities in design (including an extended period of time to process simultaneous incentive and informative cues before target array presentation). Predictions for the late incentive condition were more complex, given that informative cues were only associated with enhanced control in Experiment 1 when combined with incentive. We hypothesized

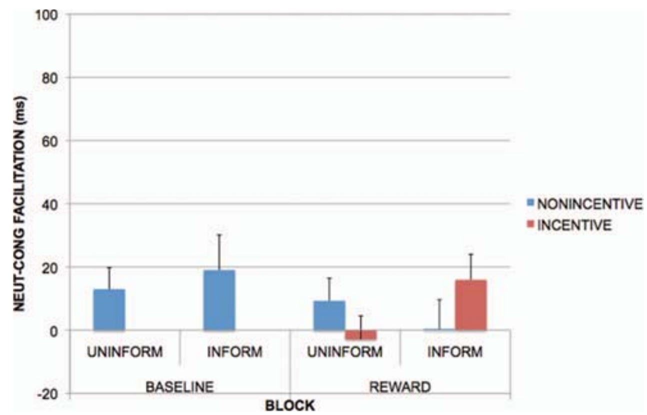

Figure 3. Experiment 2 facilitation costs (difference score between reaction times in the neutral and the congruent flanker condition). Trial-based incentive effects were examined by analyzing costs in nonincentive and incentive trials within the reward block, while block-based incentive effects were examined by analyzing costs in nonincentive trials in the baseline versus reward block. See the online article for the color version of this figure.

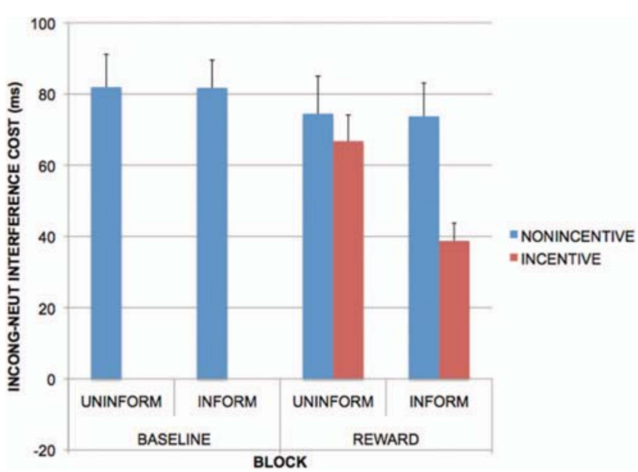

Figure 2. Experiment 1 interference costs (difference score between reaction times in the incongruent and the neutral flanker condition). Trial-based incentive effects were examined by analyzing costs in nonincentive and incentive trials within the reward block, while block-based incentive effects were examined by analyzing costs in nonincentive trials in the baseline versus reward block. See the online article for the color version of this figure.

[4] The design of Experiment 2 is such that presentation time of the incentive and informative cues is not completely balanced. However, we chose this design such that the early and late incentive conditions are matched in having a 2,000-ms cueing period before presentation of the flanker array, and also in having the two cues presented sequentially rather than simultaneously. Likewise, while the timing of the task-informative cue varies across conditions between 1,700 ms versus 2,000 ms before the flanker, we felt that this small difference would likely not contribute much to performance given the overall length of the preparation period. These design decisions were made given that our primary focus was not on the relative onset of incentive information but on processing duration.

that if participants only use task-informative cues to engage proactive control when incentive status is certain, there should be no main effect of informative cue on interference and facilitation, and the effect of incentive should be smaller than in the early incentive condition (given that incentive cue is presented only 300 ms before the array). However, if participants use task-informative cues to prepare based on the likelihood that an incentive cue will follow, a main effect of informative cue should be observed on these measures; incentive cue effect will again be smaller than under early incentive.

Method

Participants. Twenty-four healthy young adults participated (15 male, 9 female; mean age = 20.3 years ± *SE* 0.35). Participants were recruited from participant pools maintained by the Department of Psychology at Washington University in St. Louis. All participants provided written informed consent as outlined by the Washington University Human Studies Committee and received either course credit or $10/hr for their participation. Eligibility requirements followed those in Experiment 1.

Task design. Participants again engaged in an adapted version of the Eriksen flanker task (Eriksen & Eriksen, 1974): Trial stimuli were as described in Experiment 1, and trial types (incongruent, neutral, congruent) appeared in equal frequency. In all trials, participants viewed a cue (again, a centrally presented rectangle) and shapes on the screen prior to array. Color of the cue was meaningless in the baseline blocks but alerted participants to the incentive status of each trial in the reward blocks (white for nonincentive trials, green for incentive trials). Shapes on all four sides of the rectangular cue were either informative or uninformative in predicting the upcoming array, and followed same form and contingency as in Experiment 1. Informative cues were 100% predictive. Feedback was provided after each trial in the same manner as in Experiment 1.

Experiment 2 differed from Experiment 1 in manipulating the relative timing of incentive and preparatory information prior to the flanker array. Each participant completed two separate phases of the experiment, with each phase comprised of baseline followed by reward block. In one phase the timing of trials corresponded to the early incentive condition, and in the other it corresponded to the late incentive condition. Each participant completed four task blocks in total: two baseline blocks followed by two reward blocks (early and late incentive) with condition order counterbalanced across participants. Task trial structure is illustrated in Figure 4.

Liquid administration equipment. Liquid feedback was delivered following the same procedure as in Experiment 1.

Experiment procedure. As in Experiment 1, participants were asked to refrain from drinking any liquids for 3 hr prior to experiment onset, such that they would be thirsty and motivated to perform for liquid rewards, and were questioned to ensure they had adhered to this requirement prior to experiment start.

Task performance was examined under two blocked-incentive conditions: baseline (two blocks; 144 trials each) and reward (two blocks; 288 trials each). Both baseline blocks were completed before both reward blocks, but within each incentive condition, block order (i.e., administration of early vs. late incentive block) was counterbalanced. All blocks contained 50% task-informative and 50% task-uninformative trials. Participants were informed regarding the predictive value of the shapes, quizzed to verify this knowledge pre-/posttask, and explicitly instructed to consider this information as they completed the task. Following completion of the two baseline blocks, performance in these blocks was used to calculate RT criteria for each participant. RT criteria were calculated separately for early and late incentive conditions in the same manner as in Experiment 1 and used in subsequent reward blocks. Apple juice was administered as a reward on incentive trials for correct performance faster than RT criterion, while neutral solution was administered for slow or incorrect performance. All partici-

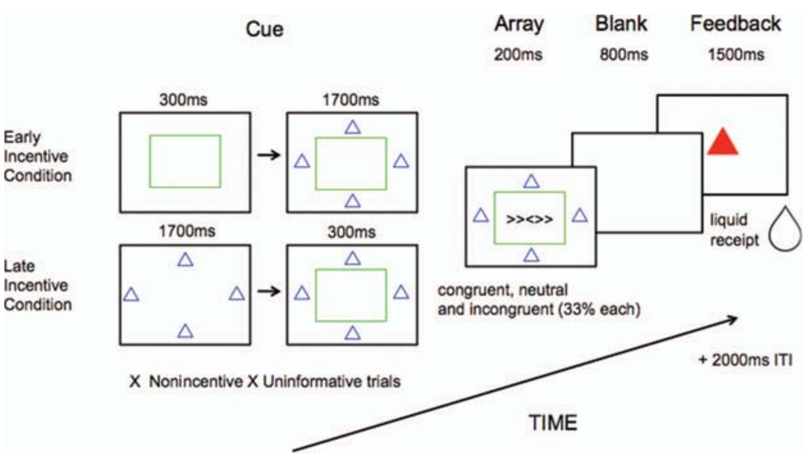

Figure 4. Trial structure for Experiment 2. The two cue orders were blocked. In the early incentive condition, participants were first presented with the white/green cue (indicating incentive status in the reward block), followed by informative/uninformative cue, followed by the array. In the late incentive condition, participants viewed an informative/uninformative cue first (following the same structure as in Experiment 1), followed by a cue that was either white or green (as previously, indicating incentive status in the reward block), followed by presentation of the array. Array presentation, feedback period, and intertrial interval followed the same timing used in Experiment 1. See the online article for the color version of this figure.

pants ($N = 24$) were successful on both pre- and posttest quizzes, indicating that they understood the informative cues while completing the task.

Results

For Experiment 2, we present global experimental effects, followed by analyses using interference costs and facilitation effects, calculated using RTs as in Experiment 1 analyses. Again, both block and trial-by-trial manipulations of incentive were utilized, providing the opportunity to examine in both block-based (baseline trials vs. nonincentive trials within the reward blocks) and trial-based (nonincentive vs. incentive trials within the reward blocks) contrasts in an analysis structure identical to that in Experiment 1, except for the addition of cue timing (early incentive, late incentive) as a factor.

Global effects. Descriptive data for RT and accuracy for all cell means are provided in Tables 3 and 4. Experiment 2 data robustly replicated the effects of trial-type (congruency) in both RTs, block-based incentive contrast: $F(2, 46) = 107.712$, $p < .001$; trial-based incentive contrast: $F(2, 46) = 145.136$, $p < .001$, and error rates, block-based incentive contrast: $F(2, 46) = 68.198$, $p < .001$; trial-based incentive contrast: $F(2, 46) = 68.228$, $p < .001$. Globally, the incentive manipulation was successful in improving performance, as participants achieved above-criteria (i.e., rewarded or avoided-punishment) performance on 75% of early incentive trials (range: 46–96%) and 71% of late incentive trials (range: 41–99%), versus the expected rate of 30% reward if performance had remained at baseline levels. This effect occurred through faster RTs in the reward blocks compared to baseline blocks, $F(1, 23) = 41.358$, $p < .001$, but was accompanied by an increase in errors, $F(1, 23) = 37.607$, $p < .001$.[5] On a trial-by-trial basis, the main effect of incentive was associated with faster RTs, $F(1, 23) = 75.621$, $p < .001$, with no significant change in error rates, $F(1, 23) = 1.929$, $p = .178$. Task-informative cues were associated with faster RTs in both the block incentive contrast, $F(1, 23) = 5.789$, $p = .025$, and trial incentive contrast, $F(1, 23) = 11.404$, $p = .003$, while no significant change in error rates was observed as a main effect of informative cue in either contrast, block incentive contrast: $F(1, 23) = .020$, $p = .890$; trial incentive contrast: $F(1, 23) = 1.097$, $p = .306$. In general, these results were highly consistent with Experiment 1. Interference and facilitation measures were examined in early and late incentive conditions as outlined below.

Block-based effects. Block-based (i.e., contextual; baseline block vs. nonincentive trials within reward block) effects were examined by examining interference and facilitation via 2 × 2 (Block × Information) ANOVAs conducted separately for early and late incentive conditions.

For the early incentive condition, interference effects were not modulated by block in either error rate, block: $F(1, 23) = 1.183$, $p = .288$; Block × Task Information: $F(1, 23) = .941$, $p = .342$, or RT, block: $F(1, 23) = 1.004$, $p = .327$; Block × Task Information: $F(1, 23) = .302$, $p = .588$. Facilitation effects showed weak counteracting patterns, with a trend-level block effect for error rates, block: $F(1, 23) = 3.217$, $p = .086$; task information: $F(1, 23) = .545$, $p = .468$; Block × Task Information: $F(1, 23) = .999$, $p = .328$, in the direction of greater facilitation in the incentive compared to baseline block, while RTs showed the opposite trend-level block effect, $F(1, 23) = 2.976$, $p = .098$; Block × Task Information: $F(1, 23) = .168$, $p = .686$; reduced RT facilitation in incentive compared to baseline block.

For the late incentive condition, interference effects were not affected by block for RT, block: $F(1, 23) = .324$, $p = .575$; Block × Task Information: $F(1, 23) = .923$, $p = .347$, but did indicate increased error interference in the incentive block, $F(1, 23) = 17.643$, $p < .001$; Block × Task Information: $F(1, 23) = .021$, $p = .885$. Facilitation effects were not modulated by block for either error rates, block: $F(1, 23) = 2.970$, $p = .098$; Block × Task Information: $F(1, 23) = .111$, $p = .742$, or RT, block: $F(1, 23) = 1.613$, $p = .217$; Block × Task Information: $F(1, 23) = 1.779$, $p = .195$.

Interference effects. To examine incentive effects on interference costs, we conducted 2 × 2 ANOVAs on these costs in reward blocks separately for the early and late incentive conditions, with incentive (nonincentive, incentive) and task information (uninformative, informative) as within-subject factors.[6] For the early incentive condition, the error rate ANOVA yielded no significant effects, incentive: $F(1, 23) = 1.183$, $p = .288$; task information: $F(1, 23) = 2.136$, $p = .157$; Incentive × Task Information: $F(1, 23) = .941$, $p = .342$, while in the RT ANOVA (results shown in Figure 5) there was a significant Incentive × Task Information interaction, $F(1, 23) = 5.649$, $p = .026$, but no main effects, incentive, $F(1, 23) = .149$, $p = .703$; task information, $F(1, 23) = .357$, $p = .556$. This pattern indicated that RT interference was selectively lowest in the presence of both incentive and task-informative cues, replicating findings from Experiment 1. Further, replicating Experiment 1, on nonincentive trials, there was no task-informative cue effect, $t(23) = -.081$, $p = .936$.

A qualitatively different pattern emerged in the late incentive condition. The error rate ANOVA indicated a significant *reversed* effect of incentive, $F(1, 23) = 17.643$, $p = .001$, such that interference was higher in incentive versus nonincentive trials, suggesting that a speed–accuracy trade-off may have specifically impacted incongruent trials, leading to an increase in interference. No other significant effects were observed for error rates, task information: $F(1, 23) = .549$, $p = .466$; Incentive × Task Infor-

[5] With a decrease in RTs and increase in error rates in the reward versus baseline blocks, we again tested for a systematic speed–accuracy trade-off by conducting correlations between changes in error rates and changes in RTs (for baseline vs. nonincentive trials in the reward block, separately for each information condition and for early/late incentive). No significant correlations were observed under early incentive, uninform: $r(24) = .162$, $p = .451$; inform: $r(24) = .193$, $p = .366$. A significant negative correlation was observed for late incentive uninformed trials, $r(24) = .407$, $p = .048$, and a trend correlation was observed for late incentive informed trials, $r(24) = .374$, $p = .072$. With the caveat that effect sizes (as indicated by correlation coefficient r) may have been small (∼.1–.2) under early incentive versus medium (∼.3–.4) under late incentive (Cohen, 1992), evidence of a systematic block-related speed–accuracy trade-off is discussed below. In addition, further analyses investigating the possibility of speed–accuracy trade-off were conducted and are included in the Supplementary Material.

[6] While incentive and task-informative cue effects on RT interference measures differed between the early and late incentive conditions as described, it should be noted that these differences did not sustain a significant three-way interaction of Order × Incentive × Task Information, $F(1, 23) = 1.864$, $p = .185$. The Order × Incentive × Task Information interaction was also insignificant for error interference, $F(1, 23) = .704$, $p = .409$.

Table 3
Experiment 2 Error Rates (Group Means, With Standard Deviations Shown in Parentheses) as a Function of Condition

	Congruent		Neutral		Incongruent	
	Uninform	Inform	Uninform	Inform	Uninform	Inform
Early incentive condition						
Baseline block	.0122 (.023)	.0156 (.036)	.0295 (.051)	.0278 (.038)	.1146 (.095)	.0972 (.070)
Nonincentive trials (reward block)	.0816 (.110)	.0677 (.099)	.1042 (.096)	.1128 (.091)	.2344 (.139)	.2465 (.128)
Incentive trials (reward block)	.0191 (.032)	.0278 (.038)	.0608 (.058)	.0434 (.045)	.1910 (.167)	.2274 (.142)
Late incentive condition						
Baseline block	.0174 (.032)	.0122 (.019)	.0347 (.060)	.0243 (.047)	.1042 (.101)	.1163 (.118)
Nonincentive trials (reward block)	.0226 (.035)	.0399 (.045)	.0625 (.059)	.0677 (.087)	.2622 (.150)	.2569 (.196)
Incentive trials (reward block)	.0208 (.035)	.0382 (.061)	.0486 (.053)	.0521 (.064)	.3472 (.202)	.3333 (.205)

mation: $F(1, 23) = .021$, $p = .885$, or for RTs (incentive: $F(1, 23) = 1.723$, $p = .202$; task information: $F(1, 23) = 1.501$, $p = .233$; Incentive × Task Information: $F(1, 23) = 2.242$, $p = .148$).

Facilitation effects. Similar analyses using the same 2x2 ANOVA structure examined facilitation effects in the two incentive timing conditions. For the early incentive condition, there were no significant effects in error rates, incentive: $F(1, 23) = 1.205$, $p = .284$; task information: $F(1, 23) = 1.941$, $p = .177$; Incentive × Task Information: $F(1, 23) = .020$, $p = .888$, or RTs, incentive: $F(1, 23) = .242$, $p = .627$; task information: $F(1, 23) = 1.978$, $p = .173$; Incentive × Task Information: $F(1, 23) = 2.609$, $p = .120$. For error rates in the late incentive condition, there were also no significant main effects, incentive: $F(1, 23) = .232$, $p = .634$; task information: $F(1, 23) = .021$, $p = .886$, but a trend-level interaction, $F(1, 23) = 3.079$, $p = .093$ suggested marginally decreased facilitation associated with incentives on task-informative cue trials. For late incentive facilitation measures calculated with RTs (shown in Figure 6), a significant main effect of task information, $F(1, 23) = 6.993$, $p = .014$, suggested stronger facilitation in informed versus uninformed trials, but no significant incentive main effects, $F(1, 23) = .049$, $p = .828$, or interactions, $F(1, 23) = .580$, $p = .454$.[7]

Discussion

Following up on findings from Experiment 1, we sought to explore how varying the timing of incentive and task-informative cues impacted RT interference and facilitation during the flanker task. In the early incentive condition, we replicated the key result from Experiment 1; that is, a significant Incentive × Task-Informative Cue interaction driven specifically by decreased interference costs in incentivized, informed trials. In contrast, the late incentive condition produced no significant effects or interactions of incentive and task information on RT interference; in this condition, incentive was actually associated with increased error interference. These findings build on observations from Experiment 1 by indicating that cue timing critically influences the RT interference effect and adequate preparation time is required for behavioral effects consistent with enhanced control to emerge. In particular, a plausible interpretation of the findings from the late incentive condition is that the timing of the reward cue did not allow a sufficient period for incentive signals to be encoded and processed in a way that enabled proactive control. Indeed, the fast RTs but increased error interference observed in this condition suggests that the incentive cue produced a simple speed-accuracy strategy shift (which reached significance in the block-based incentive contrast for task-uninformed trials), that had a negative impact particularly on incongruent trials.

One component of Experiment 2 that did not replicate Experiment 1 findings was the effect of incentive and task information cues on RT facilitation. In Experiment 1, RT facilitation was decreased on informed, incentivized trials. In Experiment 2, there was a trend for a more general reduction in facilitation in the reward relative to baseline block in the early incentive condition, but this pattern was not further enhanced in a trial-by-trial manner by incentive and task information cues. In contrast, in the late incentive condition, the opposite pattern emerged, in which RT facilitation was greater on task-informed relative to uninformed trials. One interpretation of such patterns is that task information cues might be used in a variable, strategic manner to either enhance or conserve cognitive effort in relation to task constraints. In particular, task-informative cues might enhance the use of an effortful, proactive attentional filtering strategy when there is sufficient time and incentive to do so (i.e., resulting in reduced interference on informed, incentivized trials in early incentive condition), but conversely might be exploited to relax attention on congruent trials as an alternative strategy when the timing is not sufficient to incentivize attentional filtering (i.e., resulting in increased facilitation but not reduced interference on informed, nonincentivized trials in the late incentive condition).

It is important to note that the above interpretations must be taken with caution, given that significant Order × Incentive × Task Information interactions were not observed for either interference or facilitation measures. Nevertheless, the idea that varying cue timing could lead to differential cognitive strategies is consistent with recent work suggesting that informative precues may be used in either a proactive or reactive manner, depending on task demands and cue-target interval, which must be adequately long for proactive control to emerge (Bugg & Smallwood, 2014). Future research will need to investigate further the variable strategies by which task-informative cues may be used to modulate performance.

[7] Despite some indications of differential incentive and task-informative cue effects on facilitation in the early versus late incentive condition, the Order × Incentive × Informative cue three-way interaction was not significant for facilitation calculated by errors, $F(1, 23) = 1.982$, $p = .171$, or RTs, $F(1, 23) = .397$, $p = .535$.

Table 4
Experiment 2 Median Correct Reaction Times (Group Means, With Standard Deviations Shown in Parentheses) as a Function of Condition

	Congruent		Neutral		Incongruent	
	Uninform	Inform	Uninform	Inform	Uninform	Inform
Early incentive condition						
Baseline block	463.5104 (88.945)	457.8542 (103.706)	490.8958 (105.539)	491.3229 (119.116)	549.1354 (97.911)	549.7083 (89.565)
Nonincentive trials (reward block)	401.6458 (69.104)	387.1042 (63.888)	418.25 (72.73)	406.6458 (72.503)	463.0417 (68.236)	461.2083 (73.535)
Incentive trials (reward block)	366.5 (60.898)	352.1042 (50.803)	375.875 (56.421)	374.9792 (66.438)	433.6875 (76.554)	409.0000 (96.090)
Late incentive condition						
Baseline block	436.1979 (96.236)	435.0625 (104.799)	468.0521 (98.400)	458.9688 (102.412)	532.0417 (91.565)	532.5938 (87.719)
Nonincentive trials (reward block)	354.5208 (33.136)	347.1042 (34.178)	371.1667 (46.187)	368.6875 (51.729)	442.625 (56.375)	442.0208 (63.336)
Incentive trials (reward block)	337.2917 (33.798)	332.0208 (30.800)	350.5833 (33.395)	354.7917 (36.543)	419.2917 (45.981)	413.4167 (55.639)

General Discussion

Prior work suggests that both task-informative cues and reward incentives can enhance proactive control, but how these two kinds of factors may relate and work in concert has not been well-characterized. Our data suggest that the two types of cues can positively interact at the preparatory stage (Experiment 1), but this interaction depends on cue timing (Experiment 2). In general, these findings are consistent with prior work suggesting that reward incentives enhance proactive control (Braver et al., 2009; Chiew & Braver, 2013), but further extend these findings by indicating that such incentives may improve performance specifically when preparatory information is present to be utilized, and when there is sufficient time available to make use of it.

The idea that timing may critically determine how cues impact performance dovetails with other recent studies that have begun to investigate how design manipulations may influence cue use at the preparatory stage, and whether the presence of advance information always enhances performance. This issue is beginning to be explored with both incentive and task-informative cue effects. While multiple studies suggest that incentives can enhance proactive control, recent work has begun to address whether incentive effects must necessarily be proactive or top-down in nature in order to enhance performance. For example, a recent study of reward effects on a stop-signal task (Rosell-Negre et al., 2014) suggests that reward prospect can improve performance on both 'go' and 'stop' trials but by task design, reward prospect is presented simultaneously with response target for "stop" trials. The ability for reward to improve performance under these circumstances suggests that incentive can enhance performance in a reactive as well as in a proactive fashion. A recent review by Krebs and colleagues (Krebs, Hopf, & Boehler, in press) discusses effects of reward-availability presented at target (vs. advance cue) more broadly, concluding that reward effects can occur even without advance cueing and may vary flexibly with reward manipulation and task demands; they call for direct comparisons of cued and uncued reward paradigms to examine these effects.

Regarding effects of the task-informative cue, the present results are similar to prior work in that RTs decreased under informative versus uninformative cue, but the effect of informative cues on control appeared to depend on cue timing and combination with incentive cue. Such variability in effects on performance is consistent with evidence that the value of nonincentive cues as control signals may be altered within rewarding contexts (Braem et al., 2012; Muhle-Karbe & Krebs, 2012); this variability is also in line with recent studies indicating that informative cues may engage differing control strategies depending on task demands (Bugg & Smallwood, 2014) and may be utilized more at relatively long versus short cue-target intervals (Horváth, 2013). Indeed, a critical point we believe has not yet been fully appreciated, is that the prior literature actually reveals mixed results regarding whether task-informative cues can be used to reduce interference as well as speed RTs (i.e., reflecting enhanced control). For example, although some studies find evidence that informative cues are associated with reduced interference (i.e., greater impact on high-demand trials; (Czernochowski, 2015), others report null effects for the Information × Trial Interaction (Luks et al., 2007), or report that effects of task-informative cues primarily impact congruent (low-demand) trials (Aarts et al., 2008; Bugg & Smallwood, 2014; Correa et al., 2009). In this regard, it is notable that most prior work has only included congruent and incongruent conditions without a neutral condition, so facilitation effects cannot be calculated and compared to interference, as in the present work. One exception is a recent study examining task-informative cue effects on a cued-Stroop task with incongruent, neutral, and congruent conditions (Aarts et al., 2008): Informative cues were associated with decreased interference, but also increased facilitation, which, again, is only partially consistent with the current findings.

In the present study, the inclusion of incentive cues may have interacted with task-informative cues, influencing their subsequent effect; this may help to account for discrepancies between the present study and prior work regarding informative cue effects in the absence of incentives. For example, as noted above, several studies have reported larger effects of task-informative cue on congruent relative to incongruent trials. However, we generally observed more robust cueing effects (incentive and informative cues together) on interference than facilitation (indicating that cueing effects were greater on incongruent, high-control demand

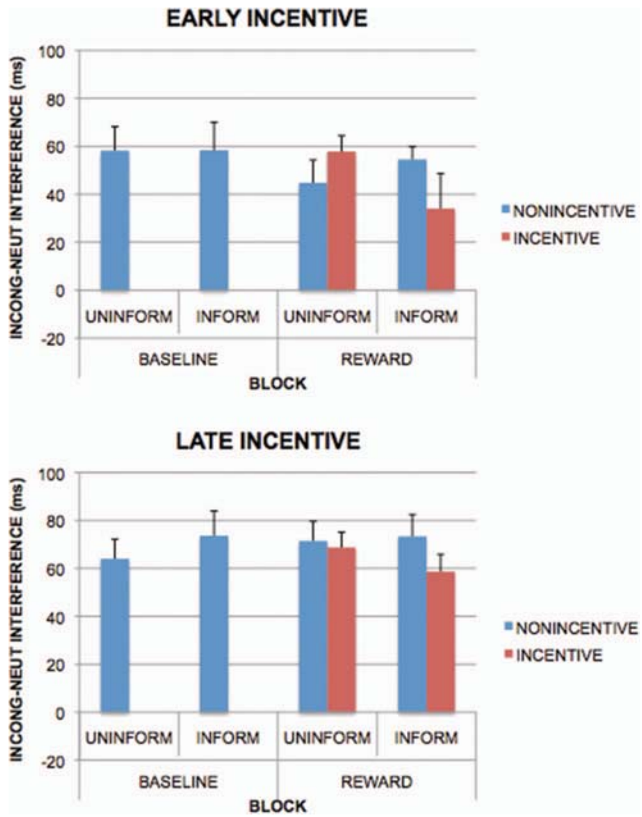

Figure 5. Experiment 2 interference costs (difference score between reaction times in the incongruent and the neutral flanker condition) shown separately for early incentive and late incentive conditions. Trial-based incentive effects were examined by analyzing costs in nonincentive and incentive trials within the reward blocks, while block-based incentive effects were examined by analyzing costs in nonincentive trials in the baseline versus reward blocks. Interference costs were calculated separately for the two cue order conditions. See the online article for the color version of this figure.

trials vs. congruent, low-control demand trials) in both studies. This effect might be qualitatively different—and more characterizable as enhanced control, versus a simple increase in response preparation leading to RT speeding—than observed when task-informative cues are presented in an experimental context where incentives are not made salient.

Interestingly, enhanced proactive control under incentive and informative cue in Experiment 1 and Experiment 2's early incentive condition was primarily observed as a trial-by-trial effect, rather than as a contextual, block-based effect. Indeed, although block-based effects were present, they were primarily found as a general pattern of RT speeding (along with increased error rate). Although we could not provide conclusive evidence in either direction, the results suggest the possibility that the block-based effect may have been better characterized as a speed–accuracy trade-off, rather than an enhancement in attentional control (since there were no block-related interactions with trial type).

The block-based findings contrast with prior work suggesting that incentive can exert both transient and sustained enhancements of cognitive control (Chiew & Braver, 2013; Jimura et al., 2010). It is possible that sustained incentive effects were not observed in the present study due to the use of immediate, primary liquid incentives, instead of monetary incentives; this is consistent with prior work indicating that primary incentives may elicit relatively more transient brain activity than secondary incentives (Beck et al., 2010). Follow-up work could clarify this issue by testing whether primarily trial-based incentive and information cueing effects are still observed even when using monetary rather than primary incentives. Additionally, further research could utilize experimental designs that examine whether there are limits on the extent to which performance can be flexibly modulated on a transient basis. For example, Experiment 2 of the present study manipulated cue timing (early vs. late incentive), but timing was blocked, while incentive and informative cues were manipulated trial-by-trial. It would be interesting to investigate whether participants could adjust performance in response to cue timing manipulations, as well as incentive and task-informative cues, if all three factors were varied by trial; or whether the resulting design would be too complex for distinct strategies to emerge on a transient basis.

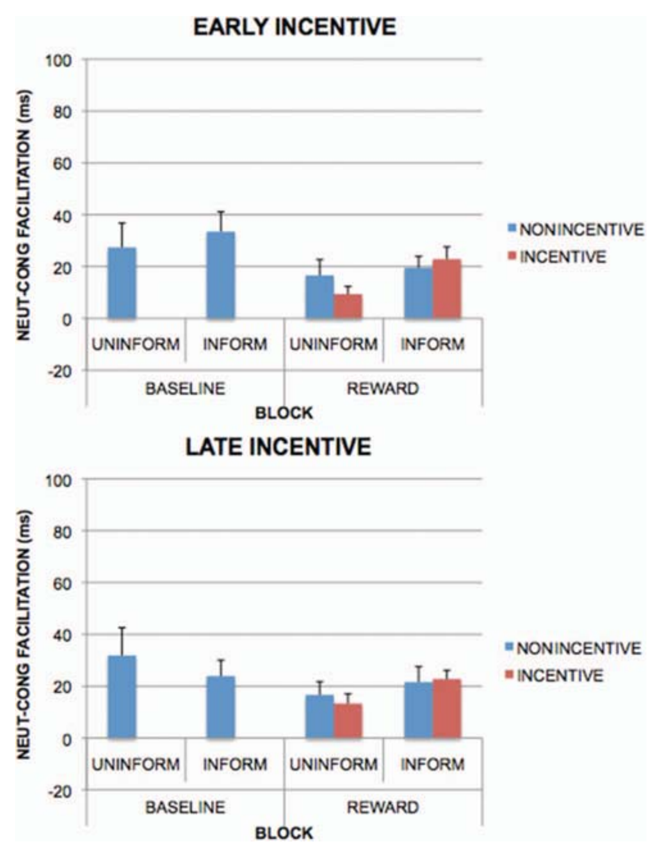

Figure 6. Experiment 2 facilitation costs (difference score between reaction times in the neutral and the congruent flanker condition) shown separately for early incentive and late incentive conditions. Trial-based incentive effects were examined by analyzing costs in nonincentive and incentive trials within the reward block, while block-based incentive effects were examined by analyzing costs in nonincentive trials in the baseline versus reward block. See the online article for the color version of this figure.

Our results are also notable in that reward incentives did not enhance performance under all conditions. While incentive was associated with RT speeding in both experiments, the Experiment 2 late incentive condition also resulted in substantial increase in error rates, which were correlated with the RT effects. This suggests that even trial-by-trial incentive effects in the late incentive condition may have been especially impacted by a speed–accuracy trade-off. Prior work has suggested that incentive payoff schemes that emphasize accuracy under time pressure (as were used in the current study), may be especially prone to producing speed–accuracy trade-offs rather than enhanced cognitive control (Dambacher, Hübner, & Schlösser, 2011). In the current work, a speed–accuracy trade-off was most prominent in the late incentive condition, where the incentive cue was only present for a short period of time; potentially, too short of a time period to have enabled proactive control effects to emerge. One interpretation of this result is that speed–accuracy trade-offs reflect performance strategy changes undertaken under high-incentive conditions that do not permit alternate, potentially more effective strategies. Specifically, it may have been that in the Experiment 2 late incentive condition, the brief incentive cue presentation *combined* with time pressure that led to a speed–accuracy trade-off, as opposed to a rapid, reactive control effect. Examining this possibility and, more broadly, the circumstances under which incentives may lead to a speed–accuracy trade-off versus increases in proactive or reactive control remains an important direction for future research.

The present study's main finding (i.e., that incentive and task-informative cues can interact) also diverges from prior work suggesting that both incentive and expectancy may increase proactive control but no further interactive benefit is observed when both manipulations are present at once (Soutschek et al., 2015; Soutschek et al., 2014). These prior studies are conceptually related to the current one, but one critical difference is the means by which participants gain task-expectancy information. In the present study, informative cues explicitly cue the presence or absence of upcoming conflict on a trial-by-trial basis. In contrast, in the designs utilized by Soutschek and colleagues (Soutschek et al., 2014; Soutschek et al., 2015), conflict expectancy is high or low, probabilistic, and constant throughout an entire block, rather than varying in a deterministic manner (i.e., 100% cue validity) across trials within-block. Thus, it may be that the differences in cue timing between the two designs could explain why incentive and conflict expectancy (conveyed by informative cues) had an interactive effect on cognitive control performance in the present data, but not in that reported by Soutschek and colleagues. Evidence from the neurophysiological literature may suggest a mechanistic basis for this effect. Neuronal recordings in primates indicate that cueing of incentive status may be associated with phasic bursts of anticipatory DA activity in the midbrain (Schultz, Dayan, & Montague, 1997). Further, advance informative cueing about nonperformance-contingent outcome has also been associated with phasic midbrain DA activity (Bromberg-Martin & Hikosaka, 2009): this has been interpreted as indicating that predictive information may be intrinsically rewarding. Given that only overt behavioral performance was measured in the present study, neural mechanisms underlying performance in the present study can only be speculated upon, but it may be possible that phasic DA responses associated with both incentive and task-informative cues may have supported enhanced preparatory control as implemented by cortical areas, providing a neurobiological basis for the observed behavioral effect.

Additionally, future work should examine neural or physiological measures concurrent to behavioral preparation. Physiological data could be critical for understanding how task-informative cues are processed differently under incentive versus nonincentive, and whether cue timing may lead to different preparatory strategies. For example, eye movements can help index deployment of selective attention (Hoffman & Subramaniam, 1995; Mall, Morey, Wolff, & Lehnert, 2014). Through comparing fixations on targets versus distracters in the array, hypotheses regarding strategy use under different preparatory manipulations (i.e., the possibility that attentional filtering could be deployed less in congruent vs. incongruent trials, as suggested by Experiment 2 late incentive condition results) could be tested. Similarly, a high temporal resolution measure such as ERPs could allow examination of preparatory neural activity and shed light on the mechanisms underlying performance. This approach has been used successfully in other studies to examine the temporal dynamics of processes related to processing prospective reward and task preparation (Schevernels, Krebs, Santens, Woldorff, & Boehler, 2014) as well as relating them to overt behavioral response (van den Berg, Krebs, Lorist, & Woldorff, 2014). Pupillometry as a concurrent physiological measure may also be useful in providing information about the temporal dynamics of potentially interactive preparatory processes, given its sensitivity to cognitive demand or effort (Kahneman & Beatty, 1966) and sensitivity to incentive effects (Chiew & Braver, 2013). Finally, neuroimaging investigations of the integration of reward-prospect and task preparation in a visual attention task have indicated that midbrain DA interactions with distributed cortical, striatal and thalamic areas underlie such integration (Krebs, Boehler, Roberts, Song, & Woldorff, 2012), providing candidate neural circuitry within which to examine integration of these processes in the context of a cognitive control task.

Taken in sum, our results provide evidence that combined incentive and task-informative cues can interact to enhance preparatory control, leading to improvements in selective attention. Increased control is not observed with either cue alone, and further, timing plays a critical role: our data suggest that both cues must be presented simultaneously for a duration sufficiently long enough for proactive control to emerge. When the incentive cue was presented for a relatively short amount of time prior to target, no control benefit was observed and a speed–accuracy trade-off was observed instead; given emerging evidence that reward can lead to enhancements in reactive control, this tradeoff may be due primarily to time pressure. Additionally, examination of interference versus facilitation effects provides tentative evidence that incentive may promote strategic use of advance informative cues to constrain or relax selective attention, depending on upcoming task demands. Further research investigating variability and flexibility in these behavioral effects as a function of incentive manipulation and task design, as well as their underlying neural mechanisms, is warranted. These results highlight the complexity of motivation-cognition interactions, indicating that proactive effects of incentive on cognitive control may critically depend on interaction with other task factors.

References

Aarts, E., & Roelofs, A. (2011). Attentional control in anterior cingulate cortex based on probabilistic cueing. *Journal of Cognitive Neuroscience, 23,* 716–727. http://dx.doi.org/10.1162/jocn.2010.21435

Aarts, E., Roelofs, A., & van Turennout, M. (2008). Anticipatory activity in anterior cingulate cortex can be independent of conflict and error likelihood. *The Journal of Neuroscience, 28,* 4671–4678. http://dx.doi.org/10.1523/JNEUROSCI.4400-07.2008

Banich, M. T. (2009). Executive function: The search for an integrated account. *Current Directions in Psychological Science, 18,* 89–94. http://dx.doi.org/10.1111/j.1467-8721.2009.01615.x

Beck, S. M., Locke, H. S., Savine, A. C., Jimura, K., & Braver, T. S. (2010). Primary and secondary rewards differentially modulate neural activity dynamics during working memory. *PLoS ONE, 5,* e9251. http://dx.doi.org/10.1371/journal.pone.0009251

Botvinick, M., & Braver, T. (2015). Motivation and cognitive control: From behavior to neural mechanism. *Annual Review of Psychology, 66,* 83–113. http://dx.doi.org/10.1146/annurev-psych-010814-015044

Braem, S., Verguts, T., Roggeman, C., & Notebaert, W. (2012). Reward modulates adaptations to conflict. *Cognition, 125,* 324–332. http://dx.doi.org/10.1016/j.cognition.2012.07.015

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

Braver, T. S., Barch, D. M., & Cohen, J. D. (2002). The role of the prefrontal cortex in normal and disordered cognitive control: A cognitive neuroscience perspective. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp. 428–447). Oxford, United Kingdom: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780195134971.003.0027

Braver, T. S., & Cohen, J. D. (2000). On the control of control: The role of dopamine in regulating prefrontal function and working memory. In S. Monsell & J. Driver (Eds.), *Attention and performance XVIII* (pp. 713–737). Cambridge, MA: MIT Press.

Braver, T. S., Krug, M. K., Chiew, K. S., Kool, W., Westbrook, J. A., Clement, N. J., . . . Somerville, L. H., & the MOMCAI group. (2014). Mechanisms of motivation-cognition interaction: Challenges and opportunities. *Cognitive, Affective & Behavioral Neuroscience, 14,* 443–472. http://dx.doi.org/10.3758/s13415-014-0300-0

Braver, T. S., Paxton, J. L., Locke, H. S., & Barch, D. M. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. *PNAS Proceedings of the National Academy of Sciences of the United States of America, 106,* 7351–7356. http://dx.doi.org/10.1073/pnas.0808187106

Bromberg-Martin, E. S., & Hikosaka, O. (2009). Midbrain dopamine neurons signal preference for advance information about upcoming rewards. *Neuron, 63,* 119–126. http://dx.doi.org/10.1016/j.neuron.2009.06.009

Bruyer, R., & Brysbaert, M. (2011). Combining speed and accuracy in cognitive psychology: Is the inverse efficiency score (IES) a better dependent variable than the mean reaction time (RT) and the percentage of errors (PE)? *Psychologica Belgica, 51,* 5–13. http://dx.doi.org/10.5334/pb-51-1-5

Bugg, J. M., & Smallwood, A. (2014). The next trial will be conflicting! Effects of explicit congruency pre-cues on cognitive control. *Psychological Research*. Advance online publication. http://dx.doi.org/10.1007/s00426-014-0638-5

Chiew, K. S., & Braver, T. S. (2013). Temporal dynamics of motivation-cognitive control interactions revealed by high-resolution pupillometry. *Frontiers in Psychology, 4,* 15. http://dx.doi.org/10.3389/fpsyg.2013.00015

Chiew, K. S., & Braver, T. S. (2014). Dissociable influences of reward motivation and positive emotion on cognitive control. *Cognitive, Affective & Behavioral Neuroscience, 14,* 509–529. http://dx.doi.org/10.3758/s13415-014-0280-0

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112,* 155–159. http://dx.doi.org/10.1037/0033-2909.112.1.155

Correa, A., 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

Czernochowski, D. (2015). ERPs dissociate proactive and reactive control: Evidence from a task-switching paradigm with informative and uninformative cues. *Cognitive, Affective & Behavioral Neuroscience, 15,* 117–131. http://dx.doi.org/10.3758/s13415-014-0302-y

Dambacher, M., Hübner, R., & Schlösser, J. (2011). Monetary incentives in speeded perceptual decision: Effects of penalizing errors versus slow responses. *Frontiers in Psychology, 2,* 248.

Engelmann, J. B., Damaraju, E., Padmala, S., & Pessoa, L. (2009). Combined effects of attention and motivation on visual task performance: Transient and sustained motivational effects. *Frontiers in Human Neuroscience, 3,* 4. http://dx.doi.org/10.3389/neuro.09.004.2009

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16,* 143–149. http://dx.doi.org/10.3758/BF03203267

Heitz, R. P. (2014). The speed-accuracy tradeoff: History, physiology, methodology, and behavior. *Frontiers in Neuroscience, 8,* 150. http://dx.doi.org/10.3389/fnins.2014.00150

Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception & Psychophysics, 57,* 787–795. http://dx.doi.org/10.3758/BF03206794

Horváth, J. (2013). Preparation interval and cue utilization in the prevention of distraction. *Experimental Brain Research, 231,* 179–190. http://dx.doi.org/10.1007/s00221-013-3681-3

Jimura, K., Locke, H. S., & Braver, T. S. (2010). Prefrontal cortex mediation of cognitive enhancement in rewarding motivational contexts. *PNAS Proceedings of the National Academy of Sciences of the United States of America, 107,* 8871–8876. http://dx.doi.org/10.1073/pnas.1002007107

Kahneman, D., & Beatty, J. (1966). Pupil diameter and load on memory. *Science, 154,* 1583–1585. http://dx.doi.org/10.1126/science.154.3756.1583

Karayanidis, F., Coltheart, M., Michie, P. T., & Murphy, K. (2003). Electrophysiological correlates of anticipatory and poststimulus components of task switching. *Psychophysiology, 40,* 329–348. http://dx.doi.org/10.1111/1469-8986.00037

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching—A review. *Psychological Bulletin, 136,* 849–874. http://dx.doi.org/10.1037/a0019842

Krebs, R. M., Boehler, C. N., Appelbaum, L. G., & Woldorff, M. G. (2013). Reward associations reduce behavioral interference by changing the temporal dynamics of conflict processing. *PLoS ONE, 8,* e53894.

Krebs, R. M., Boehler, C. N., Roberts, K. C., Song, A. W., & Woldorff, M. G. (2012). The involvement of the dopaminergic midbrain and cortico-striatal-thalamic circuits in the integration of reward prospect and attentional task demands. *Cerebral Cortex, 22,* 607–615. http://dx.doi.org/10.1093/cercor/bhr134

Krebs, R. M., Boehler, C. N., & Woldorff, M. G. (2010). The influence of reward associations on conflict processing in the Stroop task. *Cognition, 117,* 341–347. http://dx.doi.org/10.1016/j.cognition.2010.08.018

Krebs, R. M., Hopf, J.-M., & Boehler, C. N. (in press). Within-trial effects of stimulus-reward associations. In T. S. Braver (Ed.), *Motivation and cognitive control*. New York, NY: Psychology Press.

Krug, M. K., & Braver, T. S. (2014). Motivation and cognitive control: Going beyond monetary incentives. In E. Bijleveld & H. Aarts (Eds.), *The psychological science of money* (pp. 137–162). New York, NY: Springer. http://dx.doi.org/10.1007/978-1-4939-0959-9_7

Locke, H. S., & Braver, T. S. (2008). Motivational influences on cognitive control: Behavior, brain activation, and individual differences. *Cognitive, Affective & Behavioral Neuroscience, 8,* 99–112. http://dx.doi.org/10.3758/CABN.8.1.99

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. http://dx.doi.org/10.1016/j.neuroimage.2006.11.041

Mall, J. T., Morey, C. C., Wolff, M. J., & Lehnert, F. (2014). Visual selective attention is equally functional for individuals with low and high working memory capacity: Evidence from accuracy and eye movements. *Attention, Perception, & Psychophysics, 76,* 1998–2014. http://dx.doi.org/10.3758/s13414-013-0610-2

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 1423–1442. http://dx.doi.org/10.1037/0278-7393.22.6.1423

Muhle-Karbe, P. S., & Krebs, R. M. (2012). On the influence of reward on action-effect binding. *Frontiers in Psychology, 3,* 450. http://dx.doi.org/10.3389/fpsyg.2012.00450

O'Doherty, J. P., Deichmann, R., Critchley, H. D., & Dolan, R. J. (2002). Neural responses during anticipation of a primary taste reward. *Neuron, 33,* 815–826. http://dx.doi.org/10.1016/S0896-6273(02)00603-7

Padmala, S., & Pessoa, L. (2011). Reward reduces conflict by enhancing attentional control and biasing visual cortical processing. *Journal of Cognitive Neuroscience, 23,* 3419–3432. http://dx.doi.org/10.1162/jocn_a_00011

Pieters, J. P. (1983). Sternberg's additive factor method and underlying psychological processes: Some theoretical considerations. *Psychological Bulletin, 93,* 411–426. http://dx.doi.org/10.1037/0033-2909.93.3.411

Rosell-Negre, P., Bustamante, J. C., Fuentes-Claramonte, P., Costumero, V., Benabarre, S., & Barros-Loscertales, A. (2014). Reward anticipation enhances brain activation during response inhibition. *Cognitive, Affective & Behavioral Neuroscience, 14,* 621–634. http://dx.doi.org/10.3758/s13415-014-0292-9

Schevernels, H., Krebs, R. M., Santens, P., Woldorff, M. G., & Boehler, C. N. (2014). Task preparation processes related to reward prediction precede those related to task-difficulty expectation. *NeuroImage, 84,* 639–647. http://dx.doi.org/10.1016/j.neuroimage.2013.09.039

Schultz, W., Dayan, P., & Montague, P. R. (1997). A neural substrate of prediction and reward. *Science, 275,* 1593–1599. http://dx.doi.org/10.1126/science.275.5306.1593

Small, D. M., Gitelman, D., Simmons, K., Bloise, S. M., Parrish, T., & Mesulam, M. M. (2005). Monetary incentives enhance processing in brain regions mediating top-down control of attention. *Cerebral Cortex, 15,* 1855–1865. http://dx.doi.org/10.1093/cercor/bhi063

Soutschek, A., Stelzel, C., Paschke, L., Walter, H., & Schubert, T. (2015). Dissociable effects of motivation and expectancy on conflict processing: An FMRI study. *Journal of Cognitive Neuroscience, 27,* 409–423. http://dx.doi.org/10.1162/jocn_a_00712

Soutschek, A., Strobach, T., & Schubert, T. (2014). Motivational and cognitive determinants of control during conflict processing. *Cognition and Emotion, 28,* 1076–1089. http://dx.doi.org/10.1080/02699931.2013.870134

Stern, E. R., Wager, T. D., Egner, T., Hirsch, J., & Mangels, J. A. (2007). Preparatory neural activity predicts performance on a conflict task. *Brain Research, 1176,* 92–102. http://dx.doi.org/10.1016/j.brainres.2007.07.060

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica, 30,* 276–315. http://dx.doi.org/10.1016/0001-6918(69)90055-9

Taylor, S. F., Welsh, R. C., Wager, T. D., Phan, K. L., Fitzgerald, K. D., & Gehring, W. J. (2004). A functional neuroimaging study of motivation and executive function. *NeuroImage, 21,* 1045–1054. http://dx.doi.org/10.1016/j.neuroimage.2003.10.032

van den Berg, B., Krebs, R. M., Lorist, M. M., & Woldorff, M. G. (2014). Utilization of reward-prospect enhances preparatory attention and reduces stimulus conflict. *Cognitive, Affective & Behavioral Neuroscience, 14,* 561–577. http://dx.doi.org/10.3758/s13415-014-0281-z

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