



UvA-DARE (Digital Academic Repository)

Individual differences in adolescents' willingness to invest cognitive effort: Relation to need for cognition, motivation and cognitive capacity

Kramer, A.-W.; Van Duijvenvoorde, A.C.K.; Krabbendam, L.; Huizenga, H.M.

DOI

[10.1016/j.cogdev.2020.100978](https://doi.org/10.1016/j.cogdev.2020.100978)

Publication date

2021

Document Version

Final published version

Published in

Cognitive Development

License

CC BY

[Link to publication](#)

Citation for published version (APA):

Kramer, A.-W., Van Duijvenvoorde, A. C. K., Krabbendam, L., & Huizenga, H. M. (2021). Individual differences in adolescents' willingness to invest cognitive effort: Relation to need for cognition, motivation and cognitive capacity. *Cognitive Development*, 57, [100978]. <https://doi.org/10.1016/j.cogdev.2020.100978>

General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

UvA-DARE is a service provided by the library of the University of Amsterdam (<https://dare.uva.nl>)



ELSEVIER

Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Cognitive Development

journal homepage: www.elsevier.com/locate/cogdev

Individual differences in adolescents' willingness to invest cognitive effort: Relation to need for cognition, motivation and cognitive capacity

Anne-Wil Kramer^{a,*}, Anna C.K. Van Duijvenvoorde^{b,c}, Lydia Krabbendam^d,
Hilde M. Huizenga^{a,e,f}

^a Department of Developmental Psychology, University of Amsterdam, Amsterdam, The Netherlands

^b Department of Developmental Psychology, Institute of Psychology, Leiden University, Leiden, The Netherlands

^c Leiden Institute for Brain and Cognition, Leiden University, Leiden, The Netherlands

^d Department of Clinical Developmental Psychology, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

^e Amsterdam Brain and Cognition Center, The Netherlands

^f Research Priority Area Yield, The Netherlands

ARTICLE INFO

Keywords:

Cognitive effort
Effort discounting
Need for cognition
Motivation
Cognitive capacity

ABSTRACT

There exist large individual differences in students' willingness to invest cognitive effort within the academic domain. In a preregistered study, we investigated whether individual differences in adolescents' willingness to invest cognitive effort, as assessed by an experimental effort discounting task, were related to need for cognition, academic motivation and cognitive capacity. We found that adolescents' willingness to invest cognitive effort was related to need for cognition and cognitive capacity as indexed by task-performance. Our results demonstrate that individual differences in need for cognition and cognitive capacity contribute to differences in adolescents' cognitive effort-investment, but academic motivation does not.

1. Introduction

Most secondary school teachers would agree that there exist large individual differences in students' willingness to invest cognitive effort. Yet, it is unclear what underlies these individual variations. Earlier studies observing individual differences in willingness to invest cognitive effort in adults (Westbrook, Kester, & Braver, 2013), and children (Chevalier, 2018), have related these differences to a person's *need for cognition*, a trait best described as an individuals' motivation to enjoy and engage in cognitively challenging tasks (Cacioppo & Petty, 1982). Until now, no studies have investigated this relationship in adolescent populations, and it is furthermore still unclear what other factors, besides need for cognition, might be associated with adolescents' willingness to invest cognitive effort. As adolescents spend a substantial part of their time at schools where considerable cognitive effort-investment is required, the focus of the current study lies within the school domain. As such, the goal of the current study is threefold. First, we study whether the relationship between willingness to invest cognitive effort and need for cognition is also present in an adolescent sample. Second, we assess whether adolescents' willingness to invest cognitive effort is related to academic motivation. Third, we assess whether willingness to invest cognitive effort is related to academic and cognitive achievement skills, including grades, working memory performance, and general

* Corresponding author at: Nieuwe Achtergracht 129-B, 1018 WS Amsterdam, The Netherlands.

E-mail address: a.kramer@uva.nl (A.-W. Kramer).

<https://doi.org/10.1016/j.cogdev.2020.100978>

Received 3 March 2020; Received in revised form 15 November 2020; Accepted 18 November 2020

Available online 24 December 2020

0885-2014/© 2020 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license

(<http://creativecommons.org/licenses/by/4.0/>).

cognitive capacity.

Recently, a cognitive effort discounting (COG-ED) paradigm was developed in order to experimentally assess individual's willingness to invest cognitive effort (Westbrook et al., 2013). The key feature of the COG-ED is that participants make multiple choices between performing a high-effort task for a large reward or a low-effort task for a small reward. The standard COG-ED paradigm is in the domain of working memory, in which low and high-effort can be easily varied by incorporating different levels of an N-back task (Westbrook et al., 2013; Chevalier, 2018). This effort discounting paradigm relies on an adaptive algorithm, in which on sequential trials, the offer for the low-effort task will increase after the high-effort option was chosen, but decrease after the low-effort option was chosen. In this way, an indifference point is identified. If the indifference point is high, this reflects that someone was more willing to exert cognitive effort, while if the indifference point is low, someone was less willing to invest cognitive effort. In this way, the COG-ED allows willingness to invest cognitive effort to become quantifiable.

A common framework views a person's decision to invest cognitive effort as a cost-benefit analysis, where costs relate to cognitive control engagement and benefits relate to some (mostly monetary) reward (e.g. Chong, Bonnelle, & Husain, 2016; Shenhav et al., 2017; Westbrook & Braver, 2015; Inzlicht, Shenhav, & Olivola, 2018). In this way, computations that weigh costs and benefits of actions guide allocation of cognitive control to obtain a certain reward. This cost-benefit framework is supported by studies in adults and children. That is, adults (Botvinick, Huffstetler, & McGuire, 2009; Kool, McGuire, Rosen, & Botvinick, 2010; McGuire & Botvinick, 2010; Westbrook et al., 2013) and children (Chevalier, 2018) tend to avoid tasks when required cognitive control in those tasks increases, while cognitive control engagement increases as cost-benefit ratios become more advantageous. However, this cost-benefit analysis for deciding to invest cognitive effort has never been studied in adolescents.

Adolescence is characterized as a period in which cognitive control steadily increases (Crone, Wendelken, Donohue, van Leijenhorst, & Bunge, 2006; Zelazo, Craik, & Booth, 2004), and is also known as a period of heightened sensitivity to reward (e.g. Crone & Dahl, 2012). Therefore, during adolescence there may exist pronounced individual differences in both cognitive control and in reward sensitivity, the key components involved in the decision whether and how much cognitive effort should be invested. The degree to which cognitive control is engaged is constrained by cognitive capacity (Shenhav et al., 2017). This is supported by work demonstrating that cognitive effort avoidance is more prevalent in adults with limited cognitive capacity (Kool et al., 2010 see Kool & Botvinick, 2018 for a review). We therefore expect that individual differences in adolescent's willingness to invest cognitive effort for a reward are related to individual differences in cognitive capacity (i.e. working memory and general cognitive capacity) and to individual differences in reward sensitivity.

Studying how adolescents translate cognitive effort into cognitive control engagement is especially relevant within their academic context, as cognitive control engagement is important for academic achievement. For example, students may strategically engage cognitive control just to pass a course. It is therefore important to study whether individual differences in adolescent's academic motivation may be reflected in their degree of effort-discounting. Within the literature, academic motivation has been studied in the context of self-determination theory (SDT; Deci & Ryan, 2000), where a distinction is made between autonomous and controlled motivation. Autonomous motivation is in its turn subdivided into identified and intrinsic motivation, and controlled motivation is subdivided into introjected and extrinsic motivation. Autonomous motivation stems from volitional motives (e.g. personal interest), whereas controlled motivation is characterized by an external perceived locus of causality (e.g. pressure from parents) (Vansteenkiste, Sierens, Soenens, Luyckx, & Lens, 2009). The type of academic motivation that is most important for willingness to invest cognitive effort is not clearly understood. For instance, adolescents' intrinsic motivation to master a subject was found to be related to long-term effort investment for this subject (Wentzel, 1996). Furthermore, a qualitative study showed that students who were intrinsically motivated indicated to deliberately invest more effort for schoolwork (Mcinerney, Dowson, & Mcinerney, 2003). On the other hand, it has also been found that adolescents motivated themselves to invest effort in schoolwork mostly by using strategies related to controlled forms of motivation, such as performance goals (i.e. they want to perform better than others) or perceived expectations from others (Wolters, 1999). Others have also stressed the importance of more extrinsically driven motivation for actual effort investments in school (Hidi, 2000). Thus, we test whether willingness to invest cognitive effort is related to autonomous or controlled forms of academic motivation. If this is found to be the case, COG-ED might serve as experimental proxy to academic motivation in future research in addition to the use of questionnaires.

To summarize, the current study investigated whether adolescents' willingness to invest cognitive effort is related to individual differences in 1) need for cognition, 2) academic motivation, and 3) cognitive capacity. This is important in order to a) increase the overall validity of the COG-ED in a developmental sample (by demonstrating a relationship with need for cognition in adolescents), and b) to enhance understanding of the role of willingness to invest cognitive effort within the academic domain. We tested this in a preregistered study. To foreshadow the results, willingness to invest cognitive effort in adolescents was related to need for cognition and cognitive capacity as assessed by task performance, but not to academic motivation.

2. Method and materials

This study was preregistered at Open Science Framework and can be found here <https://osf.io/6tbyn/>. All materials and methods matched the pre-registration. A pre-registered pilot-study for the current study is described in the supplementary materials.

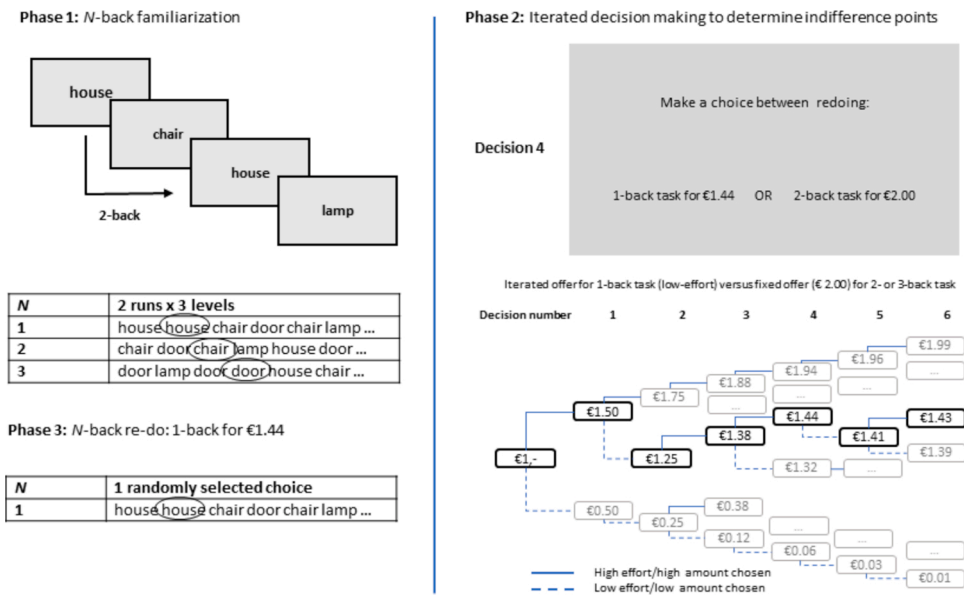


Fig. 1. Schematic overview of the COGED task. Phase 1 shows N-back familiarization, phase 2 shows an example of 1 effort discounting trial, below which a possible sequence of 1-back offers is shown, where the points represent the offer for the 1-back task. Here the sequence was: 1) high, 2) low, 3) high, 4) high, 5) low, 6) high. The top path represents the points offered when the high-effort option would always be chosen, while the bottom path represents the points offered when the low-effort option would always be chosen. *Note:* Not all possible options displayed. Phase 3 shows the N-back repeat phase. In this case, a 1-back task was randomly picked to repeat for €1.44 (i.e. choice on decision-trial 4 in phase 2). *Adapted from Westbrook et al. (2013).*

3. Method

3.1. Participants

A G*Power (version 3.1.9.2; [Faul, Erdfelder, Lang, & Buchner, 2007](#)) analysis indicated that a total of 193 participants was required to achieve an intended power of 0.80, using a correlational bivariate normal model with an expected correlation of small to medium (medium: as in [Westbrook et al., 2013](#) and [Chevalier \(2018\)](#), small: as was obtained in the a pilot-study) and a one-tailed hypothesis (positive correlation). A total of 306 secondary school students participated in this study. The students were recruited from four different schools in several medium-sized cities in the Netherlands. The level of the schools represented almost the full range of levels within the Dutch school system, excluding special needs education. The study was approved by the Ethics Review Board of the Psychology Department from the University of Amsterdam. All participating students gave informed consent, and in addition parental passive or active consent (depending on school preferences) was obtained. A total of 12 participants were excluded from the analyses due to incomplete data: 8 because the software did not record some crucial responses, and 4 because they quit the experiment prematurely. Four participants were detected as outliers ($>/< 3 SD$ from the mean on an independent variable, that is, on math GPA). However, the results did not change whether they were included in the analyses or not. Therefore we decided to retain these participants, leaving a total of 294 participants aged between 13 and 17 years ($M = 14.76$ years, $SD = 0.71$ years, $N_{females} = 121$).

3.2. Procedure

Participation in this study involved one session which took place at the school of the students. During this session, a group of students, varying between a minimum of 15 and a maximum of 28, performed the COG-ED task, the Raven and several questionnaires on their own computer or laptop. The full test-battery took between 50 and 80 min. A minimum of two and a maximum of four experimenters were always present. The COG-ED task was programmed and administered using NeuroTask Scripting Beta, (www.scripting.neurotask.com), an online test-taking environment. All other measures were administered using Qualtrics Survey Software (Qualtrics, Provo, UT). During test-taking teachers rated academic motivation and cognitive ability for each student.

3.3. COG-ED task

The cognitive effort discounting (COG-ED) task consisted of three phases. Each session started with N-back familiarization in order for participants to get accustomed to tasks varying in required level of cognitive effort (phase 1). Phase 1 was followed by effort discounting (phase 2). Finally, to ensure a real consequence of their effort discounting choices, participants repeated an additional N-back level (phase 3) based on a random selection from one of the choices they made in the effort discounting phase.

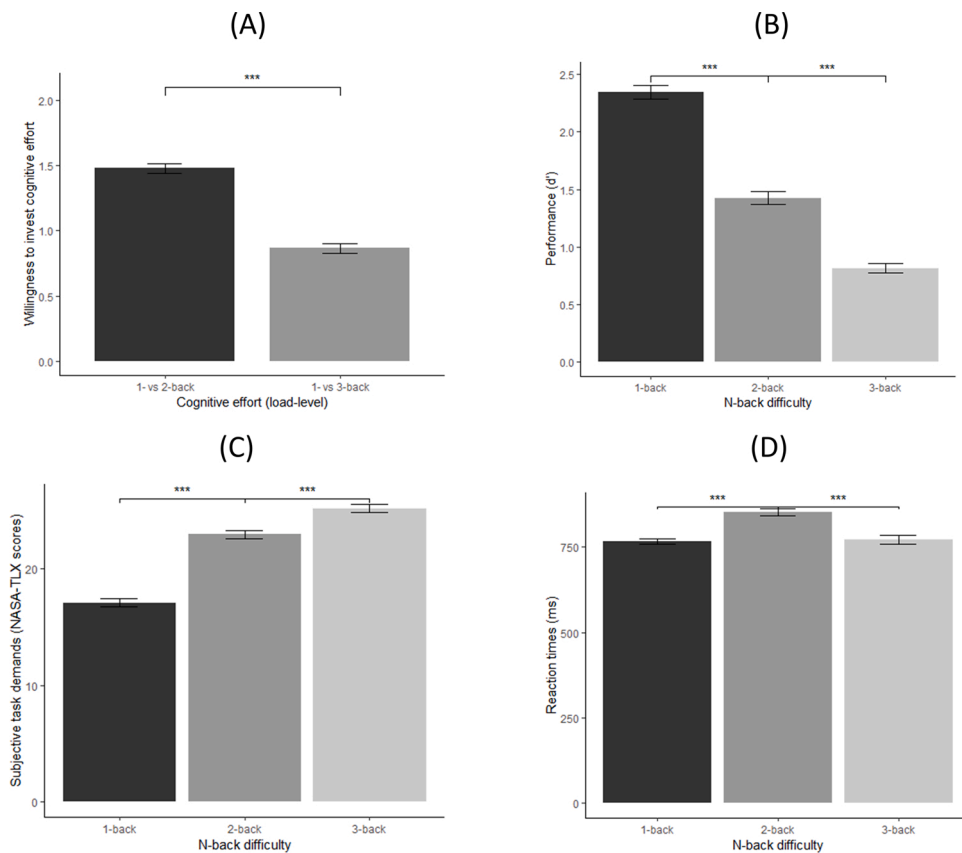


Fig. 2. A) Willingness to invest cognitive effort (assessed by indifference points) was higher for 1- vs 2-back choices than for 1- vs 3-back choices. B) Performance decreased as N-back difficulty increased (right). C) Subjective task demands increased as N-back difficulty increased from 1- to 2-back, but not from 2- to 3-back. D) Reaction times increased as N-back difficulty increased from 1- to 2-back, but decreased from 2- to 3-back. *Note:* error bars denote +/- SEM across participants. *Note:* * $p < .05$, ** $p < .01$, *** $p < .001$.

We adapted the stimuli used during the N-back task in the first phase of the COG-ED task designed by Westbrook et al. (2013) by using words instead of single letters because: 1) This allows us to manipulate the desirability of stimulus content in future experiments (e.g. desirable words relating to music or undesirable words relating to politics, and 2) It taps into the cognitive domain of language, which may resemble content that is learned at schools more closely than a classical N-back task.

Additionally, the NASA-Task-Load-Index (NTLX) (Hart & Staveland, 1988) was administered after every N-back level to assess subjective task demands. An example item of the NTLX is: “how hard did you have to work to accomplish your level of performance?”. For each of the five items of the NTLX, participants answered on a 7-point scale, ranging from 1 = “not at all” to 7 = “very much”. In the first phase (Fig. 1), participants performed a 1-, 2-, and 3-back load level of the N-back task in succession, to get experience with the varying difficulties of the N-back load levels. In the N-back tasks, participants viewed a sequence of words and had to indicate, for each current word, whether it matched the word n items back. When the word was different from the word n items back (nontarget), participants pressed a button on the keyboard, and when the word was the same as the word n items back (target), they pressed another button on the keyboard. Items consisted of four-letter neutral Dutch words starting and ending with consonants with two vowels in between (40-point Calibri font with a different color for each load-level; see also Appendix C). In order to ensure that students fully understood what was expected from them during the N-back tasks, they performed two practice blocks of 12 trials before each N-back level in addition to control-questions. The control-questions showed a potential sequence of words with the correct response below each word, with one response being a question mark. Students had to indicate what button they should press, and received feedback on their answer. If incorrect, instructions indicated to raise their hand and ask for additional instructions from the experimenters. Each experimental N-back level consisted of 64 trials, twenty-five percent of which contained targets. Participants had 2 s to respond to each item with a button press, whereafter the item was replaced by a blank screen and followed by a 1 s fixation cross. Participants were presented with feedback about their percentage correct for targets and nontargets at the end of each experimental N-back load level. In the second phase, participants performed the effort discounting task. In this phase, participants were presented with runs of six choices between a low-effort task for a small reward (i.e. 1-back for €1) or a high-effort task for a larger reward (i.e. 2- or 3-back for €2). It is important to note, however, that increasing reward incentives can increase cognitive control allocation (Sandra & Otto, 2018; Westbrook et al., 2013; Westbrook, Lamichhane, & Braver, 2019). In our pilot study, we used hypothetical rewards (i.e. points) which were most likely not incentivizing enough (see supplementary materials). We therefore used monetary rewards in the main

experiment. During effort-discounting, participants first made six choices between redoing a 1-back or a 2-back task, after which they made an additional six choices between redoing a 1-back or a 3-back task. Analogous to adjusting-immediate-amount procedures (Holt, Green, & Myerson, 2012; as reported in Westbrook et al., 2013), the choices they made were always between a smaller variable reward (starting at €1) for the easiest load level (i.e. 1-back) and a larger fixed reward (€2) for each of the more difficult load levels ($N\text{-back} > 1$). When participants selected the high-effort task (i.e. 2- or 3-back), the amount offered for the low-effort task (i.e. 1-back) was increased on the next trial. If they selected the low-effort task, the amount offered for the low-effort task on the next trial was decreased. Each in- or decrease was half as much as on the previous trial. (see Fig. 1 for a schematic display). The resulting reward offered for the low-effort task after 6 choices (i.e. the €1.43 in the example below) was taken as the *indifference point* and reflected a person's willingness to invest cognitive effort. If the indifference points are high, this indicates that someone was willing to expend a large amount of cognitive effort, while when the indifference points are low, someone was less willing to invest much cognitive effort.

To ensure participants understood all phases of the effort-discounting phase, clear step-by-step instructions were given. Similar to other studies using COG-ED, we indicated that one of their chosen effort levels would need to be repeated 'for a few times'. To ensure that participants would not simply choose the task with the largest reward without intending to put in effort while redoing it, they were further instructed that they would only receive the money if they maintained effort while repeating the randomly selected level, and that the experimenters as well as the computer could monitor their effort (as in Westbrook et al., 2013 and Chevalier, 2018). In the third phase, participants repeated 12 trials from one of the levels randomly selected from among their choices in phase 2. If a participant repeated a 2- or 3-back level, the money they received was always €2, as the amount was fixed. However, if a participant repeated a 1-back level, the money belonging to that level could vary from €0.02 to €1.98, depending on the choices they made in phase 2 (see Fig. 1 for a schematic display). At the end, participants received the money belonging to the level they repeated (Fig. 2).

3.4. Need for cognition

Need for cognition was assessed with the Need for Cognition Scale (NCS) developed by Cacioppo, Petty and Feng Kao (1984) which assesses someone's enjoyment of and engagement in cognitively demanding tasks. The NCS is a self-report questionnaire consisting of 18 items with good internal consistency ($r = .95$, Cacioppo & Petty, 1982; $r = .91$, Sadowski & Gulgoz, 1992) and test-retest reliability ($\alpha = .90$, Cacioppo & Petty, 1982; $\alpha = .88$, Sadowski & Gulgoz, 1992). An example item is: "I really enjoy a task that involves coming up with new solutions to problems". Participants had to answer on a 5-point Likert scale varying from 1 = "extremely uncharacteristic of me" to 5 = "extremely characteristic of me".

3.5. Academic motivation

Academic motivation was assessed with the Academic Self-Regulation Questionnaire (SRQ-A; Vansteenkiste et al., 2009). This is an adapted version of the classical Self-Regulation Questionnaire (SRQ) by Deci, Connell, and Ryan (1989) and measures several types of motivation. The SRQ-A consists of 16 items divided into two factors: autonomous- and controlled motivation. The SRQ-A has been translated into Dutch and shows good internal consistency for both scales ($\alpha = .87$ and $\alpha = .72$ respectively) (Vansteenkiste et al., 2009). The autonomous motivation factor is further divided into the subscales intrinsic motivation ($\alpha = .89$) and identified regulation ($\alpha = .79$). The controlled motivation factor is divided in the subscales introjected regulation ($\alpha = .69$) and external regulation ($\alpha = .77$). The questionnaire starts with "I am studying..." and then 16 motives (items) are provided for which participants indicated on a 5-point Likert scale, varying from 1 = "completely not important" to 5 = "very important", how important each of the motives was to him or her to study. An example is "I am studying because others (parents, friends etc.) oblige me to."

3.6. Cognitive capacity: Raven

General cognitive capacity or (non-verbal) fluid intelligence was assessed using the 20-minute version of the Standard Progressive Matrices (SPM-20) (Hamel & Schmittmann, 2006). The SPM-20 is a speeded version of the original SPM and consists of 60 items. The items are visual geometric designs with a missing piece. Participants had to select the correct missing part among six to eight options. The correlation between the SPM-20 and original SPM is $r = .74$ (Hamel & Schmittmann, 2006), indicating that it serves as a reasonable alternative for the longer version.

3.7. Cognitive capacity: N-back performance (working-memory)

We used participants' N-back performance from the first phase of the COG-ED task as a measure of cognitive capacity.

3.8. Teacher ratings of motivation and cognitive capacity

To obtain a comprehensive picture of students' motivation and abilities, we asked students' mentors to fill out evaluations of each student's 1) academic motivation, and 2) cognitive capacity. These teacher-ratings were given on a 10-point Likert scale that was self-constructed (see Appendix B).

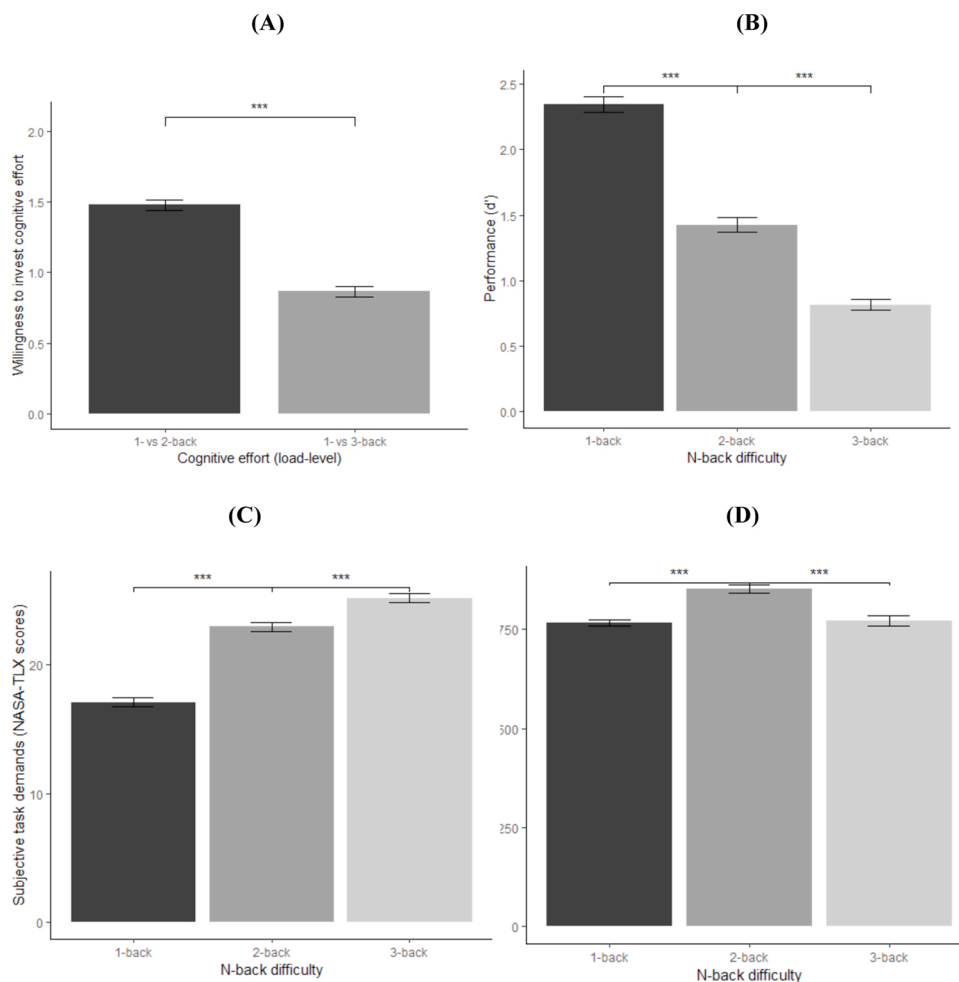


Fig. 3. A) Willingness to invest cognitive effort was higher for 1- vs 2-back choices than for 1-vs 3-back choices. B) Performance decreased as N-back difficulty increased. C) Subjective task demands increased as N-back difficulty increased from 1- to 2-back, but not from 2- to 3-back. D) Reaction times increased as N-back difficulty increased from 1- to 2-back, but decreased from 2- to 3-back. *Note:* error bars denote \pm SEM across participants. *Note:* *** $p < .001$.

3.9. Sensitivity to reward and drive

As the COG-ED paradigm uses rewards (i.e. points) to calculate someone's willingness to invest cognitive effort, individual differences in sensitivity to rewards and the drive to obtain some reward may influence the indifference points. Therefore, the reward responsiveness scale and the drive scale from the Behavioral Activation System Scales (BAS; Carver & White, 1994) were administered. We preregistered to include (one of) those scales as covariate(s) in the analyses if they would significantly affect the indifference points. The BAS reward responsiveness scale consists of 5 statements and participants indicated for each statement on a 4-point scale how true it was for them, ranging from 1 = "very true for me" to 5 = "very false for me". This scale shows acceptable internal consistency, $\alpha = .65-.73$ (Carver & White, 1994; Jorm et al., 1998). An example item is: "When I'm doing well at something, I love to keep at it". Additionally, the BAS drive scale consists of 4 statements that had to be answered according to the same format as the reward responsiveness scale. Reliability varies from $\alpha = .76-.80$ (Carver & White, 1994; Jorm et al., 1998). An example item is "When I want something, I usually go all-out to get it".

3.10. Academic engagement

In addition, we assessed academic engagement with the Perceived Academic Engagement Scale (PAES; Chen, 2005), which measures the quality of students' own academic engagement. The PAES consists of 26 items that are answered on a 5-point Likert scale, varying from 1 = "completely disagree" to 5 = "completely agree". An example item is: "I put full effort into schoolwork." We also asked how many hours, on average, they spent on homework each week.

Table 1Performance (d'), response times (RT) and experienced task demands and effort (NASA-TLX) per load level.

Load level (N)	d'		RT (ms)		NASA-TLX sum scores	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
1	2.34	1.00	765.38	130.55	17.07	5.66
2	1.43	0.90	851.33	165.13	22.92	6.01
3	0.81	0.72	771.98	226.78	25.13	6.13

*Note d' and RT used $N = 294$, NASA-TLX used $N = 285$.**Table 2**

Main- and interaction effects on the indifference points.

Independent variables	DF	Main effects			Interaction effects		
		<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2
<i>Need for cognition</i>							
NCS	291	5.286	.022* ¹	.018	1.913	.168	.007
<i>Academic motivation</i>							
SRQ-A: extrinsic (controlled)	291	0.913	.340	.003	0.995	.319	.003
SRQ-A: introjected (controlled)	291	0.005	.946	.000	1.424	.234	.005
SRQ-A: intrinsic (autonomous)	291	0.755	.386	.003	4.322	.038*	.015
SRQ-A: identified (autonomous)	291	0.389	.533	.001	0.134	.714	.000
Homework hours	291	2.000	.158	.007	0.704	.402	.002
PAES	291	2.279	.132	.008	0.956	.329	.003
Teacher-ratings motivation	268	0.021	.886	.000	0.851	.357	.003
<i>Cognitive ability</i>							
Teacher-ratings cognitive ability	268	3.703	.055	.014	0.545	.461	.002
Raven	281	0.055	.814	.000	0.448	.504	.002
Performance 1-back	291	1.641	.201	.006	0.630	.428	.002
Performance 2-back	291	1.990	.159	.007	4.594	.033*	.016
Performance 3-back	291	6.255	.013* ¹	.021	0.945	.332	.003
<i>Academic achievement</i>							
Dutch grade	291	0.760	.384	.003	0.612	.435	.002
English grade	291	2.660	.104	.009	0.850	.357	.003
Math grade	282	0.536	.465	.002	0.211	.646	.001
<i>Sensitivity to reward and drive</i>							
BAS reward sensitivity	291	0.080	.777	.000	0.000	.994	.000
BAS drive	291	0.155	.694	.001	0.057	.812	.000
<i>Other</i>							
School-level	290	2.933	.055	.020	0.264	.768	.002

Note: η^2 is partial η^2 ; * $p < .05$ ¹The effect of NCS on the indifference points still held when assessed in a multilevel model with random intercepts in which participants were nested within classrooms, $\beta = 0.007$, $p = .014$, as did the effect of performance on the 3-back task, $\beta = 0.104$, $p = .006$. These multilevel analyses were not pre-registered and thus exploratory.

3.11. Academic achievement

Next, we asked students to report their grade point average (GPA) for the courses English, Dutch and Math. These are compulsory courses for all students and have been shown to be valid estimators of academic achievement (Reed, Ouweland, Van der Elst, Boschloo, & Jolles, 2010). We added these measures because real-life measures of academic achievement and effort-investment (homework-hours) might be more closely related to experimental tasks than questionnaires.

3.12. Statistical analyses

We entered both indifference points (1 vs 2-back and 1- vs 3-back) as repeated measures (RM) and performed a separate RM-ANOVA per predictor variable. If the assumption of sphericity was violated, analyses were Greenhouse-Geisser corrected. All analyses were performed in IBM SPSS statistics version 24.0.

4. Results

4.1. Manipulation checks and descriptives

As expected, a paired t -test between the two indifference points indicated that willingness to invest effort decreased as N-back load-level increased, $t(293) = 16.998$, $p < .001$ (1- vs 2 indifference point $M = 1.48$, $SD = 0.61$, 1- vs 3 indifference point $M = 0.87$, $SD = 0.66$; see Fig. 3a). This demonstrates that adolescents report a lower willingness to exert effort for more effortful tasks.

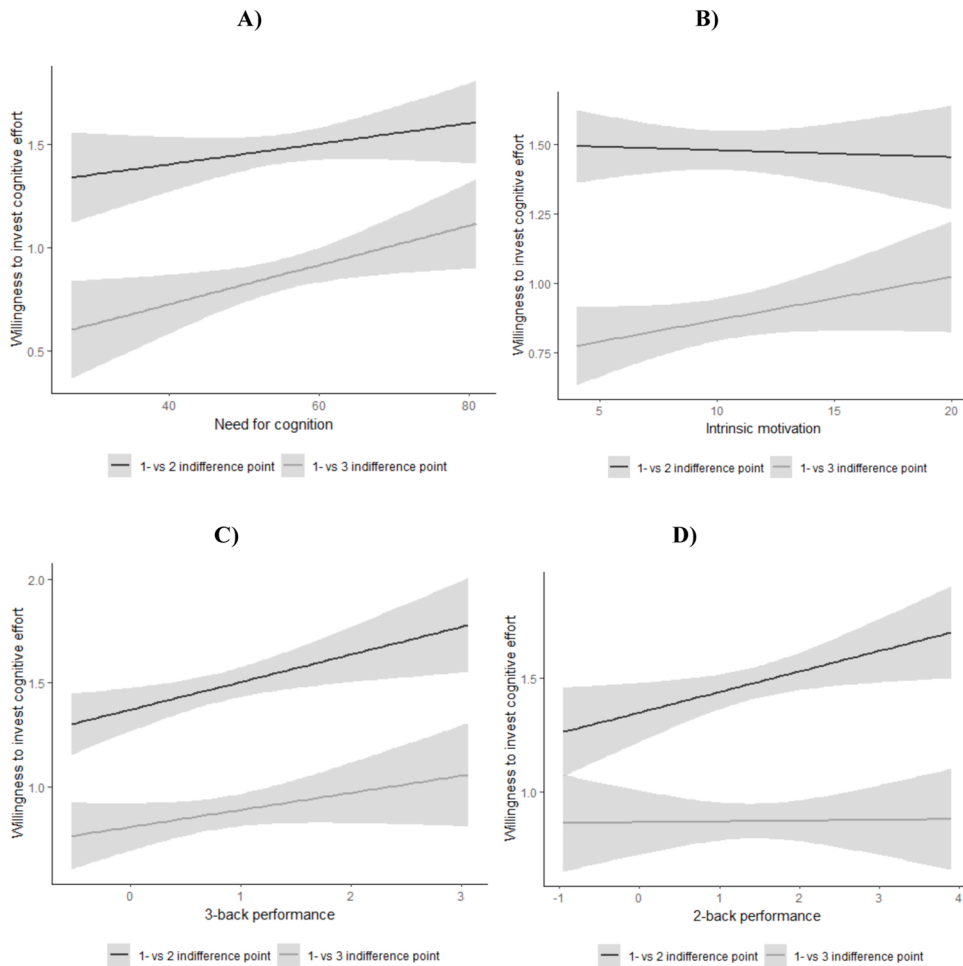


Fig. 4. A) The positive relation between NCS scores and the indifference points. B) The interaction effect between intrinsic motivation scores from the SRQ-A and the indifference points. C) The positive relation between 3-back performance and the indifference points. D) The interaction effect between 2-back performance and the indifference points. D) *Note:* shaded regions show 95 % CI.

We found linear effects of N-back load-level on N-back performance and subjective experienced effort, indicating that as N-back load-level increased, performance decreased, $F(1.856, 543.697) = 340.079, p < .001$ (Table 1 and Fig. 3b), and NASA-TLX scores increased, $F(1.773, 461.050) = 285.802, p < .001$ (Table 1 and Fig. 3c). In addition, we found an effect of N-back load-level on reaction times (RT), $F(1.618, 474.148) = 40.103, p < .001$. Visual inspection and within subject contrasts showed that the effect was quadratic $F(1, 293) = 153.025, p < .001$. Post-hoc t-tests indicated that RTs were longest in the 2-back task (Table 1 and Fig. 3d) (see for RM-ANOVA results Table 2).

4.2. Willingness to invest cognitive effort and need for cognition

We found a significant main effect of NCS scores on the indifference points, $F(1, 291) = 5.286, p = .022$. A higher NCS score was associated with more willingness to redo effortful N-back tasks, 1- vs 3 indifference point, $\beta = 0.010, p = .010$, but non-significantly related to the 1- vs 2 indifference point, $\beta = 0.005, p = .163$. (Fig. 4a).

4.3. Willingness to invest cognitive effort and academic motivation

No main or interaction effects were observed from SRQ-A scores, PAES scores, homework hours nor teacher ratings of motivation on the indifference points. We, however, found a significant interaction between the indifference points and the subscale intrinsic motivation of the SRQ-A (Table 2). This finding indicated that intrinsic motivation was not related to the 1- vs 2 indifference point, $\beta = -.014, p = .813$, yet tended to be related to the 1- vs 3 indifference point, $\beta = .104, p = .074$ (Fig. 4b). This interaction seems to suggest that students with high intrinsic motivation were more willing to redo the 3-back but not the 2-back task.

4.4. Willingness to invest cognitive effort and cognitive capacity

Cognitive capacity measures including the Raven, teacher-ratings, as well as our performance measures of the 1- and 2-back tasks showed no significant main effects on the indifference points. We did, however, observe a significant main effect of 3-back performance on the indifference points, where better 3-back performance was related to more willingness to redo the more effortful 2- and 3-back tasks (Fig. 4c and Table 2). Next, we did not find significant interaction effects between Raven scores, teacher ratings nor performance measures of the 1- and 3-back tasks. Yet there was a significant interaction effect between performance on the 2-back task and the indifference points where better performance on the 2-back task was positively related to the 1- vs 2 indifference point, $\beta = .137, p = .019$, but not to the 1- vs 3 indifference point, $\beta = .012, p = .842$ (Fig. 4d). This indicates that increased task-performance on the 2-back task is related to increased willingness to redo the 2-back but not the 3-back task.

4.5. Willingness to invest cognitive effort and academic achievement

No main and interaction effects were found between the indifference points and indices of academic achievement, including GPA for the courses Dutch, English and math and school level (Table 2).

Taken together, these results indicate that adolescents' willingness to invest cognitive effort, as assessed by the indifference points in the COG-ED task, was positively related to need for cognition. Additionally, willingness to invest cognitive effort was also positively related to performance on the N-back tasks, suggesting that participants' task-performance affected to what degree they were willing to redo those tasks.

4.6. Exploratory analyses: controlling for n-back performance

As n-back performance affects willingness to invest cognitive effort within COG-ED, we explored whether the observed effects on the indifference points were maintained after controlling for n-back performance. We therefore combined 1-, 2-, and 3-back performance scores (d') into a mean performance score and added this as a covariate. We found that the main effect of NCS on the indifference points was not significant anymore, $F(1, 290) = 3.279, p = .071$. In the same model, the effect of n-back performance was also non-significant, $F(1, 290) = 2.827, p = .094$, and we observed no interaction between performance and the indifference points. Other main or interaction effects were not affected by adding n-back performance as a covariate (see supplementary materials).

4.7. Exploratory analyses: correlations

In Appendix A we report correlation matrices between all variables. Most motivation measures correlated positively with each other, with teacher ratings of motivation, and with need for cognition. Cognitive ability measures also correlated positively with each other, with teacher ratings of ability, and with need for cognition. This indicates that our measures, including our self-designed teacher evaluations, assessed similar underlying constructs and thus contributed to a comprehensive assessment of both motivation and cognitive ability.

5. Discussion

This preregistered study was the first to administer the experimental cognitive effort discounting (COG-ED) task in an adolescent sample in order to measure willingness to invest cognitive effort. The main aim was to investigate relationships between adolescents' willingness to invest cognitive effort and need for cognition, academic motivation, and cognitive capacity.

We found that the COG-ED was related to need for cognition, as was also observed in adults by Westbrook et al. (2013) and in children (7–12 years) by Chevalier (2018). Our finding thus suggests that adolescents who enjoy thinking display larger willingness to invest effort in cognitively challenging tasks. Note, however, that this relationship between the indifference points and Need for Cognition was not observed in the pilot-study. Reasons for this might be twofold. First, the sample in the pilot-study was recruited from a homogenous educational level, thereby limiting variance in both the indifference points and need for cognition measures. Second, the hypothetical rewards in the pilot were not incentivizing enough, as we observed that the 1-back option was chosen more often in the pilot compared to the main experiment, and as we observed more variance in indifference points in the main compared to the pilot experiment (see supplementary materials). These findings suggest that it is important for future studies into adolescent effort-discounting to carefully choose rewards, and that real as opposed to hypothetical rewards may be necessary to elicit meaningful effort-based decision-making.

As we found hardly any associations with academic motivation, we conclude that the COG-ED task in its current form cannot be used as an index for academic motivation. This might be related to a discrepancy in learning goals between school work and the COG-ED. Whereas they are clear for schoolwork, they may be less clear for the N-back tasks embedded within the COG-ED. Future studies could take this into account, for example by not using the N-back but different tasks with more academic-like learning goals, such as word-learning or math. The relations between willingness to invest effort and N-back performance point out that willingness to invest cognitive effort may have partially been driven by anticipated likelihood of successful performance, and might thus be driven by cognitive capacity. This finding is in line with Self-Determination Theory (Deci & Ryan, 2000), predicting that the motivation to engage effort increases when feelings of competence increase. The finding is also in line with self-efficacy theory stating that people's beliefs in their own ability are at the core of their motivation to engage in tasks (Bandura, 2010). Furthermore, exploratory analyses indicated

Table A1
Pearson correlations between indifference points and all measures of cognitive ability.

	IDP12	IDP13	d' 1-back	d' 2-back	d' 3-back	Dutch	English	Math	Raven	Ability NCS
IDP12	1									
IDP13	.55**	1								
d' 1-back	.10	.04	1							
d' 2-back	.13*	.01	.31**	1						
d' 3-back	.14*	.08	.31**	.46**	1					
Dutch	-.06	-.01	.19**	.05	.04	1				
English	.05	.11	.22**	.07	.15*	.33**	1			
Math	.01	.01	.06	.15*	.10	.28**	.05	1		
Raven	.00	-.05	.40**	.44**	.35**	.22**	.24**	.17**	1	
Ability	-.17**	-.07	.26**	.21**	.16*	.44**	.32**	.33**	.34**	1
NCS	.08	.13*	.21**	.14*	.22**	.15*	.21**	.12*	.26**	.21** 1

Note: * $p < 0.05$, ** $p < .01$. Ability represents ability as rated by a teacher of the students.

that the effect of Need for Cognition was not significant anymore after controlling for N-back performance. This suggests that, for adolescents, as compared to both adults (Westbrook et al., 2013) and children (Chevalier, 2018), willingness to invest cognitive effort is driven more by cognitive capacity than by trait interest in effortful activities. This may also indicate that adolescents strategically allocated their cognitive control resources. That is, knowing that redoing a difficult n-back task will cost a great amount of cognitive control whereas performing well seems unrealistic, they may decide that it is not worth their effort. The effect of cognitive capacity seems, furthermore, to be task-specific, as we did not find relations with general cognitive capacity, such as the Raven or academic achievement measures. Moreover, we found no relations with reward sensitivity or drive, indicating that costs of cognitive control may be more important for adolescent's willingness to invest cognitive effort than reward. To test this, however, future studies should vary rewards.

One potential limitation of the COG-ED paradigm is that it uses rewards to quantify effort, therefore individual differences in willingness to invest effort may have been driven by reward sensitivity instead of motivation. To check for this, other studies using the COG-ED (e.g. Westbrook et al., 2013) implemented two incentive amounts, yet found the same effects for both amounts, indicating that the amount itself does not affect the underlying effort-discounting mechanism. In the current study, we included indices of reward sensitivity and drive, which both showed no relation to willingness to invest effort. For these two reasons, we consider it unlikely that the specific choice of rewards may have influenced the results.

Another limitation could be that N-back tasks embedded within the effort-discounting tasks may have been too unrelated to school practice in order to be related to academic motivation. Future studies may consider to embed more school related tasks within the COG-ED, for example math or word learning tasks. We have chosen, however, to first administer COG-ED in its current form, since objective task-load can be varied parametrically.

The current study thus provided evidence that individual differences in adolescents' willingness to invest cognitive effort are related to need for cognition and cognitive capacity. As a result, the current findings indicate that it may be worthwhile to increase students' need for cognition. Individuals with high need for cognition are characterized by their enjoyment of cognitively challenging tasks (Cacioppo, Petty, Feinstein, Blair, & Jarvis, 1996). In school practice, we could therefore aim to increase adolescents' enjoyment of those types of tasks. For example by gamification (for a meta-analysis see Dicheva, Dichev, Agre, & Angelova, 2015). Finally, the effects of task performance indicate that it may be worthwhile to adapt study material to each students' own level or to increase adolescents' feelings of competence, for example by providing positive performance feedback (Ryan & Deci, 2000; Sansone, 1989). Still, as this is the first study that assessed underlying mechanisms of willingness to invest cognitive effort in an adolescent sample, replication of these findings in independent adolescent cohorts is important for future studies. To conclude, this pre-registered study demonstrates that adolescents discount cognitive effort. We showed that need for cognition and cognitive capacity as indexed by task-performance contribute to adolescents' willingness to invest cognitive effort, but academic motivation does not.

Role of funding sources

AK was supported by the Start Impulse grant to NeuroLabNL from the Dutch National Science Agenda (NWA) [grant number 400.17.602]. HH was supported by a VICI grant awarded by the Netherlands Organization of Scientific Research (NWO) [grant number 453-12-005]. LK has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement n° 648082). AvD was supported by an ORA-grant [grant number 464-15-176] (partly) financed by the Dutch Research Council (NWO). The funding source had no role in the study design, collection, analysis or interpretation of the data, writing the manuscript, nor the decision to submit the paper for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Table A2

Pearson correlations between indifference points and all measures of (cognitive) motivation.

	IDP12	IDP13	NCS	SRQ_intri	SRQ_intro	SRQ_extr	SRQ_ident	Homework	Motivation
IDP12	1								
IDP13	.55**	1							
NCS	.08	.13*	1						
SRQ_intri	.00	.10	.53**	1					
SRQ_intro	-.03	.01	.21**	.29**	1				
SRQ_extr	.07	.01	-.12*	-.11	.18**	1			
SRQ_ident	.02	.02	.23**	.34**	.22**	-.10	1		
Homework	-.06	-.11	.13*	.21**	.01	-.16**	.08	1	
Motivation	-.03	.02	.30**	.23**	.17**	-.23**	.21**	.09	1

Note: * $p < 0.05$, ** $p < .01$. Motivation represents motivation as rated by a teacher of the students.

Declaration of Competing Interest

None.

Acknowledgements

We would like to thank Esmee Ris, Myrna Westerveld, Valeria van Thoor, Iris Wierdsma, and Lianne van Schaik for their efforts during data collection.

Appendix A. Correlation matrices between measures aimed to measure similar constructs

Correlations Table A1 indicates that most measures of cognitive ability correlate positively with each other. Regarding the indifference points, we observe that the 1- vs 2 indifference point relates positively only to 3-back performance and negatively to teacher assessed cognitive ability. The 1- vs 3 indifference point showed no relation to any measure of cognitive ability.

Table A2 shows that most measures of self-regulated motivation correlate positively with each other (i.e. the intrinsic and identified autonomous SRQ subscales and the least controlled (i.e. introjected) SRQ subscale) and also with real life measures (i.e. homework time and mentor-rated motivation). Extrinsic motivation (i.e. the most controlled SRQ extrinsic subscale) shows negative correlations with NCS, homework time and teacher evaluated cognitive motivation. The indifference points do not correlate with most measures, except for the relation between the 1- vs 3 indifference point and the NCS.

Appendix B. Self-constructed questions used for obtaining teacher-ratings

a) How do you rate the motivation for cognitively challenging tasks for this student? Indicate the most applicable answer by circling the appropriate number, where 1 = absolutely not motivated and 10 = very motivated.

Original Dutch formulation: Hoe schat u de motivatie voor cognitief uitdagende taken in bij deze leerling? Omcirkel het antwoord dat volgens u het meest van toepassing is op de lijn, waarbij 1 = absoluut niet gemotiveerd en 10 = heel erg gemotiveerd.

b) How do you rate the cognitive abilities of this student? Indicate the most applicable answer by circling the appropriate number, where 1 = very low and 10 = very high.

Original Dutch formulation: Hoe schat u de cognitieve vaardigheden in van deze leerling? Omcirkel het antwoord dat volgens u het meest van toepassing is op de lijn, waarbij 1 = zeer laag en 10 = zeer hoog.

Appendix C. words used as stimuli in the N-back task

Words used in N-back tasks Criteria for neutral words were: a) One syllable b) four different letters c) not obviously related to some subject that may or may not be interesting to people.

1. lamp (lamp in English)
2. trui (sweater in English)
3. deur (door in English)
4. huis (house in English)

Appendix D. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.cogdev.2020.100978>.

References

- Botvinick, M. M., Huffstetler, S., & McGuire, J. T. (2009). Effort discounting in human nucleus accumbens. *Cognitive, Affective & Behavioral Neuroscience*, 9(1), 16–27.
- Cacioppo, J. T., & Petty, R. E. (1982). The need for cognition. *Article in Journal of Personality and Social Psychology*, 42(1), 116–131. <https://doi.org/10.1037/0022-3514.42.1.116>
- Cacioppo, J. T., Petty, R. E., & Feng Kao, C. (1984). The efficient assessment of need for cognition. *Journal of Personality Assessment*, 48(3), 306–307.
- Cacioppo, J. T., Petty, R. E., Feinstein, J. A., Blair, W., & Jarvis, G. (1996). Dispositional differences in cognitive motivation: The life and times of individuals varying in need for cognition. *Psychological Bulletin Col-ight*, 119(2), 197–253.
- Chen, J. J.-L. (2005). Relation of academic support from parents, teachers, and peers to Hong Kong adolescents' academic achievement: The mediating role of academic engagement. *Genetic, Social, and General Psychology Monographs*, 131(2), 77–127. <https://doi.org/10.3200/MONO.131.2.77-127>
- Chevalier, N. (2018). *Willing to think hard? The subjective value of cognitive effort in children*. <https://doi.org/10.1111/cdev.12805>
- Chong, T. J., Bonnelle, V., & Husain, M. (2016). Quantifying motivation with effort-based decision-making paradigms in health and disease. *Progress in brain research* (Vol. 229, pp. 71–100). Elsevier.
- Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology*, 67(2), 319.
- Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social-affective engagement and goal flexibility. *Nature Reviews Neuroscience*, 13(9), 636–650.
- Crone, E. A., Wendelken, C., Donohue, S., van Leijenhorst, L., & Bunge, S. A. (2006). Neurocognitive development of the ability to manipulate information in working memory. *Proceedings of the National Academy of Sciences*, 103(24), 9315–9320.
- Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, 11(4), 227–268.
- Deci, E. L., Connell, J. P., & Ryan, R. M. (1989). Self-determination in a work organization. *The Journal of Applied Psychology*, 74. Retrieved from <http://www.jwalkonline.org/docs/GradClasses/Fall07/OrgPsy/Cases/motivationarticles/PERUSED/sefildeterminationinaworkorg.pdf>.
- Dicheva, D., Dichev, C., Agre, G., & Angelova, G. (2015). Gamification in education: A systematic mapping study. *Educational Technology & Society*, 18(3), 75–88.
- Faul, P. G., Erdfelder, Lang, & Buchner. (2007). *GPower*. <https://doi.org/10.3758/BRM.41.4.1149>
- Hamel, R., & Schmittmann, V. D. (2006). The 20-minute version as a predictor of the Raven Advanced Progressive Matrices Test. *Educational and Psychological measurement*, 66(6), 1039–1046.
- Hart, S. G., & Staveland, L. E. (1988). *Development of NASA-TLX (Task load index): Results of empirical and theoretical research*. Retrieved from http://stavelandhfe.com/images/NASA-TLX_paper.pdf.
- Hidi, S. (2000). An interest researcher's perspective: The effects of extrinsic and intrinsic factors on motivation. *Intrinsic and extrinsic motivation* (pp. 309–339). Academic Press.
- Holt, D. D., Green, L., & Myerson, J. (2012). *Estimating the subjective value of future rewards: Comparison of adjusting-amount and adjusting-delay procedures*. <https://doi.org/10.1016/j.beproc.2012.03.003>
- Inzlicht, M., Shenhav, A., & Olivola, C. Y. (2018). The effort paradox: Effort is both costly and valued. *Trends in Cognitive Sciences*, 22(4), 337–349.
- Jorm, A., Christensen, H., Henderson, A., Jacomb, P., Korten, A., & Rodgers, B. (1998). Using the BIS/BAS scales to measure behavioural inhibition and behavioural activation: Factor structure, validity and norms in a large community sample. *Personality and Individual Differences*, 26(1), 49–58. [https://doi.org/10.1016/S0191-8869\(98\)00143-3](https://doi.org/10.1016/S0191-8869(98)00143-3)
- Kool, W., & Botvinick, M. (2018). Mental labour. *Nature Human Behaviour*. <https://doi.org/10.1038/s41562-018-0401-9>
- Kool, W., McGuire, J. T., Rosen, Z. B., & Botvinick, M. M. (2010). Decision making and the avoidance of cognitive demand. *Journal of Experimental Psychology General*, 139(4), 665–682. <https://doi.org/10.1037/a0020198>
- McGuire, J. T., & Botvinick, M. M. (2010). Prefrontal cortex, cognitive control, and the registration of decision costs. *Proceedings of the National Academy of Sciences*, 107(17), 7922–7926.
- Mcinerney, D. M., Dowson, M., & Mcinerney, D. M. (2003). What do students say about their motivational goals?: Towards a more complex and dynamic perspective on student motivation. *Contemporary Educational Psychology*, 28, 91–113. [https://doi.org/10.1016/S0361-476X\(02\)00010-3](https://doi.org/10.1016/S0361-476X(02)00010-3)
- Reed, H., Ouwehand, C., Van der Elst, W., Boschloo, A., & Jolles, J. (2010). Measures of school performance for use in educational neuropsychology. *Frontiers in Neuroscience Conference Abstract: EARLI SIG22-Neuroscience and Education*.
- Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *The American Psychologist*, 55(1), 68–78. <https://doi.org/10.1037/0003-066X.55.1.68>
- Sadowski, C. J., & Gulgoz, S. (1992). Internal consistency and test-retest reliability of the Need for Cognition Scale. *Perceptual and Motor Skills*, 74(2), 610.
- Sandra, D. A., & Otto, A. R. (2018). Cognitive capacity limitations and need for Cognition differentially predict reward-induced cognitive effort expenditure. *Cognition*, 172, 101–106.
- Sansone, C. (1989). Competence feedback, task feedback, and intrinsic interest: An examination of process and context. *Journal of Experimental Social Psychology*, 25(4), 343–361. [https://doi.org/10.1016/0022-1031\(89\)90027-9](https://doi.org/10.1016/0022-1031(89)90027-9)
- Shenhav, A., Musslick, S., Lieder, F., Kool, W., Griffiths, T. L., Cohen, J. D., et al. (2017). Toward a rational and mechanistic account of mental effort. *Annual Review of Neuroscience*, 40, 99–124.
- Vansteenkiste, M., Sierens, E., Soenens, B., Luyckx, K., & Lens, W. (2009). Motivational profiles from a self-determination perspective: The quality of motivation matters. *Journal of Educational Psychology*, 101(3), 671.
- Wentzel, K. R. (1996). Social and academic motivation in middle school. *The Journal of Early Adolescence*, 16(4), 390–406. <https://doi.org/10.1177/0272431696016004002>
- Westbrook, A., & Braver, T. S. (2015). Cognitive effort: A neuroeconomic approach. *Cognitive, Affective, & Behavioral Neuroscience*, 15(2), 395–415.
- Westbrook, A., Kester, D., & Braver, T. S. (2013). What is the subjective cost of cognitive effort? load, trait, and aging effects revealed by economic preference. *PLoS One*, 8(7), e68210. <https://doi.org/10.1371/journal.pone.0068210>
- Westbrook, A., Lamichhane, B., & Braver, T. (2019). The subjective value of cognitive effort is encoded by a domain-general valuation network. *Journal of Neuroscience*, 39(20). <https://doi.org/10.1523/JNEUROSCI.3071-18.2019>
- Wolters, C. A. (1999). The relation between high school students' motivational regulation and their use of learning strategies, effort, and classroom performance. *Learning and individual differences*, 11(3), 281–299.
- Zelazo, P. D., Craik, F. I., & Booth, L. (2004). Executive function across the life span. *Acta Psychologica*, 115(2-3), 167–183.

References which are cited in Supplementary Materials

- Hardisty, D. J., & Pfeffer, J. (2017). Intertemporal uncertainty avoidance: When the future is uncertain, people prefer the present, and when the present is uncertain, people prefer the future. *Management Science*, 63(2), 519–527.
- Keren, G., & Roelofsma, P. (1995). Immediacy and certainty in Intertemporal Choice. *Organizational Behavior and Human Decision Processes*, 63(3), 287–297. <https://doi.org/10.1006/OBHD.1995.1080>

- Olson, E. A., Hooper, C. J., Collins, P., & Luciana, M. (2007). Adolescents' performance on delay and probability discounting tasks: Contributions of age, intelligence, executive functioning, and self-reported externalizing behavior. *Personality and Individual Differences, 43*(7), 1886–1897. <https://doi.org/10.1016/j.paid.2007.06.016>
- Reynolds, B. (2006). A review of delay-discounting research with humans: Relations to drug use and gambling. *Behavioural Pharmacology, 17*(8), 651–667. <https://doi.org/10.1097/FBP.0b013e3280115f99>
- Scheres, A., de Water, E., & Mies, G. W. (2013). The neural correlates of temporal reward discounting. *Wiley Interdisciplinary Reviews Cognitive Science, 10.1002/wcs.1246*