Willing to think hard? The subjective value of cognitive effort in children

RUNNING HEAD: Value of Cognitive Effort

Willing to Think Hard?

The Subjective Value of Cognitive Effort in Children

Nicolas Chevalier

University of Edinburgh

Nicolas Chevalier, Department of Psychology, University of Edinburgh, Edinburgh, UK.

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Correspondence concerning this article should be addressed to Nicolas Chevalier, 7 George Square, Department of Psychology, University of Edinburgh, Edinburgh, EH8 9JZ, UK. Email: nicolas.chevalier@ed.ac.uk

Abstract

Cognitive effort is costly and this cost likely influences the activities that children engage in. Yet, little is known about how school-age children perceive cognitive effort. The subjective value of cognitive effort, that is, how valuable or costly effort is perceived, was investigated in 73 7- to 12-year-olds using an effort-discounting paradigm. In two studies, it varied with task difficulty but not age, was predicted by actual effort engagement but not actual success, and related to trait interest in effortful activities and proactive control engagement. Children are sensitive to cognitive effort and use it to guide behaviors, suggesting that poor performance may often reflect reluctance to engage cognitive effort rather than low ability.

Key words: cognitive effort, need for cognition, cognitive control, executive function, children.

Like physical effort, cognitive effort is costly. This cost largely influences the activities that we engage in, leading us to opt for a challenging task that carries potential for learning or an easier one that may seem more immediately rewarding. Indeed, the extent to which one seeks, engages in, and enjoys cognitive effort predicts intrinsic motivation and academic achievement (Cacioppo, Petty, Feinstein, & Jarvis, 1996). As cognitive control is intrinsically effortful, the way one perceives and values cognitive effort may directly affect regulation of thoughts and actions. In childhood, failure to engage efficient cognitive control may not necessarily reflect poor ability, as is generally assumed, but instead reluctance to engage effort, potentially calling for different interventions. Yet, little is know about the subjective cost of cognitive effort in children. The present studies aimed to fill this gap by investigating how children perceive cognitive effort and use it to guide their behaviors.

Cognitive effort is usually thought to reflect the extent to which cognitive resources are engaged (i.e., attention is invested) in a specific activity (e.g., Dunn, Lutes, & Risko, 2016; Efklides, Kourkoulou, Mitsiou, & Ziliaskopoulou, 2006). Although it was initially thought to relate to glucose consumption through brain activity (Gailliot & Baumeister, 2007), cognitive effort may instead reflect the opportunity cost related to not being able to engage cognitive resources in alternative (and potentially more rewarding) tasks (Kurzban, Duckworth, Kable, & Myers, 2013). Importantly, actual (or objective) cognitive effort carries a perceived (or subjective) cost that only moderately relates to actual effort expenditure and also depends on other factors such as personality or mood states (Efklides et al., 2006; McGuire & Botvinick, 2010). In adults, the subjective value or cost of cognitive effort, that is, how valuable (or conversely how costly) effort is perceived, has received increasing scientific attention lately. Adults find cognitive effort aversive and decide which activities to engage in based on their respective cognitive demands (and thus effort), strategically avoiding unnecessary cognitive effort (Dunn et al., 2016; Gold et al., 2015; Kool & Botvinick, 2014; Kool, McGuire, Rosen, & Botvinick, 2010; McGuire & Botvinick, 2010; Westbrook & Braver, 2015). When given the choice between an easier and a harder task, they preferentially select the easier one (Kool et al., 2010) even if it means forgoing substantial reward to conserve cognitive effort (Massar, Libedinsky, Weiyan, Huettel, & Chee, 2015; Westbrook, Kester, & Braver, 2013). Further, the value of cognitive effort varies as a function of contextual factors and individual preferences. Specifically, adults are more likely to avoid a very difficult than a moderately difficult task, and those with low trait interest in effortful activities tend to be especially conservative of cognitive effort (Westbrook et al., 2013). It is still unclear, though, to what extent the subjective value of cognitive effort may be based on actual effort engagement (Westbrook & Braver, 2015).

Although cognitive effort may be just as aversive to children as to adults, it is unclear whether children use effort to guide their behaviors, especially given that metacognitive abilities are still emerging during childhood. For instance, as children tend to overestimate their cognitive abilities (e.g., Flavell, Speer, Green, & August, 1981), they may underestimate how much cognitive effort they are engaging or will need to engage to achieve a task, or neglect this information when deciding to carry it out. Alternatively, poor metacognitive abilities may lead children to primarily consider effort (or task difficulty), which is potentially very salient to them, and overlook the advantages (e.g., greater opportunity to learn, greater efficiency, greater reward) of more effortful tasks or strategies, potentially resulting in suboptimal behaviors.

Indeed, children often engage cognitive control (i.e., the goal-directed regulation of thoughts and actions) in suboptimal ways, despite being capable of more mature and efficient control, suggesting poor metacognitive coordination of their control abilities (Chevalier, 2015). This is particularly true of proactive control, which refers to early control engagement in anticipation of and preparation for upcoming task demands to prevent cognitive conflict before it arises (e.g., gathering thoughts before a school presentation) (Braver, 2012). Children often neglect this control mode when it would be especially efficient (i.e., when the upcoming task is predictable), in favor of reactive control, which corresponds to control engagement in the moment to resolve cognitive conflict that has arisen (e.g., improvising during questions) (Blackwell, Chatham, Wiseheart, & Munakata, 2014; Blackwell & Munakata, 2014; Chatham, Frank, & Munakata, 2009; Chevalier, James, Wiebe, Nelson, & Espy, 2014; Lucenet & Blaye, 2014; Munakata, Snyder, & Chatham, 2012; Van Gerven, Hurks, Bovend'Eerdt, & Adam, 2016). Importantly, children often neglect proactive control despite being capable of this control mode and even though they perform better when they do engage it (Chevalier & Blaye, 2016; Chevalier, Martis, Curran, & Munakata, 2015).

Could children's value of cognitive effort account for reactive control engagement even when proactive control would lead to better performance? Proactive control relies on information maintenance in working memory and sustained prefrontal activity. Thus, it requires earlier and greater cognitive effort than reactive control, which relies on information retrieval and transient prefrontal activity (Braver, Paxton, Locke, & Barch, 2009; Braver, 2012; Marklund & Persson, 2012). Children who perceive cognitive effort as more costly may be tempted to delay and minimize cognitive control engagement, hence preferring reactive to proactive control, even when the latter would yield greater performance. In contrast, children who value cognitive effort may be more willing to engage proactive control. Therefore, the subjective value of cognitive effort may impact how children engage cognitive control (i.e., reactively vs. proactively).

The present studies examined how school-age children perceive cognitive effort and whether they use it to guide their behaviors. Specifically, it addressed whether the subjective cost of cognitive effort can be experimentally assessed in children (Westbrook et al., 2013) (Studies 1 and 2), whether it is based on actual effort engagement and or successful performance (Study 1), and whether it relates to trait interest in effortful activities and proactive control (Study 2).

Study 1

Study 1 investigated whether the subjective value of cognitive effort can be experimentally assessed in school-age children. If so, it should be affected by similar factors as in adults. Specifically, we examined whether children's subjective value of cognitive effort, like adults', changes as a function of task difficulty. To this end, 7- to 12-year-old children completed a child adaptation of the Cognitive Effort Discounting paradigm originally developed for adults (COG-ED; Westbrook et al., 2013). It allowed estimating how much reward they were willing to forgo in order to conserve cognitive effort, by asking them to choose between performing a harder task (e.g., 2-back task) for a high reward or an easier task for a lower reward (e.g., 1-back task). Thus, children needed to weigh in the cost associated with each task in terms of cognitive effort as well as fatigue, probability of erring, negative feeling, etc., with potential benefits in terms of external reward, possibility to learn and improve performance, probability of success, positive feeling, etc. We examined whether children are sensitive to differences in cognitive effort associated with N-back tasks, which tap working-memory updating, of varying difficulty. If children are sensitive to differences in effort and use them to guide behavior, they should conserve cognitive effort (i.e., choose the easier task) more as task difficulty increases (i.e., when the harder tasks to choose between is of high rather than intermediate difficulty), just like adults in prior research (Westbrook et al., 2013). This would speak to the adequacy of COG-ED to assess children's subjective value of cognitive effort.

Study 1 also examined to what extent the value of cognitive effort is based on actual effort engagement or likelihood of success (Study 1). Pupil dilation is a well-established physiological correlate of cognitive effort, with larger pupil dilation indicating greater effort (e.g., Hepach & Westermann, 2016; Wierda, Rijn, Taatgen, & Martens, 2012). Therefore, phasic changes in pupil dilation were recorded while children played the N-back tasks. If the value of cognitive effort is directly based on actual effort engagement, children should conserve effort more when choosing between tasks for which pupil dilation differed more (i.e., greater difference in cognitive effort). If it is based primarily on likelihood of success, differences in response accuracy should predict effort conservation more than pupil dilation.

Method

Participants

Participants included 41 children between 7 and 12 years of age (M = 9.22 years, SD = 1.47, 18 girls, 23 boys). Most participants were Caucasian, from middle to high socioeconomic background, although demographic information was not systematically collected, and lived in Edinburgh, UK. Participants were recruited from a database of families willing to partake in research and through adverts. Prior to participating, parental informed consent was obtained and all children gave both written and verbal assent. Parents were compensated £10 for their time and travel expenses, and children received top-trump cards as a prize. All data were collected in 2015.

Materials and Procedure

A trained experimenter tested children individually in the laboratory. Children completed a child-appropriate version of the Cognitive Effort Discounting paradigm (COG-ED), adapted from Westbrook et al. (2013). The COG-ED, which was run with E-Prime 2 (Psychology Software Tools, Pittsburgh, PA), comprised three phases (Figure 1).

In Phase 1, children experienced three difficulty levels of the N-back task, which require updating information in working memory in order to detect items that repeats at a given interval. As in the original version of COG-ED, the N-back task was used here because (1) cognitive control demands ensure that the task requires cognitive effort, (2) these demands can be easily manipulated, and (3) it is appropriate for children (Pelegrina, Lechuga, García-madruga, & Elosúa, 2015). For each difficulty level, children were presented with a series of 32 pictures. Each series included 4 different pictures (smiley face, cat, house, airplane) presented one at a time for 1500 ms and preceded by a 500-ms fixation cross. Each picture was presented 8 times in each series in an unpredictable order. In the first series (‘blue game’), children had to press the response button on a gamepad each time the current picture matched the one presented on the previous trial (1-back). If it did not match, they were instructed not to press the button. In the second series (‘red game’), they had to press the button each time the picture matched the one presented two trials back (2-back). In the third series (‘green game’), they had to press the button each time the picture matched the one presented three trials back (3-back). The fixed order of difficulty level helped children understand the task and strengthened the perceived difference in task difficulty. There were 8 targets (for which a button press was expected) and 24 non-targets in each series. Feedback was provided after each button press (for 1500 ms – response time) as either a green tick sign for targets or a red cross for non-targets. Responses (i.e., button press) to targets and no responses to non-targets were scored as correct, whereas no responses to targets and responses to non-targets were scored as incorrect. After each series, scores were displayed on the monitor as percent correct for targets and non-targets. Each series was preceded by a 10-sec fixation cross, which was used to assess baseline pupil dilation, followed by a warm-up sequence of 6 pictures. The background color of the monitor matched the color of the game corresponding to each series.

Phase 2 corresponded to the cognitive effort discounting procedure. Children were told that they would be given an opportunity to decide which tasks they would subsequently play. Specifically, they had to make two runs of 6 choices. Each choice was between two N-back tasks associated with different rewards (i.e., points). Children were told that the computer would randomly pick a subset of the tasks they chose to play later. They could accumulate points for each game they would get to play and later trade these points for a prize. They were told that the more points they would win the nicer the prize they would receive and encouraged to try to win as many points they could. Importantly, children were told they would have to maintain their attention (i.e., play as hard as they could) in order to receive the points associated with the task the computer picked. This ensured that children would not simply choose the task with the greatest reward, with no intention to engage cognitive effort while later performing it. Further, they were told that, provided they maintained their attention, they would receive the points regardless of their actual performance on that task, so that choices were driven by cognitive effort associated with each task rather than likelihood of success.

The first run of choices involved the 1-back task (low difficulty) and 2-back task (intermediate difficulty). The tasks were labeled both by their names (1-back, 2-back) and by their color (blue and red games). Within this first run, choice 1 was between playing 1-back (blue game) for 100 points or 2-back (red game) for 200 points. The number of points associated with the harder game (2-back) remained constant across all 6 choices, whereas the number of points for the easier game was adjusted as a function of the prior response. If the child just chose the easier game, the number of points for that game was adjusted down for the subsequent offer. In contrast, if the child just chose the harder game, the number of points for the easier game was adjusted up. The magnitude of the adjustment was divided by two from one choice to the other (+-50 points after choice 1, +-25 points after choice 2, +-12 points after choice 3, +-6 points after choice 4, +-3 points after choice 5). For example, if a child selected the easier task for 100 points (vs. the harder task for 200 points) on choice 1, they were then offered only 50 points (100 – 50) for the easier task on choice 2. If they chose the harder task on choice 2, then they were offered 75 points (50 + 25) for the easier task on choice 3, etc. The subjective value of cognitive effort corresponds to the points offered for the easier task on the last choice of the run (i.e., when both options are equally appealing to the participant). A lower value suggests that children are willing to conserve cognitive effort (i.e., engaging cognitive effort is not valued and viewed as highly costly), whereas a higher value suggests children are willing to engage cognitive effort (i.e., engaging cognitive effort is highly valued and viewed as not costly). Children then completed a second run of 6 choices, but this time between 1-back (low difficulty) and 3-back (high difficulty).

Finally, in phase 3, children played short series (16 pictures) of N-back tasks corresponding to two of their choices (one from each choice run), and were told how many points they accumulated. All children then received top-trump cards as a prize regardless of the points they accumulated.

Bilateral pupil dilation was recorded while children played the three N-back tasks in phase 1 with a Tobii TX300 eye-tracker (Tobii Technology AB, Danderyd, Sweden) using a 300 Hz sampling rate and a 5-point calibration procedure completed before administering the task. Calibration was repeated if necessary. Children sat about 60 cm away from the eye-tracker and computer screen. Pupil size was recorded for each 10-sec fixation cross period, which was used as baseline for the following N-back task, and then during each test block. The baseline screen was of the same background color as the following N-back game in order to keep luminance constant. Pupil size across both eyes was average at each time point after removing blinks and invalid values (i.e., values below 3 mm). Values were then smoothed over a 100-ms moving window. Mean pupil size was then computed for each 10-sec baseline period. Percent change in pupil size from the corresponding baseline period was computed for each value during test block, which were finally averaged for each entire test block.

Statistical Analysis

The data were analyzed with mixed models and hierarchical regressions. Mixed models were used because of the benefits of mixed-models over repeated-measures ANOVAs and appropriateness for testing both discrete and continuous predictors (e.g., Hoffman & Rovine, 2007; Quené & van den Bergh, 2004). Preliminary analyses showed that age did not interact with any other effects. These interaction terms were therefore trimmed out to better estimate the other effects

(Singer & Willet, 2003). Satterthwaite approximations for degrees of freedom are reported. Effect sizes were indexed through Pseudo R^2.

Results and Discussion

Does the value of cognitive effort vary with task difficulty?

To establish whether N-back accuracy actually decreased as task difficulty increased, a first mixed model explored the effects of stimulus type (Target, Non-Target, difficulty (1-, 2-, 3-back), and age on N-back performance. The effects of target type, $F(1, 246) = 126.92$, $p < .001$, Pseudo $R^2 = .30$, and difficulty, $F(2, 246) = 91.06$, $p < .001$, Pseudo $R^2 = .38$, were qualified by a significant interaction, $F(2, 246) = 27.19$, $p < .001$, Pseudo $R^2 = .18$,. Accuracy to targets decreased more as difficulty increased than accuracy to non-targets (Figure 2A). Overall accuracy marginally increased with age, $F(1, 246) = 3.19$, $p = .075$, Pseudo $R^2 = .01$. These findings confirmed that children increasingly struggled with the task as difficulty increased.

Next, the subjective value of cognitive effort was explored using a mixed model with difficulty of the harder task (2-back, 3-back), age, and N-back accuracy as predictors. The effect of difficulty was significant, $F(1, 41) = 25.78$, $p < .001$, Pseudo $R^2 = .39$, showing that children were more willing to engage cognitive effort when the harder option was of intermediate (2-back) rather than high (3-back) difficulty (Figure 2B). Age and N-back accuracy had no effects, *p*s > .185. These findings show that COG-ED is appropriate to estimate the value of cognitive effort in school-age children.

Is the value of cognitive effort based on actual effort engagement or likelihood of success?

To check whether children actually engaged greater cognitive effort when N-back difficulty increased, a mixed model was run on mean percent change in pupil dilation. Difficulty had a significant effect, $F(2, 79.5) = 24.85$, $p < .001$, Pseudo $R^2 = .39$. Pupil dilation significantly increased across the 1-, 2-, and 3-back tasks, ps < .010, hence suggesting that children engaged greater cognitive effort as task difficulty increased (Figure 2C). Pupil dilation also significantly increased with age, $F(1, 41.2) = 6.57$, $p = .014$, Pseudo $R^2 < .01$, suggesting that older children engaged more cognitive effort than younger children.

Differences in pupil dilation and accuracy between tasks were indexed through residual scores. Specifically, mean pupil dilation in 2-back or 3-back was regressed on mean pupil dilation in 1-back and the residual scores were saved. The same procedure was followed for accuracy. These residual scores were then used to examine whether the subjective value of cognitive effort was predicted by task differences in pupil dilation and response accuracy, after controlling for age. To this end, two regressions were run, one for 1- vs. 2-back choices and the other for 1- vs. 3-back choices, in which age was entered first, and the corresponding pupil dilation and accuracy residual scores were entered second (forward method). For 1- vs. 2-back choices, the model retained pupil dilation but not accuracy as significant predictor of the value of cognitive effort, $F(2, 38) = 3.27$, $p = .050$, standardized $\beta = -.403$, $p = .018$ (Figure 2D). For 1- vs. 3-back choices, neither pupil dilation nor accuracy were retained in the model, $p = .564$. Therefore, the greater the difference in actual effort engagement between the two tasks, the more children tried to conserve effort, but only when choosing between an easy task and a task of intermediate difficulty, not between an easy and a hard task. In contrast, differences in actual performance had no influence on the subjective values of cognitive effort.

Study 2

Study 2 sought to replicate the effect of task difficulty on the subjective value of cognitive effort in a new sample of school-age children and probed whether the value of cognitive effort relates to stable features, specifically trait interest in effortful activities, as in adults (Westbrook et al., 2013). Children who enjoy effortful activities more should perceive cognitive effort as less aversive or as an opportunity to learn, and thus be more willing to perform a cognitively demanding task. Furthermore, as cognitive control is effortful, the subjective value of cognitive effort should relate to how cognitive control is engaged. Note, however, that it would not necessarily yield greater success, as engaging more effortful strategies can hamper performance in some situations (e.g., K. A. Blackwell & Munakata, 2014; Bocanegra & Hommel, 2014). This was tested using the AX Continuous Performance Task (AX-CPT), a well-established measure of proactive control (e.g., Braver et al., 2009; Chatham et al., 2009; Chiew & Braver, 2013). Children who value cognitive effort on COG-ED should be more willing to engage it early, showing more proactive control engagement on AX-CPT. Finally, given that COG-ED estimates the value of effort in a context where children are offered the opportunity to win prizes, one may argue that prize attractiveness, rather than effort, may drive decisions to choose the harder task. Therefore, Study 2 also addressed this possibility.

Method

Participants

Participants included 32 children between 7 and 11 years of age (M = 10.1 years, SD = 1.04, 11 girls, 21 boys). As in Study 1, most participants were Caucasian and from middle to high socioeconomic background, although demographic information was not systematically collected. Children were recruited from local after-school clubs in Edinburgh, UK. Prior to participating, parental informed consent was obtained and all children gave both written and verbal assent. Children received small stationary items as prizes for participating. All data were collected in 2015.

Materials and Procedure

A trained experimenter tested children individually in a quiet room of the after-school club. Children first rated the attractiveness of potential prizes (stationary items) on a 5-point Likert scale from 1= ‘two thumbs down’ (‘I don’t like them at all’ to 5= ‘two thumbs up’ (‘These are great prizes’) printed on a sheet of paper. They then completed the same COG-ED paradigm as in Study 1, except that pupil dilation was not recorded during the game. As a consequence, the 10-sec fixation cross before each run in Phase 1 was removed. Children completed COG-ED on a laptop and entered responses by pressing the ‘0’ key on the keyboard instead of a gamepad button. Children were told that the more points they would win the more prizes they could take home, and encouraged to try to win as many points as they could. In addition to COG-ED, children completed an AX-CPT task to assess proactive control engagement, and the Need for Cognition Scale (NCS) to assess trait interest in effortful activities.

The AX Continuous Performance Task (AX-CPT), adapted from Chatham et al. (2009), was run using E-Prime 2. In this task, children had to help a dog tell a cat that it was feeding time by pressing buttons on the keyboard. Children saw two of four possible animal pictures on each trial: dog, cat, frog, and duck. On each trial, a centrally presented 12 × 12 cm prime picture was displayed for 500 ms, followed by a 1200-ms delay, and then by a probe picture alongside two response options (a feeding bowl on the left bottom corner and a cross on the right bottom corner) that were displayed until a response was entered or the time limit elapsed. Feedback was provided for 1000 ms as either two candies along with a light tune for correct and fast responses, one candy with a light tune for correct but slow responses, or a buzzer on a neutral background for incorrect responses. On 70% of trials, the prime-probe combination corresponded to dog-cat and required pressing ‘a’ (AX trials). The remaining trials required pressing ‘l’ and fell into three types, each corresponding to 10% of trials: dog-frog (AY trials), duck-cat (BX trials), and duck-frog (BY trials). If children proactively engage control as soon as they see the dog prime (A), they should anticipate and prepare during the delay to respond to the cat probe (X), leading to slower responses and more errors on AY than BX trials. In contrast, if they engage control reactively, seeing the cat probe (X) should prompt them to decide whether or not it was preceded by a dog prime (A), leading to slower responses and more errors on BX than AY trials. Children completed 4 demonstration trials, 8 practice trials, and 40 test trials, which is sufficient to index proactive control engagement in children (Chatham et al., 2009). The time limit was infinite on practice trials, whereas on test trials it corresponded to 1.5 × the mean response time on the practice trials, in order to ensure that the pace was similarly challenging to all participants. Accuracy was scored as follows: ‘bowl’ (‘a’) responses within the time limit on AX trials and ‘cross’ (‘l’) responses within the time limit on all other trials were scored correct; all other responses or lack of responses were scored incorrect. Response times (RTs) were log-transformed after removing outliers (<200 ms or greater than M+3SD) to correct for non-normal distributions and minimize age-related differences in baseline RTs. Following Braver et al. (2009), a proactive control index was computed as follows: (AY – BX) / (AY + BX), with higher values signaling more proactive control engagement.

The Short form of the Need for Cognition Scale (NCS; Cacioppo et al., 1996) was administered in an interview format. NCS comprises 18 items that assess how much the respondent engages in and enjoys activities that require cognitive effort (e.g., ‘I would prefer difficult to simple problems’ or ‘Learning new ways to think doesn’t excite me very much’). Complex formulations were reworded to ensure children could easily understand all items (e.g., original item 6 ‘I find satisfaction in deliberating hard and for long hours’ was reworded as ‘I enjoy thinking hard and for long hours’). The questionnaire is provided in Appendix A. Children answered each item by rating how much they felt it described them using a 5-point Likert scale from ‘not at all’ (two thumbs down) to ‘very much’ (two thumbs up). NCS scores correspond to the sum of points for each response, after reversing some of the items so that more points correspond to greater need for cognition. The NCS showed acceptable internal consistency, Cronbach’s $\alpha = .79$.

Statistical Analysis

The data were analyzed with mixed models following the same approach as in Study 1. The relations of the values of cognitive effort to NCS scores and proactive control index were examined using Pearson’s correlations.

Results and Discussion

Does the value of cognitive effort vary with task difficulty?

As in Study 1, the mixed model on N-back accuracy showed main effects of stimulus type, $F(1, 32) = 124.59$, $p < .001$, Pseudo $R^2 = .32$, and difficulty level, $F(2, 192) = 112.15$, $p < .001$, Pseudo $R^2 = .46$, alongside a significant interaction, $F(2, 192) = 34.53$, $p < .001$, Pseudo $R^2 = .26$. Again, difficulty had a stronger effect on accuracy to targets than to non-targets (Figure 2A). Overall accuracy significantly increased with age, $F(1, 192) = 4.96$, $p = .027$, Pseudo $R^2 = .02$.

The mixed model examining how the value of cognitive effort varied as a function of difficulty of the harder task (2-back, 3-back), age, and N-back accuracy showed a main effect of difficulty, $F(1, 32) = 8.07$, $p = .007$, Pseudo $R^2 = .20$. As in Study 1, children were more willing to engage cognitive effort when the harder option was of intermediate (2-back) rather than high (3-back) difficulty (Figure 2B). Age and N-back accuracy had no effects, *p*s > .816.

Complementarily, following the exact same procedure as in Study 1, the difference in accuracy between 1- and 2-back or between 1- and 3-back was entered after age as potential predictors of the values of cognitive effort for the first and second choice runs, respectively. The models did not retain these factors, further suggesting that N-back accuracy did not relate to the subjective value of cognitive effort on COG-ED.

These results fully replicate Study 1 findings.

Does the value of cognitive effort relate to proactive control and trait interest in effortful activities?

To examine whether children engaged proactive control in the AX-CPT, response times (RTs) and accuracy on the AX-CPT (Table 1) were probed using two mixed models with trial type and age as predictors. For RTs, there was a significant effect of trial type, $F(3, 91.5) = 13.41$, $p < .001$, Pseudo $R^2 = .30$, whereas the effect of age failed to reach significance, $F(1, 31.7) = 3.25$, $p = .081$, Pseudo $R^2 < .01$. RTs were slower on AY trials than all other trial types, including BX trials, *p*s < .005, which is indicative of proactive control engagement. Trial type also affected accuracy, $F(3, 96) = 6.56$, $p < .001$, Pseudo $R^2 < .17$, due to greater accuracy on AX than all other trial types, *p*s < .010. All other pairwise comparisons, including AY vs. BX trials, were not significant, *p*s > .173. The effect of age was not significant either, $p = .541$. Given that RTs, but not accuracy, captured proactive control engagement, the proactive control index was computed for RTs only.

The relations of subjective values of cognitive effort to proactive control engagement (M = .023, SD = .023), and NCS scores (M = 60.8, SD = 11.2) were investigated using Pearson's correlations. The subjective value of cognitive effort for 1- vs. 2-back choices was significantly correlated with proactive control, r = .443, p = .018, and NCS scores, r = .368, p = .038 (Figure 3), even after controlling for age, r = .436, p = .023 and r = .444, p = .020, respectively. In contrast, the subjective value of cognitive effort for 1- vs. 3-back choices did not correlate with proactive control and NCS scores, all ps > .437. Finally, we also examined whether the subjective values of cognitive effort were correlated with prize rating (M = 3.2, SD = 1.2), as children may be more willing to engage effort to win prizes they find more attractive, but no significant correlations were observed, all ps > .439. The results suggest the subjective value of cognitive effort, as measured by COG-ED, relates to trait interest in effortful activities as well as proactive control engagement on a different task.

General Discussion

The present studies examined how children perceive cognitive effort and use it to guide behaviors, adapting COG-ED to school-age children. They yielded three main findings. First, the subjective value of cognitive effort varied with task difficulty, but not age. Second, it was based in part on actual effort engagement, as evidenced by pupil dilation, rather than task performance. Third, it related to broader trait interest in effortful activities, as assessed by the NCS, as well as proactive control engagement on AX-CPT.

The child adaptation of COG-ED is a sensitive and valid measure of the value of cognitive effort in children, as suggested by the replication in children of two key findings observed with younger and older adults (Westbrook et al., 2013): (1) conservation of cognitive effort increased with task difficulty, and (2) the value of cognitive effort related to trait interest in effortful activities. Critically, Study 1 added the novel finding that the value of cognitive effort (when choosing between tasks of low and intermediate difficulty) is based on actual effort engagement, further speaking to the validity of COG-ED. Specifically, children who engaged much more effort on 2-back than 1-back, as shown by the difference in pupil dilation between the two tasks, were especially likely to conserve cognitive effort. In contrast, the value of cognitive effort was not influenced by the difference in accuracy between the two tasks, or prize attractiveness. In other words, children avoided the harder task not because of the lower likelihood of success or lower motivation to win the prize, but because of the additional effort it needed. These findings show that children are already sensitive to variations in their cognitive effort across tasks and can use this information to guide behaviors.

This conclusion, however, may be limited to situations in which (1) task success may not matter, (2) tasks may not be seen as enjoyable, (3) children may not necessarily perceive the intrinsic benefit of engaging cognitive effort in terms of learning or improving their cognitive abilities (either because they do not perceive the possibility to learn or because learning that particular ability is not deemed attractive or desirable), (4) and cognitive effort engagement is mostly oriented toward extrinsic benefit or reward (prizes). In many other situations, children's decisions to engage or conserve cognitive effort may additionally be driven by perceived intrinsic benefits of learning through cognitive effort (e.g., a task that matters to them) and other factors such as how engaging and enjoyable the task is (e.g., children may engage greater effort toward a fun video game than more 'boring' homework), all of which may not be appropriately captured by COG-ED. Nevertheless, situations akin to COG-ED, involving tasks that are not perceived as enjoyable and mostly extrinsic benefits, are common in a child's life, including many school (e.g., working on math problems) or extracurricular activities (e.g., learning music theory) in which children may struggle to perceive the intrinsic benefits in terms of personal development or later life success and instead focus on extrinsic benefits (e.g., please the parent or teacher or get a reward).

Interestingly, the subjective value of cognitive effort did not vary with age. This finding was unexpected given prior research showing lower subjective values in older than younger adults and prior suggestion that lower control may be associated with lower effort value (Westbrook et al., 2013). This may not be true of children because younger children have lower control but also lower metacognition, which may lead them to overestimate their control abilities. However, because the present studies relied on small and non-evenly distributed samples within a relatively large age range, no definite conclusion can be drawn about age effects on the subjective value of control. Further research should include larger samples of children, span a wider age range, and follow children longitudinally to properly chart out the developmental course of cognitive effort perception.

The correlations between the subjective values of cognitive effort and trait interest in effortful activities and proactive control engagement on AX-CPT point out intra-individual stability across contexts. Not only did children who valued effort more show greater interest in effortful activities in general, but they were also more willing to engage greater cognitive control and do it earlier. This finding suggests that value of cognitive effort may be key to understand why children do not always use proactive control in situations where it is especially appropriate despite being capable of that control mode (Chevalier & Blaye, 2016; Chevalier et al., 2015). Children who do not engage proactive control may simply consider it is not worth the effort.

Performance variability across individuals may not necessarily reflect differences in control resources or ability to implement cognitive control, but also differences in willingness to engage extant control resources and the cognitive effort they imply (although these differences may not systematically translate into different behavioral performances). Beyond proactive control, the present findings are consistent with the central role of cognitive effort in recent theoretical models of cognitive control, according to which cognitive control is engaged toward tasks with the most advantageous ratios between cost (effort) and benefit (reward) (Shenhav, Botvinick, & Cohen, 2013; see also Kurzban, Duckworth, Kable, & Myers, 2013; Westbrook & Braver, 2015, 2016).

The relations between the subjective value of cognitive effort and pupil dilation, trait interest in effortful activities, and proactive control on AX-CPT were consistently observed for choices involving tasks with a moderate difference in difficulty (i.e., low vs. intermediate difficulty), but not tasks with a large difference in difficulty (i.e., low vs. high difficulty). Although unexpected, this pattern suggests that when one of the tasks is extremely difficult, factors other than actual effort engagement and trait interest in effortful activities have a greater weight in participants' choices on COG-ED. Consistently, adults avoid difficult tasks based on a metacognitive evaluation of task difficulty that does not necessarily match actual performance or effort engagement (as measured by blink rates), especially when the task is very difficult (Dunn et al., 2016). Similarly, the especially low accuracy rates for 3-back may have led children to build a negative metacognitive evaluation of this task that is not directly dependent on how much effort they actually engaged. For instance, they may get the sensation that they are pressing the response button randomly and thus that they have little control over their performance. This may have influenced choices involving this task to a greater extent than stable traits or individual preferences, hence the lower predictive value of the subjective value of effort for 1- vs. 3-back than 1- vs. 2-back. Alternatively, children may have perceived only little intrinsic benefit in engaging cognitive effort on the N-back in terms of learning and improving their cognitive abilities (although some children may have opted for the harder task because they perceived it as a chance to improve their performance on that challenging task). This perceived intrinsic benefit might have been enough to override the perceived cost related to greater cognitive effort when the harder task was moderately difficult but not when it was very difficult. If that is the case, stronger correlations may have been observed with trait interest in effortful activities if N-back had been presented to children as a measure of important mental abilities (e.g., intelligence). Whether or not metacognitive evaluation and perceived intrinsic benefit are key here, these findings suggest the subjective value of cognitive effort is better assessed in children using tasks that only moderately differ in difficulty.

The present findings suggest that children's motivation to avoid or engage cognitive effort in COG-ED is related in part on actual engagement of cognitive effort and how much children enjoy cognitive effort in general, but does not seem directly dependent on likelihood of success or external reward (prize attractiveness). An outstanding question for future research is what particular aspects of cognitive effort children weigh in. Such aspects may relate to fatigue, arousal, emotional experience associated with effort, enjoyment of the effortful task or effort itself, and opportunities to learn new skills or sharpen extant ones. Importantly, future research should investigate to what extent these aspects are similarly or differently considered across development.

Individual variations in the subjective cost of cognitive effort and trait interest in effortful activities may be influenced by children's intelligence mindset, that is, whether children believe intelligence is malleable or fixed. Unlike children with a fixed mindset who believe intelligence cannot be changed, those with a growth mindset believe intelligence is amenable to improvement through hard work (Haimovitz & Dweck, 2016). A growth mindset is associated with greater academic improvement over time (Blackwell, Trzesniewski, & Dweck, 2007). As it promotes learning through effort, children with such a mindset may regard cognitive effort as more valuable and be more willing to engage in effortful activities. A critical finding from the intelligence mindset literature is that mindsets are influenced by environmental factors, such as pedagogical practices and parents' view of failure (e.g., Haimovitz & Dweck, 2016), and can be modified through environmental modifications (Blackwell et al., 2007; Haimovitz & Dweck, 2016; Kamins & Dweck, 1999). For instance, encouraging a growth mindset through effort-oriented praise results in greater task persistence and sense of self-worth than praising children's inner abilities, which promotes a fixed mindset (Cimpian, Arce, Markman, & Dweck, 2007; Kamins & Dweck, 1999). Children's subjective value of cognitive effort may be similarly raised through simple environmental manipulations (e.g., by emphasizing learning through effort). Indeed, the value of cognitive effort may even mediate the beneficial effect of manipulations targeting intelligence mindsets. Changing how children value cognitive effort may be key to early interventions on low cognitive control, a major risk factor, especially prevalent in low socioeconomic conditions, putting children at risk for academic failure and cascading negative outcomes.

In conclusion, children's inclination to forgo reward to avoid cognitive effort, at least in situations where the perceived intrinsic benefit of effort may be limited (as in the present study), shows children are sensitive to variations in cognitive effort and can strategically use this information to guide behaviors. The value of cognitive effort varies across children, relates to stable trait interest in effortful activities and how cognitive control is engaged. Individual differences in behavioral performance during childhood do not necessarily reflect differences in ability, but can also reflect differences in willingness to engage cognitive effort.

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Figure 1

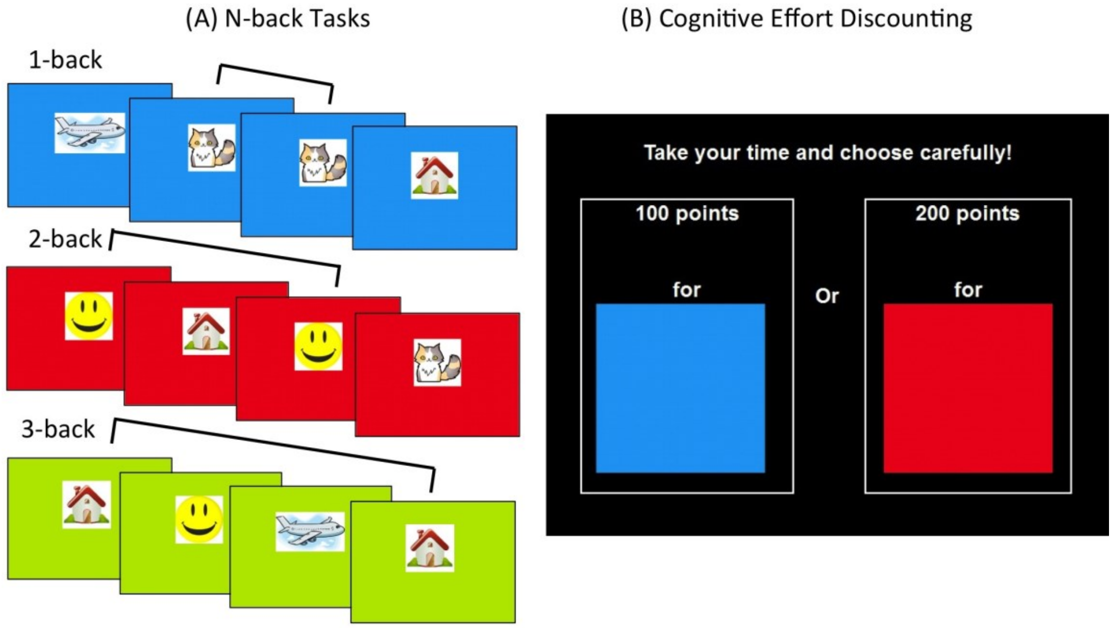

Figure 1. Child adaptation of the Cognitive Effort Discounting (COG-ED) paradigm. (A) In the first phase, children experienced three N-back tasks of increasing difficulty, 1-back (blue game—low difficulty), 2-back (red game—intermediate difficulty), and 3-back (green game—high difficulty). They had to press a button when the current picture matched the picture presented one, two, or three trials back, respectively. (B) In the second phase, children had to choose between the easy 1-back task for a smaller reward and a harder task (either 2- or 3-back) for a greater reward (2 runs of 6 choices each). The illustration only shows the first choice for the first run.

Figure 2

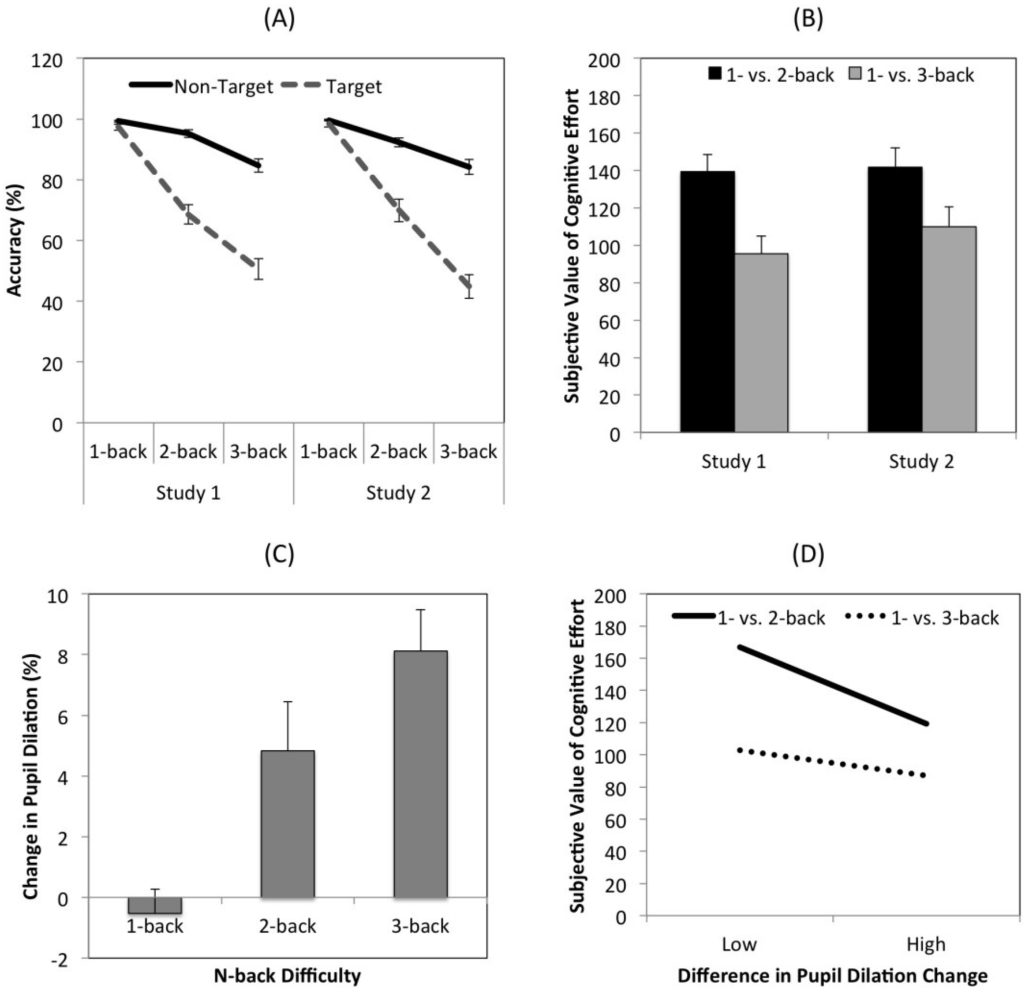

Figure 2. Cognitive Effort Discounting (COG-ED) performance. (A) Accuracy performance in phase 1 was lower for target than non-targets, and decreased as N-back difficulty increased (Studies 1 and 2). (B) In phase 2, the subjective value of cognitive effort was lower for 1- vs. 2-back choices than 1- vs. 3-back choices (Studies 1 and 2). (C) Percent change in pupil dilation from baseline increased with N-back difficulty in phase 1 (Study 1). Error bars indicate standard errors (A-C). (D) Predicted subjective values of cognitive effort as a function of the difference in pupil dilation between 1- and 2-back, and 1- and 3-back, respectively (Study 1). 'Low' and 'High' correspond to one standard deviation below or above the mean, respectively.

Pupil dilation predicted the subjective value of cognitive effort when choosing between 1- and 2-back, but not 1- vs. 3-back.

Figure 3

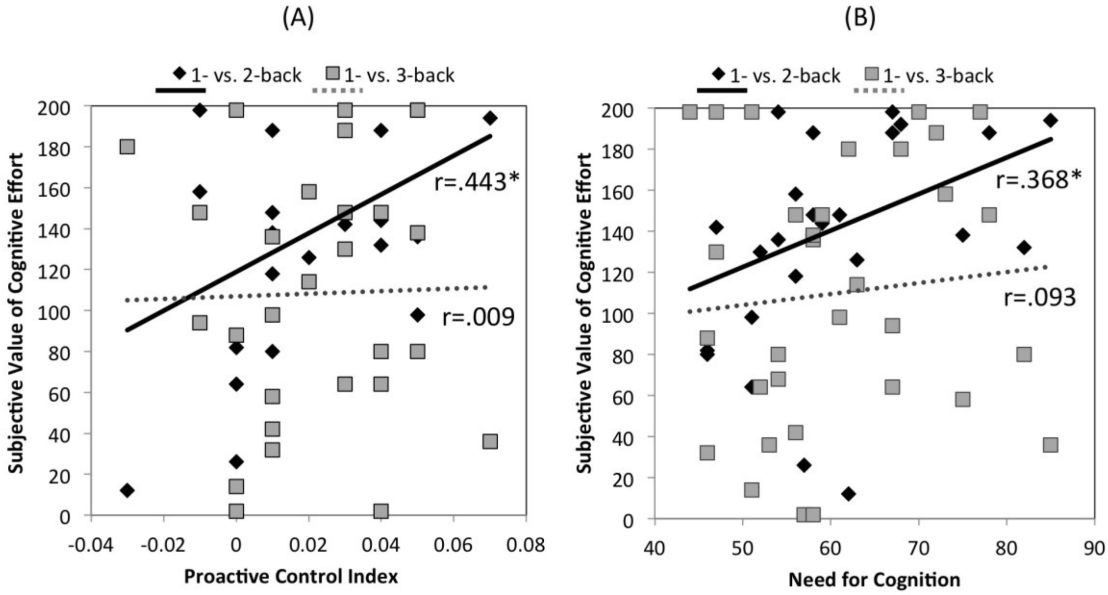

Figure 3. Raw correlations between the subjective values of cognitive effort and proactive control (A) or Need for Cognition Scale scores (B) in Study 2. Correlations were significant with the subjective value of cognitive effort for choices between 1- and 2-back, but not 1- and 3-back.

Table 1

Accuracy and log-transformed response times (RTs) on the AX Continuous Performance Task (AX-CPT).

Trial type	Accuracy		Log-transformed RTs	
	M	*SD*	*M*	*SD*
AX trials	0.91	0.08	6.12	0.27
AY trials	0.73	0.25	6.38	0.24
BX trials	0.71	0.33	6.11	0.37
BY trials	0.78	0.26	6.20	0.39

M = mean; *SD* = standard deviation; RTs = response times.

Appendix A

Child-friendly version of the Need for Cognitive Scale (NCS) adapted from Cacioppo et al. (1996)

1. I would prefer difficult to simple problems.
2. I like to have the responsibility of handling a situation that requires a lot of thinking.
3. Thinking is not my idea of fun.*
4. I would rather do something that requires little thought than something that is sure to challenge me.*
5. I try to anticipate and avoid situations where there is likely a chance I will have to think in depth about something.*
6. I enjoy thinking hard and for long hours.
7. I only think as hard as I have to.*
8. I prefer to think about small, daily projects to long-term ones.*
9. I like tasks that require little thought once I’ve learned them.*
10. The idea of relying on thought to make my way to the top appeals to me.
11. I really enjoy a task that involves coming up with new solutions to problems.
12. Learning new ways to think doesn’t excite me very much.*
13. I prefer my life to be filled with puzzles that I must solve.
14. The notion of thinking abstractly is appealing to me.
15. I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.
16. I feel relief rather than satisfaction after completing a task that required a lot of mental effort.*

17. It’s enough for me that something gets the job done; I don’t care how or why it works.*

18. I usually end up thinking about issues even when they do not affect me personally.

* Items marked with an asterisk were reverse-coded.