THE EFFECT OF PREDICTIVE CUES ON THE FLANKER EFFECT

AND NEGATIVE PRIMING

by

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ABSTRACT

The present study examined peoples' use of predictive environmental cues to exert cognitive control in preparation for early selection of target information. Braver, Gray, and Burgess (2007) suggested two forms of control: reactive, which is stimulus-driven, and proactive, which is preparatory in nature. We hypothesized that participants would engage in proactive control following "hard" cues in preparation for a difficult task. Additionally we expected increased pupil diameter following "hard" cues, a further indicator of increased cognitive control. Participants performed a modified Eriksen flanker task (e.g. ABA) in which they were given the preparatory cues "easy" and "hard," which signaled with 70% validity the probability upcoming flankers would be congruent. In Experiment 1 we found reduced flanker interference following "hard" cues. In addition, we examined negative priming effects (i.e., slower responding when the target on trial N was the distractor on trial N-1, ABA-CAC). As predicted, there was greater negative priming following "hard" cues. These results suggest that the predictive "hard" cue enhances participants' early selection of target information and suppression of distracting information. Experiment 2 included older adults and incorporated eye tracking. Participants showed increased pupil diameter and more gaze variation following "hard" cues, indicating that proactive control was indeed being used. No effects of age were obtained, suggesting that older adults may also be able to utilize cues to increase cognitive control. Finally, Experiment 3 sought to rule out an alternative explanation that the results in Experiment 1 & 2 were due to context specific effects. Experiment 3 found no effects, indicating that previous effects were not the result of automatic associations. Together, these experiments demonstrate that predictive cues can maximize performance on a flanker task.

INTRODUCTION

The ability to retain relevant information and block distractions is vital for successfully navigating life. Within any given day, internal and external factors distract and drive attention away from relevant information, resulting in potential behavioral errors. The ability to respond correctly and rapidly to environmental prompts relies on one's current attentional state. If attentional state is high, responses are typically accurate and fast. In contrast, low attentional state, or not paying attention, results in errors. Cognitive control involves maintaining a task goal, often in the face of distraction, and implementing this goal to create appropriate task responses and behaviors (Kane & Engle, 2003; Norman & Shallice, 1986).

Braver, Gray, and Burgess (2007) suggested that cognitive control can occur through two modes: proactive and reactive control. Proactive control is an effortful top-down process that is engaged before an event and is preparatory in nature. In contrast, reactive control is a bottom-up stimulus cued process that occurs after stimulus onset. Proactive control requires that task-relevant information and goals are actively maintained and kept in working memory. In contrast, reactive control can occur in the absence of goal maintenance and involves an external prompt that serves as a reminder of the task goal. Proactive control is resource demanding as it requires cognitive effort prior to the occurrence of a target stimulus. Reactive control requires little-to-no cognitive resources during the preparatory period. Cognitive control varies between individuals and circumstances. Some individuals have higher working memory capacities than others, which affects how successfully proactive control can be used. Additionally, situational

factors such as hunger or fatigue can effect cognitive control can therefore influence the ability to successfully engage proactive control.

Differences in proactive and reactive control are indexed using a variety of conflict paradigms including Stroop, saccade, and flanker tasks. The Stroop task (Stroop, 1935) presents words, typically color names in various colors and instructs participants to respond to the color in which the word is presented (e.g., the color "blue") and not to read the word (e.g., the word "red"). For congruent stimuli, the color and word name match (e.g., red in the color red); whereas for incongruent stimuli, the word and color mismatch (e.g., red in the color blue). The Stroop effect refers to the tendency to commit more errors and/or have longer reaction times during incongruent trials relative to congruent trials. Word reading is an automatic process. Participants can improve performance on incongruent trials by engaging in proactive control by preparing to suppress word reading and instead focus attention on ink color. When the goal of color naming is not maintained, participants must instead rely on reactive control, which requires that the conflicting responses contained within an incongruent stimulus trigger retrieval of the task goal of color naming. In this case, the more automatic word reading process produces errors, or the task goal is retrieved in time to halt word reading, but the extra time dealing with the conflict leads to slower reaction time (RT; Cohen, Dunbar, & McClelland, 1990; Kane & Engle, 2003).

The saccade task is another measure of cognitive control. In the saccade task participants must maintain the task goal of looking away from a distracting cue, and instead looking in the opposite direction to make a response (Kane, Bleckley, Conway,

Engle, 2001). Looking away from the distracting cue is called an antisaccade. Proactive control can improve performance in an antisaccade task through preparing oneself to suppress the automatic response of looking toward a flashing stimulus.

Similar to the Stroop and saccade tasks, the flanker task requires participants to respond to a stimulus amidst distracting information. Participants are instructed to respond to the middle letter in a stimulus (e.g., BBABB, respond "A"), while ignoring the flanking items. Flanking items can match (e.g., AAAAA, respond "A") or mismatch (e.g., AABAA, respond B) the center target item, creating congruent and incongruent trials respectively. The flanker effect, or flanker interference, is the difference in errors and/or reaction times to congruent and incongruent items. Participants are typically faster and have fewer errors in congruent trials relative to incongruent trials (Eriksen & Eriksen, 1974). Proactive control in the flanker task involves preparing oneself prior to stimulus onset to respond as quickly and accurately as possible to the center letter while suppressing flanker information. When proactive control is successfully engaged the flanker effect should be reduced.

Within the Stroop and flanker tasks, negative priming can serve as a secondary measure of cognitive control. Negative priming can occur when previously distracting information on one trial becomes the target on the next trial. The suppression of distracting information in the first trial (e.g. prime trial) is carried over into the following trial (e.g. probe trial). On ignored repetition trials the current target is a previously ignored item. Unrelated trials do not repeat the previously ignored item. Negative priming is the difference between ignored repetition and unrelated trials. According to

inhibitory accounts of negative priming, if proactive control is executed during the prime trial one should be suppressing the distracting information, which carries over to the probe trial, causing more negative priming (Tipper, 1985; Houghton & Tipper, 1994).

The neural substrates for proactive and reactive control have been demonstrated within Stroop and saccade tasks. Macdonald et al. (2001) found increased prefrontal cortex activity (PFC) following incongruent Stroop items relative to congruent items. This implies that the PFC is vital in executing cognitive control during difficult and distracting tasks. Further, Kerns et al. (2004) identified the anterior cingulate cortex (ACC) as a conflict monitor that posits the need for increased cognitive control. During high conflict Stroop trials, the ACC showed increased activation. In addition, the ACC signals resulted in greater PFC activity prior to the following trial, which indicates a relationship between the ACC and PFC and the engagement of cognitive control. Macdonald et al. (2001) demonstrated that the ACC on trial N led to increased PFC activation on trial N+1. The ACC may modulate the strength of PFC activation, thus influencing the amount of cognitive control exhibited on following trials. An fMRI study by De Pisapia and Braver (2006) provided additional evidence for PFC and ACC involvement on proactive and reactive control, respectively. They found prolonged evidence of PFC activation in mostly incongruent lists and transient ACC activity in mostly congruent lists.

In an event-related fMRI study conducted by Brown, Vilis and Everling (2007), found additional evidence for a relationship between PFC activation and increased cognitive control was found. They reported that during correct antisaccade trials, the

PFC exhibited significant activation just prior to target onset, whereas antisaccade trials with no PFC activation were associated with errors. There was also greater PFC activation associated with faster reactions times. This, in conjunction with previously mentioned studies is evidence of PFC activity enhancing responses through cognitive control.

In summary, proactive control results from sustained PFC activity, and reactive control is directed by activation in the ACC following response conflict. Prolonged PFC activity is vital for maintaining task goals and early selection of correct information over distractions. Conversely, the ACC detects conflict between competing responses and triggers the PFC to retrieve task goals from memory (Braver Gray, & Burgess, 2007; Hutchison, 2011).

Increasing the proportion of congruent items in a list presumably increases the need for attentional control to keep the task goals active. Logan and Zbrodoff (1979) varied congruency across lists with 20% congruent and 80% congruent lists. They found that Stroop interference was smaller in the 80% incongruent lists. Similarly, Kane and Engle (2003) varied item congruency at the list level, with proportion congruency either 0% or 75%. They posited that the goal would be neglected in trials with 75% congruency, whereas increasing the number of congruent trials would make the task more sensitive to goal maintenance. They found that the task goal was maintained more strongly in the 0% congruent condition due to the frequently encountered incongruent stimuli serving as a goal reminder. These and other previous studies that vary item congruency at the list

level assumed differences in proactive control based on overall list composition

(Hutchison, 2001; Kane & Engle, 2003; Logan & Zbrodoff, 1979).

There are problems with the assumption that list based congruency effects reflect

proactive control. This was first demonstrated by Jacoby, Lindsay, and Hessels (2003),

whom manipulated congruency at the item specific level rather than at the list level They

did this by making individual Stroop items either mostly congruent or mostly

incongruent. For example, the word "blue" was congruent 80% of the time, whereas the

word "green" was congruent 20% of the time. Overall, word lists were 50% congruent.

Participants could not rely on expecting congruent or incongruent items because they

could not know which type of item would appear on the next trial. This removes a

confound in list-based manipulations, where mostly congruent/incongruent lists contain

mostly congruent/incongruent items and vice versa. They argued that, rather than using a

global list-wide control, participants are likely responding to individual stimuli or

automatically learning a response. They found the same results as list based

congruencies; mostly incongruent items had smaller Stroop effects than mostly congruent

items. This suggests that list based effects may actually be item specific proportion

congruent effects in disguise. Bugg, Jacoby and Toth (2008) later demonstrated that this

confound was most likely the case. When congruency was manipulated at the item level

they found the same results as list wide effects. These item specific effects cannot be the

result of a central, global proactive mechanism because participants do not know the

congruency prior to stimulus onset. However, it is possible that item specific control is an

automatic process. Jacoby and colleagues (2003) identified the possibility of stimulus

response contingency learning, in which participants learn a response associated with a target, as well as a more general reactive control mechanism in which particular stimuli cue the need to direct attention towards or away from word reading.

Hutchison (2011) unconfounded list-based and item-based effects in the Stroop task by orthogonally manipulating item-specific proportion congruence and list–wide proportion congruence. He found effects of both list wide and item specific effects, demonstrating that list-based effects can also reflect top-down control and are not always item-based effects in disguise, supporting the idea that multiple forms of cognitive control interact in conflict tasks.

Unconfounding item and list based effects still does not control for possible sequential effects. Sequential effects occur when responses on a trial are affected by the previous trial. If a previous item was congruent, RTs to following congruent items will be faster. Similarly, when the previous item was incongruent, RTs to the following incongruent stimulus is also faster. This sequential effect produces a benefit for repeated stimuli, but a cost when reversed and results in reduced conflict effects, like the Stroop or flanker effects, following incongruent trials (Gratton, Coles, & Donchin 1992).

Item-based effects and sequential effects could both give the illusion of cognitive control in mostly incongruent lists. To solve these problems, cueing procedures can be used to flexibly direct proactive control on a trial-by-trial basis while keeping list-wide congruency constant. When an item is cued to be incongruent, participants can engage in proactive control to suppress the potentially conflicting stimuli, therefore increasing accuracy and decreasing reaction time. However, when told an item will be congruent,

participants can relax proactive control and conserve cognitive energy on the following trial.

Posner, Snyder, & Davidson (1980) showed enhanced performance when participants were provided with specific location cues on a trial-by-trial basis. When the cue matched the target, participants were significantly faster when correctly cued to stimulus location than when incorrectly cued. They determined that knowing where to expect a stimulus allowed participants to direct attention, allowing faster and more accurate responses. Logan and Zbrodoff (1982) also demonstrated the benefit of cueing in a spatial Stroop task, using the cues "X" or "O" to indicate whether the following trial would be matching or mismatching, respectively, in addition to a neutral non-informative cue. Reaction times were significantly faster for the cued conditions relative to the neutral condition. Because there were only two response options, they concluded that participants were using an attention switching strategy, producing responses opposite of the distracting stimulus when given the mismatching cue.

Gratton, Coles, & Donchin (1992, Experiment 3) proposed that participants should be able to change strategy rapidly on the basis of top down, context driven mechanisms. To test this concept, they manipulated the probabilities of compatibility on a trial-by-trial basis while cueing whether the upcoming stimulus would likely be congruent or incongruent. They hypothesized that, given enough time, participants should be able to adjust their response strategies according to the cue and respond appropriately. They showed that participants were able to use cue to their benefit and improve performance. Reaction times were faster following valid cues. They argued that this

favors a top-down approach, and that participant responses can be influenced by expectancy of congruent or incongruent stimuli.

Despite the evidence that these studies provide for the use of cued proactive control, they only offered two response options. In this case, participants may attend to distracting information and simply learn to give responses s=consistent with or opposite from those distractors, depending on cue. Bugg, Smallwood, and Lim (in press) addressed this problem by cuing participants in a 4-option Stroop task whether the upcoming trial would be matching or conflicting, or they were given a non-informative cue. Reaction times were faster following the informative cue for congruent and incongruent items. However, this does not necessarily differentiate between the use of proactive and reactive control because the cues were 100% valid. Participants were likely using proactive control when given the conflicting cue; however, following the matching cue, it is impossible to know whether they were simply relaxing control or instead intentionally reverting to word reading. Thus, 100% valid cues are apt at determining the use of proactive control for incongruent trials, but are uninformative in relation to reactive control.

To address this problem, cue validity can be manipulated. Manipulating cue validity helps determine the use of proactive and reactive control by looking at trials where the cue is not valid. By indicating if a trial likely is "easy" or "hard", and decreasing validity to below 100%, differences between valid cues and invalid cues can be examined. Presumably, proactive control should be engaged following "hard" cues and reactive control should be used following "easy" cues. Evidence for reactive control

should manifest following an invalid easy cue. Reaction times to incongruent stimuli should be significantly longer following invalid "easy" cues because relaxed proactive control leads to greater competition from distracting information and late selection of the appropriate color response (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver et al, 2007).

The primary objective of the current study was to determine if the use of predictive cues could direct engagement in proactive or reactive control. To accomplish this, participants in Experiment 1 completed a flanker task proceeded by cues that indicated the difficulty of the upcoming task at less than 100% validity. In Experiment 2, eye tracking was incorporated as a secondary measure of cognitive control. Additionally, older adults were recruited to assess the effect of cues on cognitive control in an older population and examine potential differences between young and old populations. Finally, Experiment 3 examined the possibility that our cueing effect is due instead to unconscious learning of the relation between cues and upcoming congruency.

EXPERIMENT 1

In Experiment 1, participants completed four blocks of flanker task trials. The difficulty of each trial was cued, with 70% accuracy, using the cues "easy" or "hard". Two primary patterns were predicted. Flanker interference was predicted to decrease following "hard" cues compared to "easy" cues. Specifically, proactive control should be engaged following "hard" cues leading to early selection and reduced flanker interference. In addition, early suppression of distractors following "hard" cues should lead to increased negative priming on the following trial. These hypotheses are supported by previously discussed findings that indicate increased cognitive control when expecting difficult tasks.

Method

Participants and Design

Seventy-six male and female participants between the ages of 18 and 35 years were recruited from an introductory psychology course to participate for course credit. Participants were tested individually in a laboratory setting for one hour. Cue ("easy" vs. "hard") and condition (congruent vs. incongruent) were varied within subjects. The primary dependent variables were RT and error rates during the flanker task.

Apparatus and Stimuli

Dell Optiplex Gx270 computers, with Intel Pentium 4 2.40 GHz processing unit with 1.5 GB of RAM, were used to collect experiment data. The flanker task was

programmed using E-Prime E-Studio software (version 2.0). Stimuli were presented on a

16-inch Dell monitor, with 1024 x 786 resolution. All text was presented on a black

background in white Courier New, 24 point font.

Procedure

Before beginning the experiment, participants read and signed a consent form

explaining potential risks and benefits of the experiment. Participants were seated at a

computer and given instructions for how to complete the flanker task. Instructions

indicated key response assignments and defined the predictive cues and their accuracy,

which was 70%. Participants were also informed that "hard" cues were worth 10 points,

and "easy" cues were worth 1 point. Points were incorporated to strengthen the use of

cues, because pilot studies indicated that participants reported not using cues.

Participants were told to respond as quickly and accurately as possible to a letter triplet

that was either congruent (e.g., AAA) or incongruent (e.g., ABA). Letter triplets

consisted of the letters A, B, C, and D. Participants were told to respond to the center

letter. Key responses were assigned to the A, C, N, and L keys; these keys represented the

responses A, B, C, and D respectively. At the start of the experiment participants were

given 15 trials to learn the key response assignment. Following key assignment practice,

participants were given 20 practice flanker trials.

Trials progressed in a fixed random order, with 50% overall cue and item

congruency. At the start of each trial, participants were given a cue, either "easy" or

"hard" for 600 milliseconds, followed by a 1500 millisecond fixation (+). Following

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fixation, the target flanker item was presented for 1200 milliseconds or a response was made.

There were 240 total trials. Of those trials, 72 were critical congruent trials (36 "easy", 36 "hard") and 72 were critical incongruent trials; (36 "easy", 36 "hard"). To reinforce cue validity, the remaining 96 trials were filler items, in which the congruency matched the cue. Included in the filler trials were 24 negative priming trials (12 ignored repetition trials, 12 unrelated trials). These trials were always incongruent and were proceeded by a "hard" cue. A rest break was provided approximately every 70 trials. Each rest break informed participants of total points earned. Upon completion of the flanker task, participants were debriefed and given course credit.

<div align="center">Results</div>

Flanker Interference

Seven participants with more than 20% overall errors were excluded from analyses, resulting in 69 total participants. A 2 (Cue) x 2 (Condition) repeated-measures ANOVA was performed, with Cue and Condition as between-subjects factors. All results reported as significant are associated with a $p < .05$. These data are shown in Table 1. In RTs, there was no main effect of Cue, $F(1,68)=.326$, MSE=296, $\eta_p^2 = .005$. There was a main effect of Condition, [$F(1,68)=668.592$, MSE= 515, $\eta_p^2 = .908$], such that RTs increased during incongruent trials. Most importantly, as predicted, there was an interaction between Cue and Condition [$F(1,68)=10.87$, MSE=33, $\eta_p^2 = .138$], such that there were increased flanker effects following "easy" cues. In terms of errors, the data

mimicked the RT data. There was no effect of Cue (F(1,68)=.513, MSE= 20, η^2_p = .007).

There was a main effect of Condition [F(1,68)=27.998, MSE= 20, η^2_p = .292],

participants committed more errors following "hard" cues. As with RTs, the predicted

Cue x Condition interaction was significant, such that the flanker effect was reduced

following "hard" cues F(1,68)=4.824, MSE= 10, η^2_p = .066.

Negative Priming

Negative priming was analyzed using a repeated-measures ANOVA, with

Previous Cue and Negative Prime Conditions as within-subjects factors. Analyses

revealed no significant main effect of Previous Cue, (F(1,68)=.417, MSE= 890, η^2_p =

.006). There was a significant main effect of Condition, (F(1,68)=24.55, MSE= 908, η^2_p

= .265), indicating negative priming such that responses were slower following ignored

repetition trials. Finally, as predicted, there was numerically more negative priming

following "hard" cues. Moreover, negative priming was significant following the "hard"

cue (p=.000) but not following "easy" cues (p=.06). However, the interaction between

Cue x Negative Priming failed to reach significance F(1,68)=2.249, MSE=1149, η^2_p =

.032). There were no significant effects in the error data (all F's <1.1 and η^2_p <.02)

Table 1: Mean RT and error rates following "easy" and "hard" cues in
Experiment 1 as a function of condition

| | Cue | | | |
| | "Easy" | | "Hard" | |
Condition	RT (ms)	Errors (%)	RT (ms)	Errors (%)
Incongruent	646	8.0	637	6.7
Congruent	568	4.4	574	5.0
Flanker Effect	*78**	*3.6**	*63**	*1.7**
Ignored Repetition	644	7.1	652	8.3
Unrelated	632	7.6	628	8.3
Negative Priming	*12*	*0.4*	*24**	*0*

Note: * = $p < .05$, two-tailed.

Discussion

The finding that flanker interference decreased following "hard" cues supports the hypothesis that proactive control increases following "hard" cues. Participants showed increased RTs following invalid "easy" cues, suggesting that proactive control was relaxed and instead reactive control was engaged following target presentation. If proactive control had instead been used in all trials, there should be no difference between "easy" incongruent and "hard" incongruent trials. This suggests that providing a predictive cue of upcoming conflict can improve performance on a flanker task when expecting conflict. Additionally, it supports the notion that proactive and reactive control can be manipulated on a trial-to-trial basis.

The trend towards increased negative priming following hard cues, although not significant, further supports the prediction that proactive control is engaged following hard cues. It was expected that by adding more participants in Experiment 2, the

Condition x Cue interaction would become significant and further validate the use of

proactive control following "hard" cues.

EXPERIMENT 2

Experiment 2 sought to replicate Experiment 1 and incorporated both eye tracking and included older adults in addition to young adults. Pupil diameter is a physiological response associated with increased cognitive load and effort (Beatty, 1982 a,b). Pupillometry has been increasingly used to index cognitive control in relation to development, decision-making, motivation, and incentive. Chiew and Braver (2013) used a cuing paradigm in conjunction with incentive and observed increased pupil dilation during incentive trials, which suggests trial-by-trial variations in attentional control. It is hypothesized that our cuing paradigm will show similar results. Pupil dilation should increase following "hard" cues in preparation for a more demanding and effortful task.

There is evidence that adults experience varying degrees of cognitive impairments with age (Balota, Dolan, & Duchek, 2000). Specifically, tasks involving executive functions that originate from the frontal lobe are typically impaired. Frontal lobe impairments can result in slower processing, reductions in inhibitory control, and deficits in attention and memory (Castel, Balota, Hutchison, Logan, Yap, 2007). Given these age related declines, it is reasonable to predict that older adults could possibly benefit from a cueing procedure. As adults age task reminders can increase functionality and performance on tasks. The use of focal cues can increase performance and are less demanding of attentional resources (Rose, Rendell, McDaniel, Aberle, & Kliegel, 2010). Cues could function as external support, which is more beneficial for older adults (Craik, et al., 2007). On the other hand, the opposite could be true. Given reduced attentional capacity, it may be too difficult for older adults to attend to cues and respond to stimuli.

Given the lack of cued attentional control research in older adults, either outcome could

be plausible. However, it is expected that older adults will use the cues and they will

show a cueing benefit similar to younger adults.

General predictions were the same as Experiment 1; Flanker interference should

decrease following "hard" cues compared to "easy" cues. Negative priming should

increase following "hard" cues compared to "easy" cues. In addition, pupil diameter

should increase following "hard" cues relative to "easy" cues. In terms of age related

differences, older adults should have overall slower reaction times than young adults.

Similar to that of young adults in Experiment 1, older adults will also show a benefit of

cue.

Method

Participants and Design

Seventy-five participants were recruited from the introductory psychology subject

pool to participate for course credit. Younger participants were between the ages of 18-

25. Forty-five older participants were recruited from a local newspaper advertisement.

Older adult participants were ages 55 and older (M=66.7). Participants were tested

individually in a laboratory setting for one hour.

Apparatus and Stimuli

A Panasonic CF-50 ToughBook laptop, with a Mobile Intel Pentium 4-M 2.00

GHz processor, 768 MB of RAM, and an AT Mobility Radeon 7500 Display Adapter

was used. Stimuli were presented on a 17-inch NEC Multisync LCD 1760v monitor, with a 60 Hz refresh rate, attached to the laptop via an RS232 USB serial port.

Procedure

The procedure was the same as Experiment 1, with the addition of two educational and mental batteries. After giving consent, participants were first given the Shipley vocabulary test and the Mini Mental State Exam. The Shipley vocabulary test was used to ensure that all participants had similar literacy levels (Shipley, 1940). The mini mental state exam was given to ensure that no participants showed any signs of dementia. Participants then completed the flanker task.

Trials progressed the same as Experiment 1 for young adults. For older adults, cues were presented for 900 milliseconds, followed by a 1500 ms fixation (the symbol "+"). Following fixation, the target flanker item was presented for 1800 ms or a response was made. The increased cue and target duration were used to control for age related slowing (Salthouse, 1976). Pupil dilation and gaze location were measured during the 1500 ms fixation between the cue and flanker stimulus.

Results

There was no difference in scores on the MMSE [$t(112)=-1.316$, $p=.191$] between young ($M=29.03$, $SD=1.02$) and older adults ($M=29.25$, $SD=.67$) Additionally, there was a marginally significant difference between Shipley scores, [$t(115)=-1.864$, $p=.065$], such that older adults ($M=29.66$, $SD=2.92$) had better vocabulary cores than young adults

(*M*=28.62, *SD*=2.93). This indicates that none of our older participants were showing age-related cognitive impairments at testing.

Flanker Interference

Five participants were excluded for more than 20% total errors. This resulted in 101 total participants, 70 young adults and 47 older adults. A 2 (Cue) x 2 (Condition) x 2 (Age) mixed model ANOVA was performed, with Cue and Condition as within-subjects factors and Age as a between-subjects factor. There was a significant main effect of Cue [F(1,115)=5.70, MSE= 105, η_p^2 = .047], such that reaction times were faster following "hard" cues. There was also a main effect of Condition [F(1,115)=769.05 MSE=.849., η_p^2 = .870], RTs increased for incongruent trials. Additionally, there was a significant main effect of Age [F(1,115)=123.97, MSE=3777 η_p^2 = .519], such that older participants had slower reaction times. No other effects were significant (all *F's* <1.4, all *p's* >.42).

For errors, there was a significant main effect of condition on error rate [F(1,115)=.27.091, MSE=20, η_p^2 = .191], such that participants committed more errors following "hard" cues. There was a marginal effect of age [F(1,115)=3.17, MSE=20, η_p^2 = .027], such that young adults committed slightly more errors than young adults. There was a marginal Condition x Age interaction [F(1,115)=3.54, MSE=60 , η_p^2 = .030], such that the flanker effect was marginally greater for older adults compared to young adults (All *F's* <1.4, all *p's* >.21).

Negative Priming

Negative priming was analyzed using a mixed model ANOVA, with previous Cue and Condition as within-subjects factors and age as a between subjects factor. Analyses revealed a significant main effect of Previous Cue, [$F(1,115)=11.827$, MSE= 1018.090, $\eta_p^2 = .093$]. There was a significant main effect of Condition, [$F(1,115)=27.555$, MSE= 1038.343, $\eta_p^2 = .193$] with slower RTs on ignored repetition trials, which indicates negative priming. There was also a significant main effect of Age [$F(1,115)=112.569$, MSE= 4624.448, $\eta_p^2 = .495$], such that older adults had longer RT. As was found in Experiment 1, there was numerically more negative priming following "hard" cues (*M*=26) than following easy cues (*M*=12). For older adults only, the negative priming effect was significant following "hard" cues [t(46)=3.381, *p*=.001], but not following "easy" cues [t(46)=1.544, *p*=.129]. However, the Previous Cue and Condition interaction was not significant $F(1,115)=1.70$, MSE= 1153, $\eta_p^2 = .015$. No other RT differences were significant. There were no significant effects in error rates (all *F's* <1.4, all *p's* >.172).

Table 2: Mean reaction times and errors as a function of cue and age

| | Cue | | | |
| | "Easy" | | "Hard" | |
	RT (ms)	Errors (%)	RT (ms)	Errors (%)
Old Adults				
(N = 47)				
Incongruent	786	3.4	790	4.1
Congruent	707	1.9	714	3.0
Flanker Effect	*79**	*1.5**	*76**	*1.1*
Ignored Repetition	791	7.5	813	9.7
Unrelated	780	7.8	786	9.8
Negative Priming	*11*	*-0.3*	*26**	*-0.1*
Young Adults				
(N = 70)				
Incongruent	656	5.2	659	6.4
Congruent	581	2.9	585	3.1
Flanker Effect	*75**	*3.7**	*73**	*3.3**
Ignored Repetition	658	6.6	667	7.5
Unrelated	646	5.3	653	5.0
Negative Priming	*12**	*1.3*	*14**	*2.5**

Note: * = $p < .05$, two-tailed.

Pupil Dilation

A 2 (Cue) x 2 (Age) repeated measures ANOVA was performed to analyze differences in pupil dilation following "easy" and "hard" cues. As predicted, there was a significant effect of cue, [$F(1,96)=13.73$, MSE= 10, $\eta_p^2 = .117$], such that pupil dilation increased following "hard" cues relative to "easy" cues. There was also a main effect of age, [$F(1,96)=77.97$, MSE= 319, $\eta_p^2 = .428$], such that older adults had overall smaller pupil dilation compared to young adults. There was no significant interaction between

cue and age [$F(1,96)$=.495, MSE= 10, η_p^2 = .005], indicating that there was no difference

between young and old adults in the effect of cue on pupil diameter.

Table 3: Mean Pupil Diameter as a function of cue and age

	Cue	
	"Easy"	"Hard"
	Diameter (mm)	
Old Adults **(N = 36)**	3.99	4.01
Young Adults **(N = 62)**	5.16	5.18

Pupil Dilation and Accuracy

Ninety-six participants were included in the pupil dilation analysis; participants

missing pupil dilation data were not used, resulting in 55 young adults and 40 old adults.

A 2 (Cue) x 2 (Accuracy) x (Age) repeated measures ANOVA was performed to analyze

differences in pupil dilation during accurate and inaccurate trials. These data are shown in

Table 4. As in the previous analysis, there was a significant main effect of cue,

[$F(1,93)$=4.299, MSE= 97, η_p^2 = .044], such that pupil dilation was larger following

"hard" cues. There was also a significant main effect of Age, [$F(1,93)$=68.644, MSE=

30.519, η_p^2 = .425]. Additionally, there was a marginal main effect of Accuracy

[$F(1,93)$=3.584, MSE= 25, η_p^2 = .037], such that pupil dilation was larger for accurate

trials. No other comparisons were significant (all F's <3.0, all p's >.08).

Table 4: Pupil Dilation and Accuracy

	Cue	
	"Easy"	"Hard"
Old Adults **(N = 40)**		
Accurate	3.957	4.033
Inaccurate	4.025	4.051
Young Adults **(N = 55)**		
Accurate	5.171	5.195
Inaccurate	5.144	5.148

Note: * = $p < .05$, two-tailed.

Pupil Time Course

In addition to analyzing overall pupil dilation, we sought to determine the time course of pupil diameter change across the 2 second fixation period between cue presentation and target onset. Seventy-four participants were included in this analysis. Thirty-seven young adults and 6 old adults were excluded from analysis due to missing or incomplete data. A 6 (Bin) x 2 (Cue) x 2 (Age) mixed model ANOVA was conducted to determine if there was a difference across bins within the 2 second fixation period. In addition to replicating the overall effects of Cue [$F(1,72) = 15.80$, $MSE = 145$, $\eta_p^2 = .180$], and Age, [$F(1,72) = 21.99$, $MSE = 9.86$, $\eta_p^2 = .233$], there was a main effect of Bin ($F(1,72) = 12.81$, $MSE = 403$, $\eta_p^2 = .151$], such that pupil dilation increased across Bins. There was also a significant interaction between Bin and Age [$F(1,72) = 7.42$, $MSE = 252$, $\eta_p^2 = .100$], such that young adults pupil diameter increased across bins whereas older adults did not. There was also a significant Cue x Bin

interaction, [$F(1,72) = 4.541$, *MSE* =240, $\eta_p^2 = .059$], such that "easy" cues showed more pupil increase across bins. No other effects were significant (all *F's* <1.4, all *p's* >.85).

Figure 1. Older adult time course of pupil dilation as a function of cue.
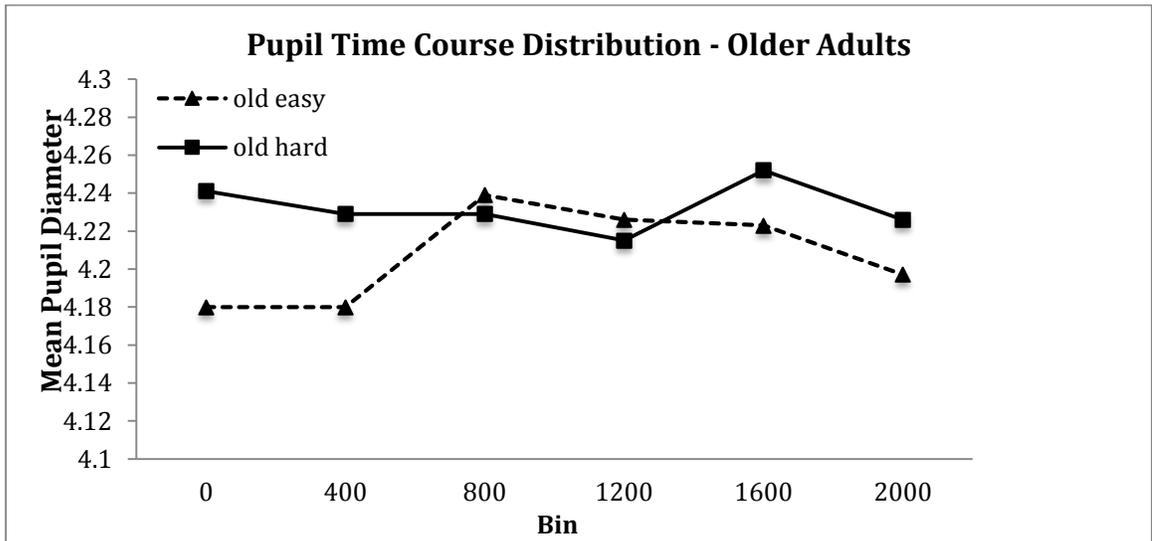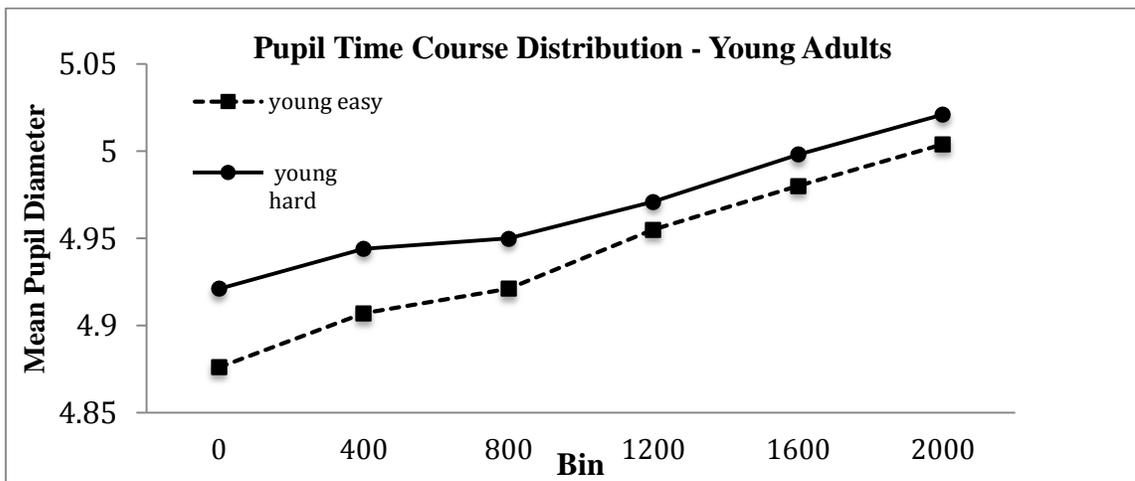

Figure 2. Young adult time course of pupil dilation as a function of cue.

<u>Gaze Variation</u>

Gaze variation was calculated by using the standard deviation of eye movement along the X-axis of the computer screen. This analysis was done using the left eye only, as right and left eye movements are highly correlated. Gaze variation was calculated separately for "easy" and "hard" cues. Forty-nine participants were included in the gaze fixation analysis, participants missing fixation data, 27 young adults and 2 old adults, were not included. A 2 (Cue) x 2 (Age) repeated measures ANOVA was performed to analyze differences in gaze fixation following "easy" and "hard" cues. The trend indicated that there was more gaze variation following "easy" cues compared to "hard," however this difference did not reach significance ($F(1,47)$=1.642, MSE= 18204., η_p^2 = .034, p=.20).

There was a main effect of age, [$F(1,47)$=15.827, MSE= 9102, η_p^2 = .252], such that older adults had less gaze variation compared to young adults. There was no interaction between cue and age, (F<1).

Table 5: Mean Gaze Variation as a function of cue and age in Experiment 2

	Cue	
	"Easy"	"Hard"
	Diameter (mm)	
Old Adults (N = 36)	79.27	77.4
Young Adults (N = 62)	187.93	186.77

Discussion

The results of Experiment 2 did not fully replicate the previous findings of Experiment 1. Most importantly, we did not find a significant interaction between Cue and Condition. The reason for this is unclear. One possibility is that participants failed to utilize cues, or were not paying attention to cues. Additionally, the flanker task may not be the best measure of cognitive control. Tipper (1985) suggests that negative priming may be a better measure of cognitive control, which may explain why there was significantly more negative priming only following hard cues, As predicted, there was a significant increase in pupil diameter following hard cues. This serves as a manipulation check and indicates that participants were indeed using cues and preparing for the upcoming trial. However, this physiological difference did not translate to less flanker interference in RTs or errors following hard cues. Additionally, there was a marginal effect of accuracy, such that pupil diameter was larger for accurate trials. As with the main effect of cue, this validates the pupil dilation measure as reflecting cognitive effort. Specifically, when participants were more focused and exuding more proactive control they responded more correctly.

In addition to the difference in pupil diameter between "easy" and "hard" cues, gaze fixation indicates how focused participants were on the task. Further, older adults had less errors overall, which may indicate better, or increased, effort compared to young adults. Additionally, older adults showed less variation in gaze fixation compared to younger adults. This indicates that older adults are more focused on the target location, and their eyes wandered less than young adults. The effect of cue was trending in the

direction of less gaze variation following "hard" cues, indicating that overall, participants may be focusing the spotlight of attention more on target stimuli following "hard" cues than following "easy" cues. We speculate that if our sample size was larger for gaze variation, this effect may have reach significance.

The time course analysis revealed that young adults have a linear increase in pupil diameter across the 2000 ms fixation point. This occurred following both "easy" and "hard" cues, indicating that even following "easy" cues they were preparing to respond. Older adults show a quadratic effect, such that pupil dilation increased initially the tapered at the end of the fixation period. The reason for this pattern in older adults is unclear. It is possible that they attempted to use the cues early in fixation but were unable to maintain attentional vigilance throughout fixation.

Older adults had overall slower reaction times compared to young adults. This is not surprising, as older adults typically show age related slowing which manifests in RT (Castel, Balota, Hutchison, Logan, Yap, 2007). However, given the trend towards more negative priming and less flanker interference following "hard" cues, we can speculate that older adults do benefit, at least slightly, from predictive cues.

EXPERIMENT 3

In Experiment 3, predictive cues were changed to non-words to test whether increased performance following "hard" cues is simply a result of stimulus response learning. Crump et al. (2006) found that contextual elements could automatically modulate interference in a conflict task. The context specific proportion congruent (CSPC) effect reflects learning an association between contextual cues and item congruency. Crump et al. demonstrated this by presenting Stroop items in one of two locations, that varied in proportion congruency. For instance, items presented above fixation were likely to be congruent, whereas items presented below fixation were likely incongruent. They indeed found the CSPC effect such that Stroop interference was reduced when stimuli were presented in the mostly incongruent location. They argued that this CSPC effect occurs automatically, rather than a controlled level, such that contextual cues signaled the need to suppress irrelevant information.

Contrary to the present cueing paradigm, Crump et al. (2006) presented context and Stroop stimuli simultaneously. In the following paradigm, the context (cue) was presented temporally, removed from the stimulus. Thus, it is less likely participants would learn to automatically associate cues with likely conflict. There is still a chance that temporally removed contextual cues could still cause a contextual, automatic process to occur. Therefore, Experiment 3 sought to examine the possibility that the previous Cue x Condition interaction observed in Experiment 1 was a product of context specific proportion congruent learning. It was predicted that there would not be a learned

association between cue and congruency. Traditional flanker interference and negative

priming effects are expected; however there should be no interaction with cue type.

Method

Apparatus and Stimuli

The same computers, software and specifications used in Experiment 1 were used

in Experiment 3. Flanker and negative prime stimuli remained the same, but "easy" and

"hard" cues were replaced with non-words "haun" and "brab" respectively. These words

were matched to "easy" and "hard" in bigram frequency and orthographic neighborhood

to control for any sublexical effects on attentional preparation.

Procedure

The procedure was similar to Experiment 1 with minor changes. Cues were

changed to non-words and points were removed. Despite the fact that stimuli following

"haun" and "brab" were 70% congruent or incongruent respectively, participants were

not informed of the validity or relationship between cue and item congruency in the

instructions. Participants were simply instructed that the non-words would signal the start

of the next trial.

Results

Flanker Interference

Similar to Experiments 1 and 2, participants with more than 20% errors were

excluded from analyses. Seventeen participants were excluded for more than 20% errors

on critical trials. This resulted in 50 participants. A 2(Cue) x 2 (Condition) repeated

measures ANOVA was performed, with cue and flanker condition as within-subjects

factors. There was a main effect of Condition [$F(1,49)$=312.42, MSE=557, η_p^2 = .864],

such that RT increased for incongruent trials. No other effects were significant (all F's

<2.36, all $p's$>.134). Error data mimicked RT data, there was a main effect of Condition,

[$F(1,49)$=22.275, MSE=20.00, η_p^2 = .313], such that participants had more errors

following incongruent flanker items. No other differences were significant (all F's <1.13,

all $p's$>.20).

Negative Priming

Negative priming was also analyzed using repeated measures ANOVA, with

Previous Cue and Condition as within-subjects factors. Analyses revealed a significant

main effect of Previous Cue, [$F(1,49)$=19.34, MSE=1161, η_p^2 = .283]. Participants were

faster following the non-word "haun," which replaced the "easy" cue. There was a

significant main effect of Condition, [$F(1,49)$=4.94, MSE=1523, η_p^2 = .092]. There was

not a significant interaction between Previous Cue and Condition. In terms of errors,

there was a main effect of Condition, [$F(1,49)$=4.17, MSE=23, η_p^2 = .032], such that

participants had more errors following unrelated stimuli.

Table 6: Mean RT and error rates following "haun" and "brab" cues

| | Cueing | | | |
| | "haun" | | "brab" | |
	RT (ms)	Errors (%)	RT (ms)	Errors (%)
Incongruent	667	6.9	667	7.6
Congruent	605	10.7	612	10.2
Flanker Effect	*62**	*3.8**	*55**	*2.6*
Ignored Repetition	673	9.8	684	12.8
Unrelated	651	15.5	682	15.7
Negative Priming	*22**	*-5.3**	*2*	*-3.1*

Note: * = *p* < .05, two-tailed.

Discussion

There was no interaction between Cue and Condition, confirming our prediction that stimulus context specific learning was not the cause of our previous effects. Had this been the case, our results would have replicated the Cue x Condition interaction, with more flanker interference following the "haun" ("easy") cue. This would have meant the cues functioned as context, automatically triggering attention toward or away from distractors; however, this does not seem to be the case. Since there was no interaction between cue and condition, the results from Experiment 1 are indeed likely to be a result of intentionally engaged proactive control. Moreover, the negative priming results were opposite to those in Experiments 1 and 2, suggesting that earlier findings of significant negative priming following "hard" cues was not due to automatic context specific learning.

GENERAL DISCUSSION

The results from Experiment 1 indicate that performance can be influenced by trial-to-trial variations in attentional control. Decreased flanker interference and increased negative priming following "hard" cues supports the notion that proactive control is engaged when difficulty is expected. Further, increased pupil dilation following "hard" cues in Experiment 2 validates the use of cues and supports that cognitive effort increases when expecting conflict or difficulty.

Experiment 2 failed to replicate the Cue x Congruency interaction in Experiment 1. The reasons for this are unclear. The only procedural difference between the two experiments was the addition of the eye tracker and incorporating a group of older adults. The failure to replicate is not likely due to the addition of older adults, as there was no 3-way interaction with age.

Experiment 3 helped to rule out the alternative explanation to Experiment 1 that context specific proportion congruent learning is occurring. Experiment 3 tested the possibility that the effects in Experiment 1 were due to context specific learning. Our results suggest that this is not the case.

A cue predicting difficulty optimizes anticipation for the following event, increasing top-down control. In saccade tasks, when participants are expecting to perform an antisaccade, increased frontopareital activation results from increased preparation (Brown, Vilis & Everling, 2007). The "hard" cue in the present study acts in a similar way as an antisaccade cue, by signaling participants that increased cognitive control is needed in the upcoming trial.

The interaction observed between Condition and Cue in Experiment 1 highlights the effect of pretrial attentional state. When presented with an "easy" cue, participants relax attentional control, resulting in increased reaction time on incongruent trials. Increased pupil diameter in Experiment 2 after "hard" cues, but not "easy" cues, supports the hypothesis that pretrial attentional states influence performance. When participants expected the following stimuli to be "hard," they were able to engage in early selection of targets and suppression of distractors. Bochove, Haegen, Notebaert, and Verguts (2012) supports this claim. They sought to support the notion that neuromodulation explains trial-by-trial fluctuations in cognitive control. By examining eye blinks and pupil dilation, which are associated with neuromodulators like dopamine and norepinephrine, respectively. They found that pupil dilation and blink rate predicted enhanced cognitive control in a similar flanker task, which suggests a phasic influence of dopamine. This helps explain trial-to-trial adaptations in cognitive control in response to conflict. Their adaptation-by-binding model suggests that response conflict caused by incongruent flankers increases binding between task demand representations, the target stimulus, and the response. This further explains previous findings that ACC activation on one trial (indicating reactive control) triggers increased PFC activation (indicative of proactive control) prior to the following trial.

An alternative explanation for increased pupil diameter during "hard" trials is incentive. If participants are associating "hard," 10-point cues with an incentive, pupil diameter may be increasing simply in response to this reward incentive. Heitz, Schrock, Payne, and Engle (2007) found that when money was an incentive, pupil diameter

increased for both high and low span participants. However, the interpretation was that incentive increased effort, that in turn was reflected in larger pupil dilation and improved performance. Nonetheless, it is possible that higher reward cues increase pupil dilation automatically, independent of effort. A way to circumvent this problem would be to include a trial that presents the point value after the stimulus. If pupil diameter increases after late presentation of points, the response is thought to be in response to reward, not attentional control. However, it is not expected that pupil diameter would increase in the late presentation condition, because it is believed to be a genuine measure of proactive cognitive control in this paradigm. It is hypothesized that pupil diameter will only increase as a result of increased cognitive control, in preparation for a difficult task. The accuracy and pupil dilation effects argue against this alternate explanation, since pupils were more dilated following accurate trials versus inaccurate trials. If participants were responding to incentive pupil would be similarly dilated for accurate and inaccurate trials.

One important consideration is effect size. Overall, we had small effect sizes in all experiments. In Experiment 1, the partial eta squared for the Cue x Condition interaction was only .138. This small effect size may indicate that the flanker task is not a sensitive paradigm for cognitive control. To increase the amount of conflict in flanker trials different stimuli can be used. Increasing the number of flankers (e.g. AAABAAA) or using arrows (e.g. →→←→→) may increase the amount of interference and conflict during incongruent flanker stimuli. However, using arrows presents issues similar to those discussed previously in experiments by Logan and Zbrodoff (1979) where there were only two response options and participants simply learned to respond opposite of

the stimuli. Further, the time course of pupil dilation (table 4) indicates that differences between "easy" and "hard" cues occur prior to 1200 ms. This indicates the possibility that a 2000 ms fixation period between cue and stimulus onset is too long, and possibly removing the effects of cues. In the future, fixation can be shortened to determine if this is the case.

Future directions include the possibility of using ERP and/or fMRI techniques to identify the underlying physiological mechanisms. In the saccade task, preparation resulted in increased frontoparietal activation. The same pattern of activation would be expected for "hard" trials, but not "easy" trials (Brown, et al. 2007). Increased prefrontal PFC activation would also be also expected for "hard" trials relative to "easy" trials (Miller & Cohen, 2001). Increased activation of both the PFC and frontoparietal regions indicates increased attentional control. If the "hard" cue truly results in increased cognitive control, we should see activation in both regions. Comparatively, when an incongruent trial is preceded by an "easy" cue, ACC activation should occur in response to conflict. Then, in the following trial, the PFC should be more active as a result of ACC activation in the previous trial. This serves as a reactive response. The "easy" incongruent trial activates the ACC, which in turn activates the PFC and reminds the participant of the task-relevant goal (Macdonald, et al, 2000).

Another possible direction would be to use this task in older adults diagnosed with dementia of the Alzheimer's type (DAT). Healthy older adults showed a benefit of cue. Hutchison, Balota, and Ducheck (2010) indicated that performance on the Stroop task was a good discriminator between healthy aging and early onset of DAT. Given

similar properties in amounts of attentional control required by Stroop and flanker tasks, it is possible this task could also discriminate between healthy aging and DAT. Additionally, it would determine if adults with DAT can benefit from the use of predictive cues, and possibly present another approach to help alleviate the various attention and memory symptoms that present with DAT. There are multiple potential benefits of the use of external cues for older adults, such that attention and memory can be cued and serve as reminders.

Future research should also examine how fluctuations in attention are related across the entire task, not just trial-to-trial. It is important to determine if these fluctuations have a more global effect on task performance beyond individual trials. Manipulating the proportion congruency at a list-wide level could test this notion. RTs, errors, and pupil dilation could be assessed across blocks to determine if attentional state changes at a global level, rather than only trial-by-trial.

This study provides evidence that pre-trial attentional state and changes in attention state determine subsequent performance. Specifically, the results from Experiment 1 suggest that when attentional state is directed by an "easy" cue, performance tended to decrease compared to when directed by a "hard" cue. This is reflective of relaxing cognitive control and relying reactive control. When participants were highly focused on the task in "hard" cued trials, performance improved. In particular, flanker interference was much smaller following "hard" cues than following "easy" cues. This is supported by Experiment 2, which showed increased pupil diameter following "hard" cues; attentional control increased in preparation for the more difficult

task. These combined results support that the capability to focus and maintain attention contributes to successful task completion and results in better overall performance during difficult and conflicting cognitive tasks.

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