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Brief article

# Cognitive capacity limitations and Need for Cognition differentially predict reward-induced cognitive effort expenditure

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ABSTRACT

While psychological, economic, and neuroscientific accounts of behavior broadly maintain that people minimize expenditure of cognitive effort, empirical work reveals how reward incentives can mobilize increased cognitive effort expenditure. Recent theories posit that the decision to expend effort is governed, in part, by a cost-benefit tradeoff whereby the potential benefits of mental effort can offset the perceived costs of effort exertion. Taking an individual differences approach, the present study examined whether one's executive function capacity, as measured by Stroop interference, predicts the extent to which reward incentives reduce switch costs in a task-switching paradigm, which indexes additional expenditure of cognitive effort. In accordance with the predictions of a cost-benefit account of effort, we found that a low executive function capacity—and, relatedly, a low intrinsic motivation to expend effort (measured by Need for Cognition)—predicted larger increase in cognitive effort expenditure in response to monetary reward incentives, while individuals with greater executive function capacity—and greater intrinsic motivation to expend effort—were less responsive to reward incentives. These findings suggest that an individual's cost-benefit tradeoff is constrained by the perceived costs of exerting cognitive effort.

## 1. Introduction

Goal-directed behavior is constrained by the capacity limitations of cognitive processing—for example, an individual's working memory capacity, or the amount of the information to which an individual can simultaneously attend. Because cognitive processing is inherently resource-limited, our decision to engage in effortful cognitive processing should be dictated, in part, by its costs and benefits. According to a recent influential account of cognitive control, the utility of expending cognitive effort is, simply put, the expected benefit obtained by exerting cognitive effort minus the cost of this effort exertion (Shenhav, Botvinick, & Cohen, 2013).

Underlining this point, people consistently avoid exertion of cognitive effort (Inzlicht, Schmeichel, & Macrae, 2014; Westbrook & Braver, 2015), and effort avoidance is more prevalent in individuals with limited cognitive ability (Kool, McGuire, Rosen, & Botvinick, 2010). That is, the cost of effort expenditure appears to weigh more heavily for cognitive capacity-limited individuals, and as a result, these increased internal effort costs drive decisions towards less cognitively effortful courses of action (Kurzban, Duckworth, Kable, & Myers, 2013).

At the same time—and again in accordance with the notion of a cost-benefit tradeoff—when large reward incentives hinge on successful deployment of controlled processing, people increase their level of cognitive effort expenditure relative to circumstances when reward incentives are smaller or nonexistent (Aarts et al., 2014; Bijleveld, Custers, & Aarts, 2010; Capa, Bouquet, Dreher, & Dufour, 2013; Hübner & Schlösser, 2010; Locke & Braver, 2008; Padmala & Pessoa, 2011) For example, in the Stroop task, large potential rewards enhance the processing of task-relevant stimulus information, resulting in faster and more accurate responding (Krebs, Boehler, & Woldorff, 2010). This body of work suggests that reward incentives can effectively offset perceive effort costs, and in doing so, 'mobilize' cognitive processing resources in the service of goal-directed behavior (Botvinick & Braver, 2015).

Considering these two separate lines of research together yields a compelling and untested question: how might an individual's cognitive capacity predict the extent to which reward incentives can mobilize cognitive effort? As cognitive costs may loom larger for individuals with smaller cognitive capacities because they tend to avoid effort expenditure (Kool et al., 2010), and reward incentives can increase the net utility of cognitive effort expenditure by offsetting its costs, one possibility is that the mobilizing effects of reward incentives should be

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greater for lower-capacity individuals (for whom these costs are large) than for higher-capacity individuals (for whom these costs may be negligible). Alternatively, lower-capacity individuals might be less responsive to reward incentives, as these benefits have larger costs to offset, and therefore, the marginal utility of increasing effort expenditure is smaller for these individuals.

By changing the benefits associated with effort exertion while keeping task difficulty constant, we can disambiguate between these two predictions: in the former account, we should expect to see a marked increase in effort exertion among individuals for whom effort costs are perceived to be large (i.e., the effective load on processing resources is high) but not among individuals for whom these effort costs are small, while in the latter account, we should instead expect higher-capacity individuals, for whom these effort costs are perceived to be low and therefore the marginal utility of increased effort larger, to increase their effort exertion.

To test these possibilities, we manipulate the amount of reward tied to performance in a simple task-switching paradigm that requires participants to frequently switch between two tasks (Monsell, 2003). The pervasive "switch costs"—the difference in response times (RTs) between task switches and task repetitions—result from task-set reconfiguration processes that are demanding of central executive resources (Monsell, 2003). Following previous work (Braver, Reynolds, & Donaldson, 2003; Kool et al., 2010), we interpret a reduction in switch costs as an indication of increased cognitive effort investment.

Separately, we measure each individual's Stroop incongruence effect, taken here as a measure of executive-dependent processing ability (Kane & Engle, 2003), and accordingly, examine how this processing capacity bears upon reward-induced modulations of task switch costs. While the Stroop and task-switching rely, in part, on shared executive functions (Miyake et al., 2000), they also make unique requirements upon response inhibition and task-set shifting processes, respectively. The use of qualitatively different cognitive control tasks to separately assess baseline individual differences and responsivity to reward incentives minimizes the possibility of (near) transfer of practice between the two tasks and further, highlights the generalizability of the relationship between inherent capacity limitations and decisions about effort expenditure.

We also examine the possibility that individuals might vary in how they value cognitive effort, independent of cognitive ability, as operationalized by the Need for Cognition scale (NFC; Cacioppo, Petty, & Kao, 1984). Indeed the NFC scale predicts the amount of money an individual will forego to avoid cognitive effortful activity (Westbrook, Kester, & Braver, 2013). By the same token, we would expect here that individuals high in NFC— who place more intrinsic value on effort expenditure—should be less responsive to monetary incentives in Task-switching, relative to low-NFC individuals. That is, to the extent that high-NFC individuals place intrinsic value in exertion of cognitive effort (or simply do not treat it as costly), we expect that these individuals should be less sensitive to the costs and benefits of cognitive effort exertion, and accordingly, should exhibit a smaller reward-induced reduction in task switch costs.

## 2. Methods

### 2.1. Participants and design

54 participants were recruited through McGill participant pool and the university community and gave written consent in accordance with the McGill Research Ethics Board. Prior to the main task, participants completed the NFC scale, an 18-item questionnaire which measures the extent to which individuals engage with and enjoy cognitively demanding activities (e.g., "I prefer complex to simple problems" and "I prefer my life to be filled with puzzles I must solve"; (Cacioppo et al., 1984). We also administered the behavioral inhibition system/behavioral activation system scales (BIS/BAS; Carver & White, 1994) to assess individual differences intrinsic motivation and reward sensitivity respectively, also part of our standard laboratory questionnaire battery, we administered the Barratt Impulsiveness (Patton, Stanford, & Barratt, 1995) and the Generalized Anxiety Disorder (GAD-7; Spitzer, Kroenke, Williams, & Löwe, 2006) scales.

Participants completed one block of a Stroop task followed by two separate task-switching blocks in which the reward for correct responses (High Reward versus Low Reward) was manipulated as a counterbalanced, within-subjects factor. We excluded the data of 7 participants who failed to perform either task with an accuracy of at least 80% and 2 participants who missed 15 or more response deadlines in any block of the experiment, leaving 45 participants in the final analyses. We further excluded 2 participants with missing NFC questionnaire responses from analyses using NFC questionnaire data.

### 2.2. Stroop task

Participants performed a computerized version of the Stroop task (Otto, Skatova, Madlon-Kay, & Daw, 2015) which required them to identify, as quickly and as accurately as possible, which one of three colors the word on the screen was presented: red, green, or blue, by pressing one of three keys ('j', 'k,' and 'l' respectively) while ignoring the meaning of the word (Fig. 1A). Before starting with the task, the participants first completed a short practice block to get them accustomed to the task. Each Stroop block consisted of 120 trials, 30 incongruent and 90 congruent. On each trial, the participant saw the stimulus (a color word sized 100 × 350 pixels) 500 ms after the onset of the trial. The participant then had 1.5 s to make a response. No feedback was provided. RGB color codes (255, 0, 0), (0, 255, 0), (0, 0, 255) were used for red, green, and blue respectively.

### 2.3. Task-switching paradigm

After performing the Stroop, participants were informed that they

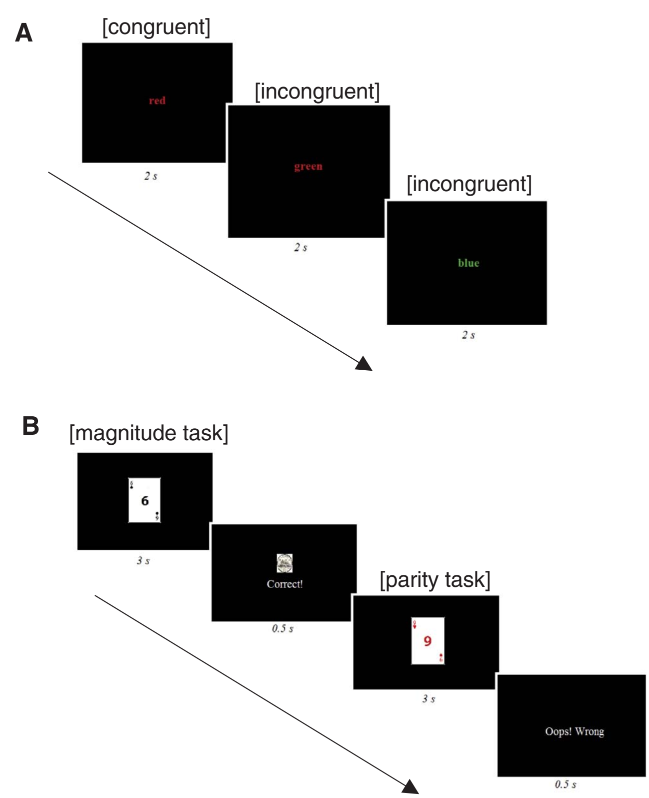


**Fig. 1.** (A) Computerized Stroop task. (B) Task-switching paradigm.

will receive a performance-contingent cash bonus on the subsequent task-switching paradigm, which consisted of two blocks where the reward available for making a correct response was manipulated as a counterbalanced, within-subjects factor (High Reward versus Low Reward).

The task-switching paradigm is a modified card-choice version of that used by Kool et al. (2010). Participants were presented with a picture (200 × 300 pixels) of a common playing card of one of two suites: Spades (black) and Hearts (red). Each card contained a red or black number in the center (color corresponding to the suit of the card) indicating its value; the cards varied from 2 to 9, omitting 5. The number stimulus was presented in the center of the 'card,' as well as the top-left and bottom-right corners of a white card, in either red or black. Upon presentation of a red card the participant had to use one of the two response keys to indicate whether the card is bigger than 5 ('magnitude' task). Upon presentation of a black card, the participant had to indicate whether the number on the card was odd or even ('parity' task; see Fig. 1B). As the cue indicating the task to be performed was presented at the same time as the stimulus in question, the length of the cue-stimulus interval was effectively zero. Participants performed 140 trials in each block (i.e., reward condition), with an equal number of magnitude and parity task trials. Participants were presented with the stimulus (card) 100 ms after the onset of the trial; they had 3 s to respond and were then given feedback on their response. If the participant took too long to answer, the trial was automatically counted as a miss and the next card was shown. The number stimulus was presented in the center of the 'card' in a 40-point san-serif font, as well as the top-left and bottom-right corners of a white card, in either red or black. Participants were told in the beginning of the trial whether they will be paid 5c (High Reward condition) or 1c (Low Reward). Following the first task-switching block, participants completed an unrelated filler task followed by an 8-min music break, and then a subsequent task-switching block with the remaining reward condition.

### 2.4. Data analysis

All inferential statistics were computed using mixed-effects regressions using the lme4 package (Pinheiro & Bates, 2000) for the R programming language. RT regressions were conducted on correct trials only and RTs were log-transformed to remove skew (Ratcliff, 1993). We employed logistic regression in models examining response accuracy. To account for practice effects in the task-switching blocks, a linear predictor of trial block was included as a predictor variable. The individual reward effects plotted in Fig. 3 are the estimated per-subject regression coefficients from the group analysis (conditioned on the group level estimates) superimposed on the estimated group-level effect.

## 3. Results

### 3.1. Task performance

As is typical in the Stroop task (Krebs et al., 2010; Otto et al., 2015), we found that incongruent trials elicited longer RTs ($\beta = 0.12$, $SE = 0.015$, $p < .0001$) and less accurate responses ($\beta = -1.47$, $SE = 0.001$, $p < .0001$; Table 1). From these data, we calculated each participant's Stroop RT cost as the difference between standardized RTs on incongruent and congruent trials, yielding our measure of executive function (EF). Analyzing RT and accuracy across the two task-switching blocks on switch trials in both conditions (where the current task differed from the previous subtask) and repeat trials (where the current task was the same as from the previous subtask), we observed typical task switch costs (Kool et al., 2010; Monsell, 2003): participants were significantly slower ($\beta = 0.17$, $SE = 0.014$, $p < .0001$) and less accurate ($\beta = -0.10$, $SE = 0.05$, $p = .047$) on task switches than task repetitions (Table 1). There were no significant correlations between individual Stroop RT costs and switch costs expressed in accuracy ($r = -0.00062$, $p = .99$) or switch costs expressed in RT ($r = -0.041$, $p = .79$). Echoing the documented relationship between NFC and fluid intelligence, we found a moderate negative correlation between NFC and Stroop RT costs ($r = -0.37$, $p = .015$)—that is, greater EF ability here predicted larger NFC scores (Hill et al., 2013).

**Table 1**
Average median RTs and error for congruent versus incongruent trials in the Stroop task and in repeat and switch trials across the two blocks of the task-switching paradigm.

| | RT (ms) | | Accuracy | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| *Stroop task* | | | | |
| Congruent | 579.710 | 78.500 | 0.975 | 0.023 |
| Incongruent | 697.560 | 132.620 | 0.903 | 0.080 |
| *Task-switching (low-reward block)* | | | | |
| Task repeat | 767.747 | 155.087 | 0.952 | 0.034 |
| Task switch | 945.880 | 176.837 | 0.941 | 0.040 |
| *Task-switching (high-reward block)* | | | | |
| Task repeat | 791.075 | 123.487 | 0.949 | 0.038 |
| Task switch | 945.981 | 146.854 | 0.936 | 0.046 |

### 3.2. Reward incentives and switch costs

Among all subjects, task switch costs appeared lower on High Reward blocks than Low Reward blocks (Fig. 2), in line with the finding that reward incentives increase deployment of cognitive control

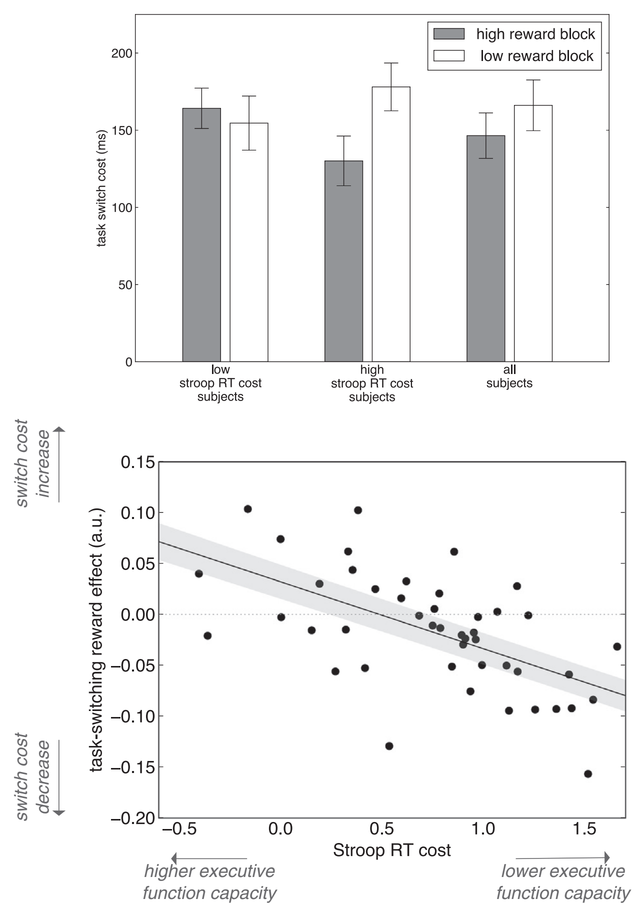


**Fig. 2.** (A) Task-switch costs (in RT) as a function of reward condition for all participants (right two bars), and low- and high-EF participants as assessed by a median split on Stroop RT costs. (B) Relationship between EF capacity (abscissa) and the effect of reward on task switch costs (ordinate).

resources (Bijleveld et al., 2010; Locke & Braver, 2008; Padmala & Pessoa, 2011). However, the effect of reward was not significant at the group level ($\beta = -0.01$, $SE = 0.01$, $p = .34$), suggesting the possibility that either or both a weak effect of reward itself or inter-subject heterogeneity rendered this effect statistically undetectable.

### 3.3. Individual differences in executive function

To visualize how individual differences in EF might bear upon switch costs across the different reward conditions, we performed a median split upon participants according to their Stroop RT costs (i.e. EF ability), and then examined task-switching costs, expressed in RT, as a function of reward block for these two resultant groups (Fig. 2A). While the high EF group (i.e. low Stroop RT costs) did not appear sensitive to the reward manipulation, the low EF group (i.e. those with high Stroop RT costs) appeared highly sensitive to the reward manipulation. That is, increasing reward incentives reduced task switch costs—a marker of increased cognitive effort exertion—but only amongst individuals with more limited cognitive capacities.

The relationship between individual differences in EF and reward-induced switch cost changes is visualized in Fig. 2B for the entire subject sample. Using a mixed-effects regression with EF treated as a continuous variable, we found a significant three-way interaction between Stroop RT costs, reward condition, and trial type (task switch versus task repeat; full model in Table 2). We found no significant interaction between trial type and reward, revealing that the reward-induced reductions in task-switching costs was dependent upon individual EF, and there was no significant interaction between trial type and Stroop RT cost, suggesting that EF capacity was not itself predictive of overall switch costs. Applying the same regression approach to the accuracy data, we found no significant relationship between reward and trial type ($\beta = -0.054$, $SE = 0.047$, $p = .22$), between trial type, Stroop RT costs, and reward ($\beta = 0.024$, $SE = 0.042$, $p = .57$), or reward alone ($\beta = 0.021$, $SE = 0.04$), suggesting that reward-induced switch cost modulations did not manifest in response accuracies.

### 3.4. Individual differences in Need for Cognition

Plotting the resultant switch costs as a function of reward block and NFC score median (Fig. 3A) reveals that low-NFC individuals exhibited a reward-induced switch cost reduction, and rather surprisingly, high-NFC individuals exhibited a reward-induced switch costs increase. In other words, large reward incentives *increased* the amount of effort exerted by low-NFC individuals but *decreased* the amount of effort exerted by high-NFC individuals. The relationship between NFC scores and reward-induced switch cost changes was significant in a regression using continuous NFC scores in the full sample (Table 3; see Fig. 3B for a visualization of the effect).

**Table 2**
Mixed-effects regression coefficients indicating the influence of trial type (task switch versus task repeat), reward level, experimental block, and individual Stroop RT costs upon RTs in the task-switching paradigm.

| Coefficient | Estimate (SE) | p-value |
|---|---|---|
| (Intercept) | 6.8642 (0.0331) | < 0.0001* |
| Trial type | 0.175 (0.0171) | < 0.0001* |
| Reward | 0.0095 (0.0115) | 0.836 |
| Stroop RT cost | 0.0167 (0.0264) | 0.351 |
| Block | −0.1113 (0.0101) | < 0.0001* |
| Trial type × reward | −0.0139 (0.0152) | 0.345 |
| Trial type × stroop RT cost | 0.0094 (0.0155) | 0.367 |
| Reward × stroop RT cost | 0.0111 (0.0108) | 0.642 |
| Trial type × reward × stroop RT cost | −0.0373 (0.014) | 0.008* |

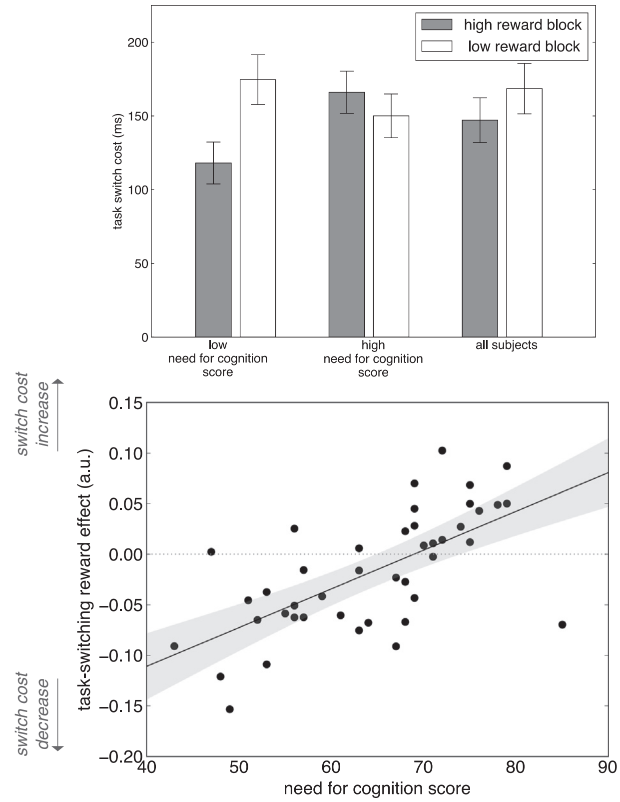


**Fig. 3.** (A) Task-switch costs (in RT) as a function of reward condition for all participants (right two bars), and low- and high NFC participants as assessed by a median split. (B) Relationship between NFC scores (abscissa) and the effect of reward on task switch costs (ordinate).

**Table 3**
Mixed-effects regression coefficients indicating the influence of trial type (task switch versus task repeat), reward level, experimental block, and NFC scores upon RTs in the task-switching paradigm.

| Coefficient | Estimate (SE) | p-value |
|---|---|---|
| (Intercept) | 6.8625 (0.0321) | < 0.0001* |
| Trial type | 0.1748 (0.0171) | < 0.0001* |
| Reward | 0.0103 (0.0113) | 0.627 |
| NFC | −0.0013 (0.0269) | 0.563 |
| Block | −0.1103 (0.0097) | < 0.0001* |
| Trial type × reward | −0.0139 (0.0152) | 0.35 |
| Trial type × NFC | −0.0045 (0.016) | 0.149 |
| Reward × NFC | −0.0233 (0.0108) | 0.352 |
| Trial type × reward × NFC | 0.0382 (0.0145) | 0.008* |

### 3.5. Individual differences in reward sensitivity

Finally, we considered the possibility that the effect of the reward manipulation may depend on individual sensitivity to reward (Braem, Verguts, Roggeman, & Notebaert, 2012; Van Steenbergen, Band, & Hommel, 2009) irrespective of cognitive capacity or intrinsic motivation to expend effort, by controlling for any effects of this individual difference with the Behavioral Activation Scale (Carver & White, 1994). Accordingly, we examined task-switching RTs using the same multi-level regressions as reported in Tables 2 and 3, with the addition of BAS scores as a covariate (and the interactions with trial-by-trial variables) and found the same significant three-way interactions between trial type (stay versus switch), reward condition, and Stroop RT cost ($\beta = -0.033$, SE = 0.013, p = .012) as well as NFC scores ($\beta = 0.035$, SE = 0.013, p = .007). Further, BAS scores exerted no significant predictive effects upon overall RTs, switch costs, or reward-induced switch cost changes in both the Stroop RT cost model (all *ps* > .49) and NFC score model (all ps > .51). These analyses suggest that (1) the observed individual differences in executive function and Need for Cognition operate independently from individual differences in reward sensitivity and (2) that neither reward-induced speeding nor reward-induced switch cost reductions were modulated by individual differences in reward sensitivity as measured by the BAS scale.

## 4. Discussion

Here we examined how individual differences in cognitive capacity, measured by Stroop interference, constrain the relationship between reward incentives and cognitive effort exertion in task switching. Assuming a simple cost-benefit account of effort, we found that reward-driven modulations of cognitive effort are more prevalent in low-EF individuals because the presumed costs associated with task-switching loom large, and accordingly, large reward incentives (i.e., increased benefits) measurably offset the costs of effort exertion. By contrast, high-EF individuals did not increase their cognitive effort investment in accordance with reward incentives because, according to our account, these effort costs are negligible relative to the increased benefits for expending effort. These results elucidate how cost-benefit computations regarding cognitive effort expenditure, whether explicit or implicit, are directed in part by cognitive processing constraints (Shenhav et al., 2013).

At the same time, we found that individuals low in Need for Cognition—who have little intrinsic motivation to perform cognitively demanding activities—were more inclined to increase cognitive effort investment in accordance with reward incentives. As previous work reveals that low-NFC individuals will forego larger amounts of monetary reward in order to avoid effort expenditure (Westbrook et al., 2013), our result further highlights how effort expenditure decisions are governed by perceived costs, which are determined not only by processing capacity but also dispositional factors such as intrinsic motivation to expend effort. In support of the idea that the inclination (or disinclination) to expend cognitive effort could relate to cognitive ability, the present results and previous work by other groups reveal that NFC—a putatively motivational variable —appears to correlate with EF ability under certain task circumstances (Hill et al., 2013).

Importantly, task-switch costs and overall RTs did not differ as a function of EF capacity (Table 2) or NFC (Table 3), suggesting against the possibility that reward-induced switch cost reductions are limited by ceiling effects in performance within high-capacity and high-NFC individuals. Rather, our results suggest that the observed shifts in effort expenditure are explained jointly by cognitive processing constraints (or intrinsic motivation to expend effort) and reward incentives. And curiously, while past studies have found that reward incentives can incur task switch cost reductions in specific circumstances (Aarts et al., 2010; Müller et al., 2007), the switch cost reductions observed here could not be explained by the reward manipulation alone. Indeed, some past work finds equivocal evidence for the ability of reward incentives alone to reduce switch costs (Aarts et al., 2014). In the present study, the increase in potential rewards in high- versus low-reward trials (10 versus 5 cents) may not be substantial enough to increase effort outlay alone but, intriguingly, were large enough to elicit differences between individuals in reward-induced effort expenditure.

While it is possible that Stroop RT costs—our measure of EF capacity—could reflect differences in nonspecific motivation or task engagement, the reward-induced effort expenditures observed here could not be explained by individual differences in responsivity to rewards (as measured by the BAS scale), supporting the notion that the individual differences observed here likely index subjective effort costs rather than reactivity to benefits. Intriguingly, previous work has found that under certain circumstances, motivational states—assessed either by self-report measures or inferred from dopamine synthesis capacity—predict deleterious effects of reward upon cognitive control (Aarts, Wallace et al., 2014; Van Steenbergen et al., 2009). Further work is needed to more precisely characterize the interplay between motivational states, cognitive capacity, and incentives insofar as they inform decisions about cognitive effort expenditure.

While the Stroop and Task-switching are broadly considered to be demanding of EF resources, the two tasks make different demands upon antagonistic components of cognitive control: flexibility and stability (Miller & Cohen, 2001). In particular, Stroop performance is thought to benefit from increased behavioral stability (e.g., task-set maintenance) while task-switching performance is thought to benefit from increased behavioral flexibility (e.g., continuous task-set updating). Underlining this tradeoff, reward incentives and have been demonstrated to promote behavioral stability (Müller et al., 2007), while central dopaminergic activity is associated with enhanced cognitive flexibility (Dreisbach et al., 2005; Steenbergen, Sellaro, Hommel, & Colzato, 2015). The observation that rewards promote increased flexibility—albeit dependent on EF capability or NFC—suggests that manipulating rewards in tasks favoring behavioral stability, such as the Stroop, could incur detrimental effects. Intriguingly, dopamine availability is demonstrated to predict the extent to which reward incentives deleteriously impact cognitive control (Aarts, Wallace et al., 2014).

In summary, the present study identifies important constraints governing the relationship between reward incentives and cognitive control deployment. However, understanding more specifically how controlled processing across diverse, but well-characterized task paradigms is jointly shaped by cognitive capacity constraints, reward incentives, and intrinsic motivation will help elucidate both the signatures of cognitive effort exertion and the circumstances under which cognitive effort is invested versus withheld.

## Supplementary material

All raw data pertaining to this study can be accessed via the Open Science Framework at http://osf.io/gqvsh.

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