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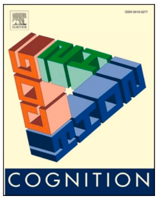

The subjective evaluation of task switch cues is related to voluntary task switching

L. Vermeylen [a,*], S. Braem [a], W. Notebaert [a], M.F.L. Ruitenberg [b,c]

[a] Department of Experimental Psychology, Ghent University, Belgium
[b] Department of Health, Medical and Neuropsychology, Leiden University, the Netherlands
[c] Leiden Institute for Brain and Cognition, the Netherlands

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ABSTRACT

Task switching refers to the effortful mental process of shifting attention between different tasks. While it is well-established that task switching usually comes with an objective performance cost, recent studies have shown that people also subjectively evaluate task switching as negative. An open question is whether this affective evaluation of task switching is also related to actual decision making. In this pre-registered study, we therefore examined whether individual differences in the negative evaluation of task switch cues are related to less voluntary task switching. To this end, participants first performed a cued task switching paradigm where abstract cues signaled task transitions (repetition or alternation). In a second phase, these transition cues were used as prime stimuli in an affective priming procedure to assess participants' affective evaluation of task switching. In a third phase, participants were allowed to freely choose whether to switch or repeat tasks. We found that a more negative evaluation of task switching cues was related to lower switch rates in the voluntary task switching phase. This finding supports neuroeconomic theories of value-based decision making which suggest that people use their subjective value of control to decide whether to engage in (different) tasks.

1. Introduction

In our everyday lives we are often faced with multiple tasks between which we have (or want) to switch back and forth. For example, we might be drafting a report on our laptop while answering incoming emails and responding to instant messages of colleagues and friends. Such flexible switching of attention is considered an important cognitive control function (Diamond, 2013) and is consistently found to be associated with so-called “switch costs”: people are slower (and tend to make more errors) after alternating tasks relative to repeating tasks. This suggests that switching attention between tasks is a difficult and effortful process (for reviews, see Monsell, 2003; Kiesel et al., 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010).

The probability that we will switch to a certain task, is likely driven by the potential (immediate) rewards that are associated with that task (Braun & Arrington, 2018). For example, we might be more inclined to switch our attention to the instant message of a friend rather than the email full of comments on a previous draft of a report you are working on. However, in situations where the potential rewards of two tasks are equal, people tend to dislike (Van Dessel, Liefooghe, & De Houwer, 2020; Vermeylen, Braem, & Notebaert, 2019) and minimize switching between tasks (Arrington & Logan, 2004; Kool, McGuire, Rosen, & Botvinick, 2010). For example, we recently demonstrated such disliking by showing that people judge cues that predict task switches as more negative relative to cues that predict task repetitions (Vermeylen et al., 2019). Importantly, this shows that next to the traditional “switch cost” there is also an “affective cost” to task switching. Van Dessel, Liefooghe, & De Houwer, 2020 found that the negative evaluation bias towards task switching cues can even be induced by merely instructing subjects that the cue will predict task switches (on the condition that one has prior experience with task switching).

The idea that effortful cognitive control processes such as task switching and conflict processing (e.g., Dreisbach & Fischer, 2012, 2015) carry an evaluative cost is consistent with Botvinick's (2007) proposal that cognitive control can be better understood in the context of value-based decision making in which demanding processes are registered as a cost (see also Shenhav et al., 2017; Shenhav, Botvinick, & Cohen, 2013). This cost or negative value proposedly drives a form of avoidance learning where people will tend to avoid situations that require control-demanding or effortful mental processes. This idea is

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[*] Corresponding author at: Department of Experimental Psychology, Henri Dunantlaan 2, B-9000 Ghent, Belgium.
E-mail address: Luc.Vermeylen@ugent.be (L. Vermeylen).

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reminiscent of the law of least effort, which posits that people tend to minimize *physical* effort (Zipf, 1949). In the psychological domain, people are also found to minimize *mental* effort. This has been shown in many voluntary task switching studies, where participants tend to show a bias towards repeating rather than alternating between tasks, even though participants are typically instructed to choose both tasks equally (e.g., Arrington & Logan, 2004, 2005; Orr, Carp, & Weissman, 2012; Vandierendonck et al., 2010). Similarly, work by Kool et al. (2010) showed that when people are given a choice between tasks that are associated with either a high or low frequency of task switching, over time, they tend to prefer the task with a low frequency of task switching.

Taken together, people tend to evaluate task switching as negative, and voluntary task switching and demand selection tasks show that people also tend to avoid task switches. Therefore, in line with neuroeconomic theories of value-based decision making (Shenhav et al., 2013, 2017), a straightforward explanation would be that people avoid switching *because* they dislike it. However, the actual relationship between the evaluation of task switching and actual voluntary task switching behavior has not been investigated. Therefore, the current study aimed to test whether individual differences in the affective evaluation of the task switching process are related to voluntary task switching. Specifically, we expected that an individual that shows a more negative evaluation of task switching, should show a smaller tendency to voluntarily switch between tasks. While admittedly such a correlational approach does not allow for causal interpretations, observing the hypothesized correlation would provide first support that these two variables are at least related, while the lack of a correlation would falsify the hypothesis, and the associated theories more generally.

To this end, we ran a pre-registered study in which we set out to (1) replicate the finding that task switching cues are evaluated as negative (Van Dessel, Liefooghe, & De Houwer, 2020; Vermeylen et al., 2019), and (2) test the hypothesis that these affective evaluations are related to voluntary task switching behavior. Participants first performed a task switching paradigm in which they had to switch between making a size or animacy judgment on target words. Here, abstract transition cues (non-words) signaled whether participants had to switch or repeat tasks. In a second phase, these transition cues were used as prime stimuli in an affective priming procedure in which they precede neutral target stimuli that have to be evaluated as rather pleasant or rather unpleasant (Fazio, 2001; cf. Fritz & Dreisbach, 2013, 2015). The goal of these first two phases was to perform an exact replication of Vermeylen et al. (2019), and thus to replicate the finding that task alternation cues are evaluated as more negative than task repetition cues. We also sought to replicate the observation that this priming effect is related to the performance switch costs (larger switch costs being positively related to a more negative evaluation).

In a third phase, participants again performed the same task switching paradigm with one important difference: This time, transition cues were absent and participants were allowed to voluntarily choose which task they wanted to perform next (with the restriction that they should choose both tasks equally often). The goal of this third voluntary task switching phase was to investigate the relationship between participants' evaluation of task switching cues and their voluntary task switching behavior. Here, we expected that participants with a more negative evaluation of task alternation cues would also show a lower probability of voluntarily switching between tasks.

Finally, participants also completed personality trait questionnaires to investigate whether the affective evaluation of task switching cues or voluntary switch rate were related to the personality traits of apathy, impulsivity, autism spectrum symptoms, and reward sensitivity. While it seems normative to dislike and avoid task switching to some extent, it might be that disturbances in the evaluation or allocation of effortful processes such as task switching are related to certain clinically related symptoms and personality traits. Apathy, which can be thought of as failure or reluctance to engage in effortful situations, has been proposed to be due to increased effort costs (which might devalue potential rewards to be gained from exerting effort, see Le Heron, Apps, & Husain, 2018). Second, Patzelt, Kool, Millner, and Gershman (2019) found that a lack of perseverance – a facet of impulsivity – was associated with a greater avoidance of mental effort. A similar mechanism might be at play in people with Autism Spectrum Symptoms (ASS). People with ASS are often rigid and inflexible in daily life, yet there is little evidence for a relation with impaired task switching performance in laboratory task switching paradigms (Geurts, Corbett, & Solomon, 2009). Still, it might be that they evaluate task switching as costlier (more negative), or chose to switch less when given the opportunity to (Hoofs, Princen, Poljac, Stolk, & Poljac, 2018; Poljac, Hoofs, Princen, & Poljac, 2017; Poljac, Poljac, & Yeung, 2012), which would explain a larger preference for stability and rigidity in daily life. Finally, it has been found that higher reward sensitivity (i.e., people with high levels of enjoying and anticipating rewards) is related to a more negative evaluation of task switching (Vermeylen et al., 2019). Here, one potential explanation could be that in the absence of reward (as is the case in the current and previous task switching experiments), people who avidly anticipate rewards decrease their expected payoff of investing mental effort more steeply, which in turn might increase its associated negative affect and avoidance. All hypotheses were preregistered using the AsPredicted form which, along with data and analyses scripts, can be found on our Open Science Framework repository.[1]

2. Methods

2.1. Participants

Our sample size was based on the original study (Vermeylen et al., 2019), in which the sample size was determined using sequential Bayesian hypothesis testing by increasing the sample until a decisive Bayes Factor (*BF*) of larger than 6 (or $< 1/6$) was obtained for the hypothesis that task switching cues are evaluated differently relative to task repetition cues. Vermeylen et al. (2019) ended up collecting data from 80 participants for Experiment 1 and 69 participants for Experiment 2. We decided to match the maximal sample size set in the original experiment for the current study, i.e., collect data from 80 participants. This sample size should allow us to replicate the original finding, and to detect small-to-medium one-tailed correlations ($r = 0.27$, based on an 0.05 error rate and 0.80 power). We anticipated that we would have to exclude some participants and therefore enrolled 95 participants. After applying our exclusion criteria (see "Data Analysis" below), 80 participants remained. The average age of our participants was 19.53 years ($SD = 2.89$; 69 females). All participants were students at either Ghent University or Leiden University and received partial course credits for their participation. The study adhered to the general ethical protocol of the ethics committee of the Faculty of Psychology and Educational Sciences of Ghent University and was approved by the Psychology Research Ethics committee (CEP) of Leiden University.

2.2. Experimental tasks and stimuli

The stimuli, materials, and procedure are similar to the original study (Experiment 2, Vermeylen et al., 2019) except for the voluntary task switching paradigm. In the task switching paradigms, target stimuli consisted of 320 high-frequent words each presented only once to rule out episodic memory confounds. All words could be judged on whether they were living or non-living, and whether they were smaller or larger than a basketball (see also, Braem, 2017; Schneider, 2015). Both dimensions were crossed orthogonally resulting in four categories including 80 target words each. At random, half of the target stimuli were selected for the cued task switching phase and the other half were selected for the voluntary task switching phase. The four categories were

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[1] https://osf.io/j72uf/?view_only=792095732a314d1e88fad19cb74bd593

balanced across phases. All stimuli were presented in the center of the screen in a white font against a black background. The experiment was built with the jsPsych javascript library (de Leeuw, 2015).

Fig. 1 illustrates the trial sequences in each of the three phases of the study. In the cued task switching paradigm, we used the non-words OXEYA, YOVIN, AFUBU, and UPUSU as transition cues, which were rated by an independent sample of 44 subjects as having a neutral valence (as used in Mertens, Dessel, & Houwer, 2018). Counterbalanced across participants, one non-word was assigned as a task alternation cue and one as a task repetition cue. Each combination of transition cue and task was equiprobable. On the first trial of each block, participants were shown which task to start with (ALIVE? or SIZE?). If participants made a mistake, they would receive the message "WRONG!" along with the task of the erroneous trial (ALIVE? or SIZE?). Participants responded with their left hand (D/F keys) for one task and the right hand (J/K keys) for the other task (counterbalanced). Within each hand, we also counterbalanced the possible response mappings (e.g., D for not alive and F for alive vs. D for alive and F for not alive).

In the affective priming procedure, target stimuli consisted of 90 Chinese pictographs that were randomly selected from an online generator for typographic filler text (http://generator.lorem-ipsum.info/_chinese). Participants had to evaluate these targets as rather pleasant or rather unpleasant (S for unpleasant and L for pleasant). The transition cues from the cued task switching paradigm functioned as prime stimuli. Each of the Chinese pictographs was paired once with each transition cue. To ensure processing of the prime stimuli, catch trials were dispersed throughout the task: When participants saw the non-word "HUZON", they had to press space bar instead of evaluating the target.

In the voluntary task switching paradigm, participants again judged whether the presented stimuli were living or non-living, or whether they were smaller or larger than a basketball. However, this time the non-word transition cues were replaced with a hashtag (#) indicating that participants were allowed to choose which judgment task they performed randomly, as if decided by flipping a coin. Participants again responded with their left hand (D/F) for one task and the right hand (J/K) for the other task (counterbalanced). This allowed us to track which task participants decided to perform.

2.3. Procedure

Participants started with the cued task switching paradigm. They received the instructions for both the animacy and size tasks and were informed that "living" could refer to every living organism, including animals, trees, plants, fruits, or vegetables. Following the instructions, they practiced the tasks separately (10 trials each), after which they practiced both tasks together with transition cues (but in each case with different target stimuli than in the experimental trials, 24 trials). After practice, participants proceeded to the first phase of the experiment. They were presented with two blocks of 80 trials (160 trials in total), separated by self-paced rests (max. One minute) during which the average reaction time and accuracy from the preceding block were shown. Each experimental trial started with a fixation cross (1000 ms) followed by the transition cue (500 ms) and the target (3 s response deadline). Feedback (1500 ms) was shown if the response was too slow or wrong.

In the second phase, participants were instructed to judge Chinese pictographs as rather pleasant or rather unpleasant. They were told that they would be shown one of the transition cues before each target but were explicitly told to not let these words influence their judgment. Each trial started with a fixation cross (1000 ms) followed by the prime (400 ms) and the target (until evaluation, no response deadline). Participants started with 20 practice trials (including the primes, but with different Chinese pictographs than in the experimental trials) in which feedback reinforced the evaluation that was made (e.g., "you evaluated the pictograph as rather pleasant"). They then started the actual affective priming paradigm as described above (i.e., without feedback). There were three blocks (66 trials per block; 198 trials in total) separated by self-paced rests (max. One minute). Six trials per block were catch trials (i.e., once every ~10 trials).

In the third phase, participants were told that they were going to execute the first task again (i.e., the task switching paradigm), with the difference that they could now freely choose which task they were going to perform on each trial (with the constraint that they had to choose at random, as if flipping up a coin). The transition cue now consisted of a hashtag (500 ms). Participants again performed two blocks of 80 trials (160 trials in total), separated by self-paced rests (max. One minute) which showed the average reaction time and accuracy from the preceding block.

Finally, participants completed four questionnaires. The Apathy Motivation Index (AMI; Ang, Lockwood, Apps, Muhammed, & Husain, 2017, observed Cronbach's alpha: 0.68) scale was used to assess apathy levels in daily life (example item: "I feel sad or upset when I hear bad news"). Since there was no Dutch version of the AMI scale available, we translated the items of the scale into Dutch using a forward–backward procedure with two independent bilingual translators for each step in the procedure. The Impulsive Behavior Scale (UPPS-P; Bousardt, Noorthoorn, Hoogendoorn, Nijman, & Hummelen, 2018, observed Cronbach's alpha: 0.90)[2] was used to assess trait impulsivity (example item: "I have trouble controlling my impulses"). The Dutch version of the Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Hoekstra et al., 2008, observed Cronbach's alpha: 0.62) was used to measure autistic traits (example item: "I prefer to do things the same way over and over again."). The Behavioral Inhibition and Activation Scales (BIS/BAS; Carver & White, 1994; Franken, Muris, & Rassin, 2005, observed Cronbach's alpha for the reward responsiveness scale: 0.58) were used to assess the tendency to avoid aversive outcomes and approach goal-oriented outcomes (example item: "When good things happen to me, it affects me strongly").

2.4. Data processing and analysis

Our main dependent variables are the negative affective priming effect, the cued switch costs, and the voluntary switch rate (Spearman-Brown corrected split-half [odd/even trials] reliability reported in parentheses). The negative affective priming effect is the difference in the percentage of negative judgements of neutral targets after alternation primes relative to repetition primes in the affective priming paradigm ($r = 0.52$). The switch cost is the difference in reaction time or error rate between the task alternations and task repetitions in the cued task switching paradigm or voluntary task switching paradigm ($r = 0.64$). The voluntary switch rate is the percentage of correct voluntary task alternations relative to task repetitions, excluding the first trial of the voluntary task switching phase ($r = 0.88$).

For our Repeated Measures ANOVAs, we report generalized eta squared (η_g^2) effect sizes which allow comparison across within- and between-subjects designs (Bakeman, 2005). For our Bayesian analyses we report the BF_{10} (calculated with the BayesFactor package in R) which quantifies the evidence for the alternative hypothesis against the null hypothesis. We used the default priors from the package. For Bayesian *t*-tests the Cauchy prior width is 0.707. For the Bayesian ANOVAs, the prior width is 0.5 for fixed effects and 0.1 for random effects. For Bayesian correlations the prior width is 0.333.

In our reaction time (RT) analyses, we included only correct trials with RTs slower than 200 ms and within 2.5 *SD* from each subject's mean RT (removing 2.88% of all correct trials). We excluded participants who had a mean RT deviating more than 2.5 SD from the overall mean RT (1 participant), performed on or below chance level, or had a mean accuracy below 2.5 *SD* from the mean accuracy (in either the cued or

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[2] Dutch translation by FPA de Boog, GGZ Warnsveld, The Netherlands.

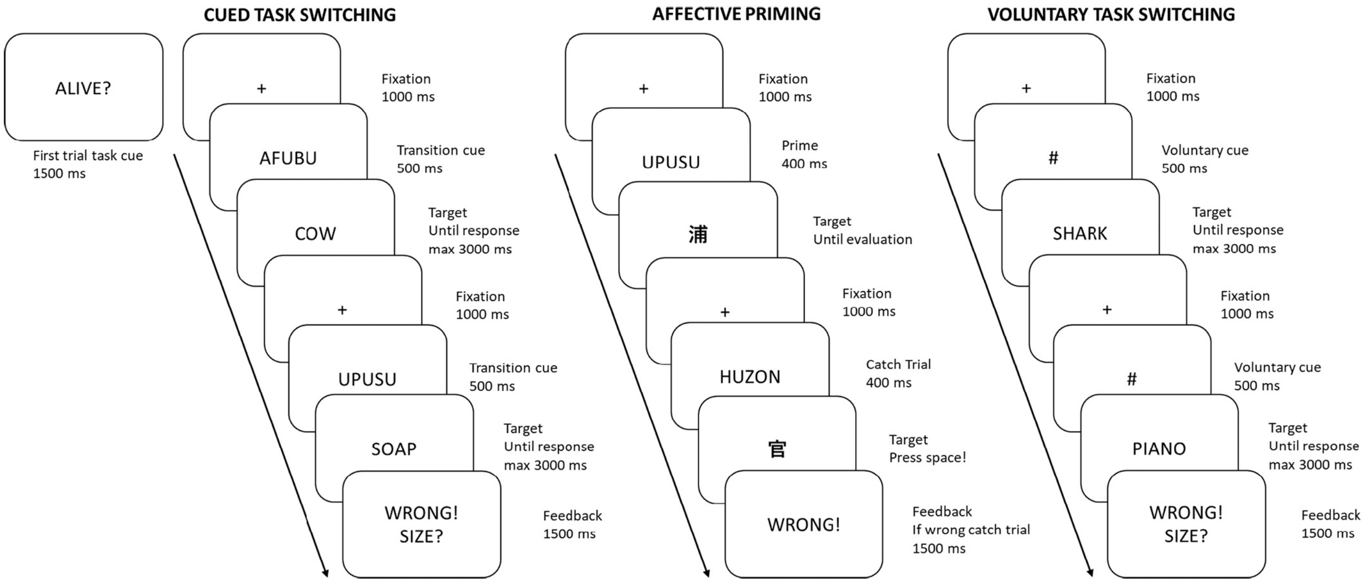

Fig. 1. Example trial sequences. Participants first performed a cued task switching paradigm where the tasks were to categorize words on either size or animacy, and on each trial transition non-word cues indicated whether they had to repeat or alternate between the two tasks. In a second phase, the same transition cues were used as primes in an affective priming procedure where the task was to evaluate Chinese pictographs. In a final phase, participants repeated the task switching paradigm where the non-word cues were replaced with hashtags. Here, participants were instructed to freely choose the task they wanted to perform on the upcoming trial.

voluntary task switching paradigm; 6 participants). In the affective priming paradigm, we excluded participants who showed extreme judgements (less than 10% or more than 90% of negative judgements; 4 participants) or chance level (50%) performance on catch trials in the affective priming paradigm (0 participants). Additionally, we excluded participants that showed no switching in the voluntary phase (6 participants). Participants who were identified as outliers according to any of these criteria were removed from all analyses. In total, 15 unique participants were excluded.

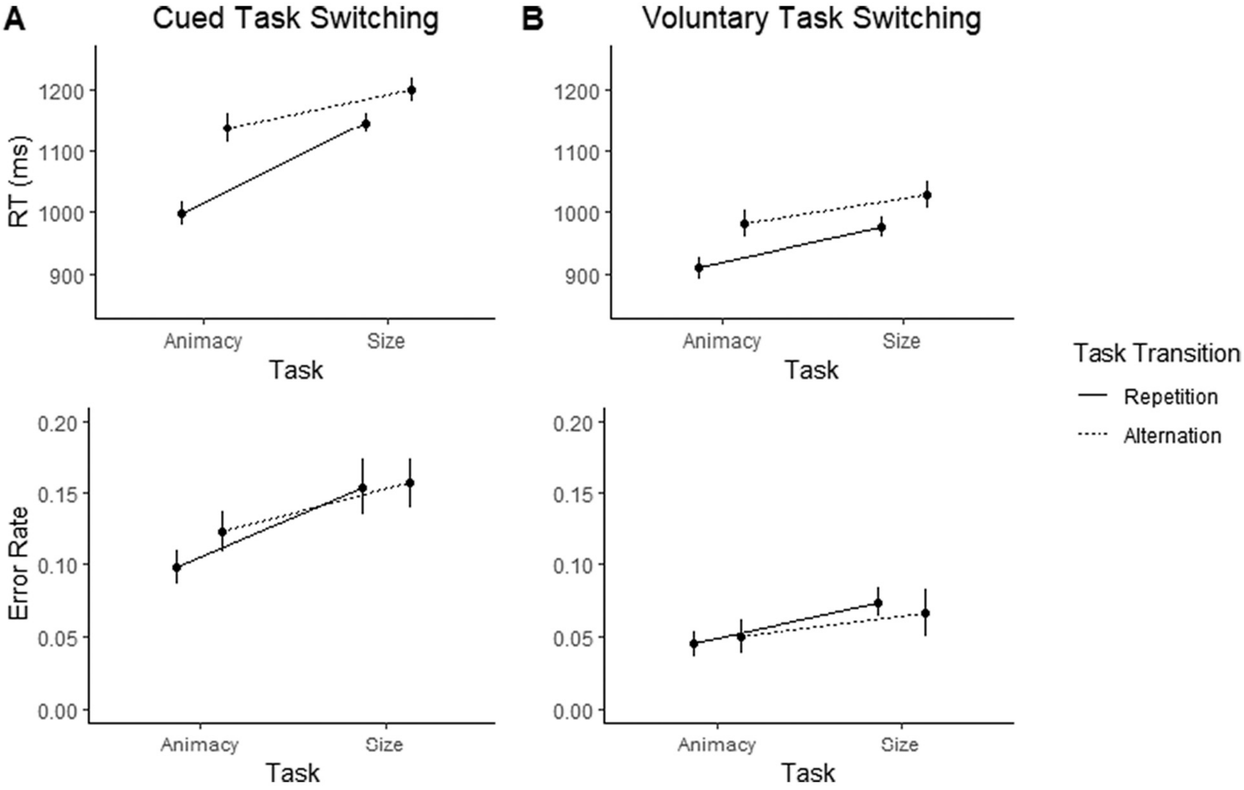

Fig. 2. Reaction time (RT) and error rate in **(A)** the cued and **(B)** the voluntary task switching paradigms. Error bars denote the 95% within-subject CI.

3. Results

3.1. General performance in the task switching paradigms

Before continuing to our pre-registered analyses, we first assessed general performance on the cued and voluntary task switching paradigms. For the cued task switching paradigm, we conducted a repeated measures ANOVA with task (2; animacy or size) and task transition (2; task repetition or task alternation) as within-subject factors on the dependent variable RT (Fig. 2A, top row). Results showed that participants responded faster in the animacy task ($M = 1068$ ms, $SE = 24.2$) relative to size task ($M = 1172$ ms, $SE = 24.2$), $F(1,79) = 103.89$, $p < .001$, $\eta_g{}^2 = 0.050$. We found a main effect of task transition, $F(1,79) = 73.84$, $p < .001$, $\eta_g{}^2 = 0.040$, replicating the typical finding that people respond slower after task alternations ($M = 1168$ ms, $SE = 24.3$) relative to task repetitions ($M = 1072$ ms, $SE = 24.3$). We also found an interaction effect between task and task transition, $F(1,79) = 25.32$, $p < .001$, $\eta_g{}^2 = 0.009$, showing that the switch costs were larger in the animacy task ($M = 138.4$ ms, $SE = 14$), relative to the size task ($M = 54.7$ ms, $SE = 24.3$). The same repeated measures ANOVA on the dependent variable error rate (Fig. 2A, bottom row), showed a main effect of task, $F(1,79) = 38.04$, $p < .001$, $\eta_g{}^2 = 0.050$, as participants made fewer errors in the animacy task ($M = 11.00$, $SE = 0.92$) relative to the size task ($M = 15.50$, $SE = 1.03$). We did not find a main effect of task transition, $F(1,79) = 3.20$, $p = .080$, $\eta_g{}^2 = 0.005$, or an interaction effect between task and task transition, $F(1,79) = 1.59$, $p = .210$, $\eta_g{}^2 = 0.003$.

In the voluntary task switching paradigm, the same repeated measures ANOVAs were conducted on the RT and accuracy measures (Fig. 2B). For the RT measure, we again found main effects of task, $F(1,79) = 27.35$, $p < .001$, $\eta_g{}^2 = 0.020$, showing that participants were faster on the animacy task ($M = 947$ ms, $SE = 19.7$) relative to the size task ($M = 1003$ ms, $SE = 19.7$), and of task transition, $F(1,79) = 32.80$, $p < .001$, $\eta_g{}^2 = 0.030$, showing that participants were slower on task alternations ($M = 1005$ ms, $SE = 19.7$) relative to task repetitions ($M = 944$ ms, $SE = 19.7$). We did not find an interaction between task and task transition, $F(1,79) = 2.73$, $p = .010$, $\eta_g{}^2 = 0.001$. For the error rate measure, we again found only a main effect of task, $F(1,79) = 12.18$, $p < .001$, $\eta_g{}^2 = 0.030$, showing that participants made fewer errors in the animacy task ($M = 4.74$, $SE = 0.43$) relative to the size task ($M = 7.03$, $SE = 0.63$). We did not find a main effect of task transition, $F(1,79) = 0.05$, $p = .830$, $\eta_g{}^2 < 0.001$, or an interaction effect between task and task transition, $F(1,79) = 1.02$, $p = .032$, $\eta_g{}^2 = 0.003$.

Finally, we assessed voluntary task switching behavior. As typically observed in voluntary task switching studies (e.g., Arrington & Logan, 2004; Arrington & Logan, 2005; Orr et al., 2012; Vandierendonck et al., 2010), we found that participants avoided switching between tasks (37.66%) although they were instructed to choose the tasks randomly ($t(79) = 9.38$, $p < .001$; t-test for the hypothesis that the true mean is not equal to 50%). In addition, we conducted a repeated measures ANOVA with switch rate as the dependent measure and task as a within-subject factor. Here, we found a main effect of task, $F(1,79) = 38.12$, $p < .001$, $\eta_g{}^2 = 0.077$, showing that participants were more likely to switch away from the size task ($M = 42.2$, $SE = 1.40$) relative to the animacy task ($M = 35.2$, $SE = 1.35$). This might be because the size task was relatively more difficult, as evidenced by the slower RTs and lower accuracy for this task.

In sum, the general performance results are in line with what is expected and know from cued and voluntary task switching paradigms: people are slower after task transitions relative to task repetitions ("switch costs") and show a bias to repeat tasks in a voluntary context.

3.2. The affective evaluation of task switch cues

As per our pre-registration, we evaluated whether we could replicate the findings from Vermeylen et al. (2019). To that end, we focused on the affective priming paradigm in which the alternation and repetition cues served as prime stimuli before the evaluation of neutral targets. First, we investigated whether task alternation primes led to more negative evaluation of neutral targets relative to task repetition primes. We used a logistic linear mixed effects model where we predicted the probability to judge the target stimulus as negative by the prime condition (the task alternation cue or the task repetition cue), including crossed random effects for subject and target item. We found that task alternation primes led to significantly more negative judgements on the neutral target stimuli ($M = 49.8\%$, $SE = 1.96$) than task repetition primes ($M = 47.3\%$, $SE = 1.95$), $\chi^2(1) = 7.93$, $p = .005$, thus replicating the negative affective priming effect (Fig. 3).

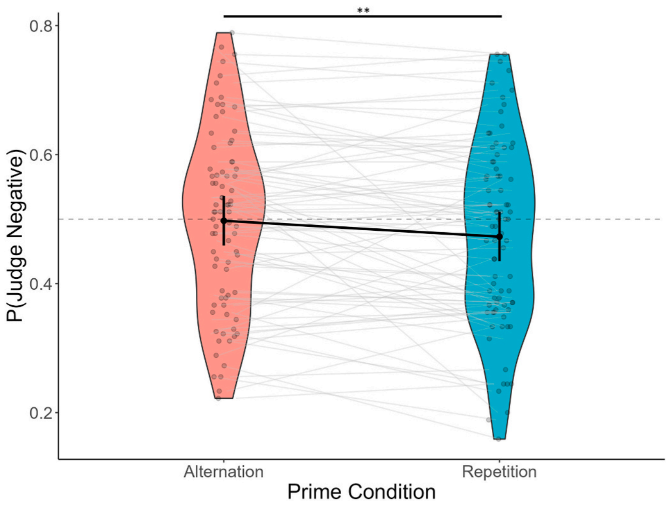

Fig. 3. Participants were more likely to judge neutral targets as negative when the preceding prime stimulus was the alternation cue relative to when the prime stimulus was the repetition cue. Error bars denote the 95% CI. The dashed grey line denotes P(Judge Negative) = 0.5.

Vermeylen et al. (2019) also found that this negative affective priming effect was positively related to the switch costs from the cued task switching phase as well as to trait reward responsiveness (as measured by the corresponding subscale from the BIS/BAS questionnaire). In the current experiment we did not find evidence for the positive relationships between the negative affective priming effect and the switch costs in the cued phase ($r = -0.010$, $p = .533$, $BF_{10} = 0.24$), nor trait reward responsiveness ($r = 0.07$, $p = .739$, $BF_{10} = 0.17$). We also did not find evidence for a positive relationship between the negative affective priming effect and the switch costs in the voluntary phase ($r = -0.08$, $p = .764$, $BF_{10} = 0.159$).

3.3. The relationship between the evaluation of switch cues and voluntary task switching behavior

Next, we investigated whether participants' switch rates in the voluntary phase were related to the negative evaluation of task switch cues in the affective priming phase. Specifically, we tested whether stronger disliking of task switch cues is related to lower switch rates in the voluntary phase. Indeed, we observed that more disliking of task alternation primes (i.e., larger negative affective priming effect) was related to a lower switch rate in the voluntary phase, $r = -0.200$, $p = .037$, $BF_{10} = 2.15$ (Fig. 4A). Although the negative evaluation of switch cues did not correlate with the switch cost in performance in the cued phase (see above), we still investigated whether this switch cost might correlate with the voluntary switch rates (as previously shown in voluntary task switching studies, e.g., Mittelstädt, Miller, & Kiesel, 2018, 2019). Indeed, a correlation analysis showed that higher switch rates in the voluntary phase were related to lower switch costs in the cued phase, $r = -0.215$, $p = .027$, $BF_{10} = 2.77$ (Fig. 4B). In other words,

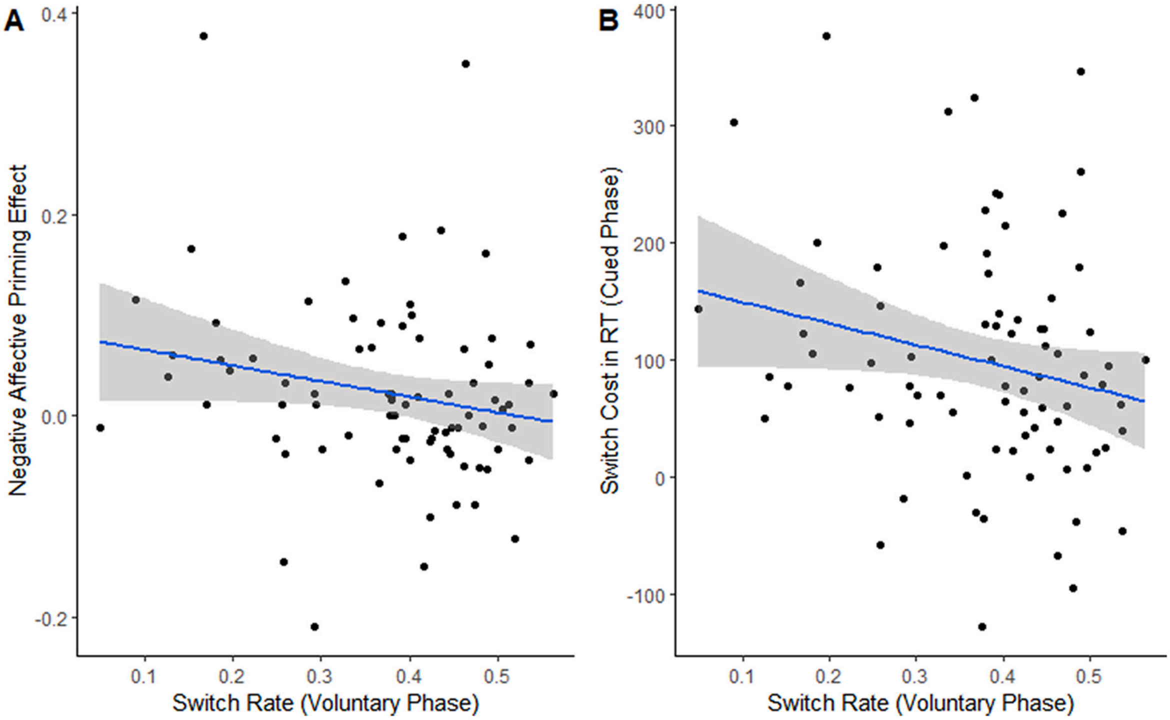

Fig. 4. (A) Higher negative affective priming (more disliking of task switching) was related to lower voluntary switch rates. (B) Higher switch costs in the cued task switching phase were related to lower switch rates. Grey area denotes the 95% CI.

individuals who were better at switching in the cued phase were also more likely to switch in the voluntary phase.

In a follow-up exploratory analysis, we investigated the determinants of task transitions in the voluntary task switching paradigm in a more fine-grained manner. We used a logistic linear mixed effects model where we predicted the probability of a task alternation by the interaction between Task (animacy or size), the affective priming effect, and the switch costs from the cued task switching paradigm while controlling for the effect of Block (block 1, block 2) and including random intercepts for each subject. Since both the negative affective priming effect and switch costs (and their interaction) are present in this model, this analysis allows us to investigate whether the relationship between these measures and the switch rate are still present when controlling for each other and whether they potentially interact to determine the extent of

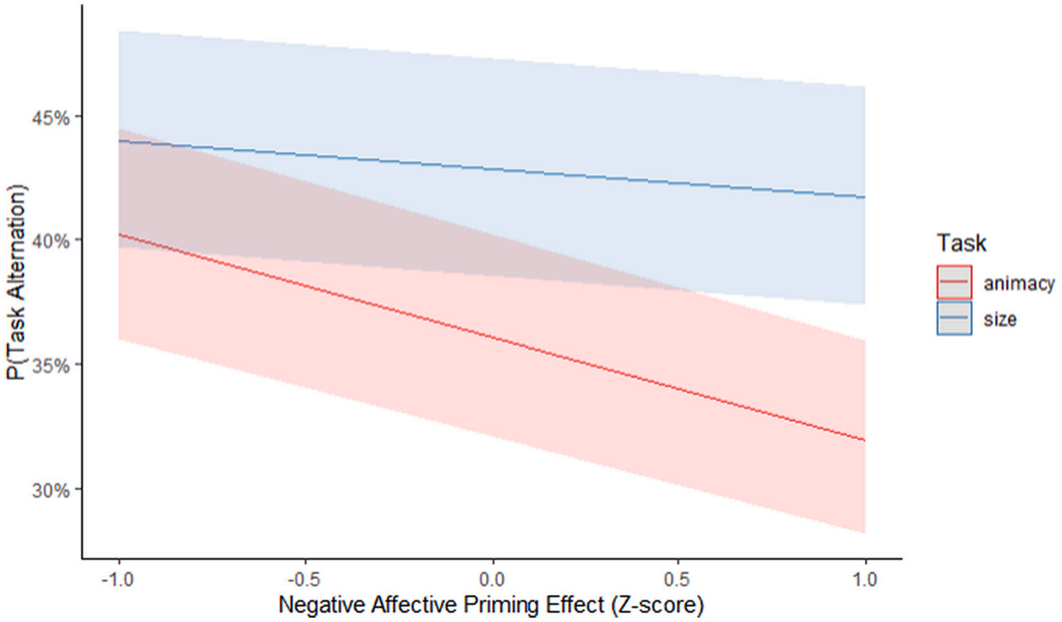

Fig. 5. The relationship between the negative affective priming effect and the probability of a task alternation for the animacy and size task separately. Positive values of the negative affective priming score denote a larger than average negative evaluation of task switching cues, whereas negative values denote a smaller than average negative evaluation of task switching cues. The shaded areas denote the 95% CI.

the switch rate. Including interactions with Task in the model allowed us to further investigate whether the effect of these measures on the switch rate differed between the tasks.

We found an effect of Task, $\chi^2(1) = 60.26$, $p < .001$, replicating our earlier finding that participants were more likely to switch away from the size task ($M = 40.6$, $SE = 1.52$) relative to the animacy task ($M = 33.4$, $SE = 1.38$), presumably because the size task was more difficult (as reflected by the longer RT and lower accuracy for this task). We also found an effect of Block, $\chi^2(1) = 27.98$, $p < .001$, showing that the switch rate decreased from block 1 ($M = 39.4$, $SE = 1.48$) to block 2 ($M = 34.6$, $SE = 1.41$). Further, the model confirmed our findings from the pre-registered correlational analyses on the relationship between switch rate and the negative affective priming effect: We found that the negative affective priming effect significantly predicted the probability of a task alternation, $\chi^2(1) = 7.53$, $p = .006$. More specifically, higher negative affective priming was related to a lower probability of a task alternation ($\beta = -0.180$, $z = 2.84$, $p = .004$). The switch costs from the cued task switching paradigm also significantly predicted the probability of a task alternation, $\chi^2(1) = 4.82$, $p = .028$, with higher switch costs being related to a lower probability of a task alternation ($\beta = -0.136$, $z = -2.19$, $p = .028$, cf. the correlation between the switch costs and switch rate reported above). Finally, we observed an interaction between Task and the negative affective priming effect, $\chi^2(1) = 8.60$, $p = .003$, but not between Task and the switch costs from the cued task switching paradigm, $\chi^2(1) = 0.79$, $p = .372$, between the affective priming effect and the switch costs, $\chi^2(1) = 1.94$, $p = .163$, nor a three-way interaction between Task, the negative affective priming effect and the switch costs, $\chi^2(1) = 0.63$, $p = .742$. The significant interaction between Task and the negative affective priming effect shows that a more negative evaluation of task switching cues was mostly predictive of task alternations on the animacy task ($\beta = -0.173$, $SE = 0.063$) relative to the size task ($\beta = -0.052$, $SE = 0.063$; Fig. 5). In other words, participants who dislike task switching more tend to avoid task alternations (or prefer task repetitions), and this avoidance of task alternations (or preference for task repetitions) is more outspoken for the relatively easy task (i.e., the animacy task).

3.4. Individual differences and personality traits

Finally, we ran correlation analyses to examine the relationship between our main behavioral dependent measures (i.e., the switch costs, the negative affective priming effect, and the switch rate) and personality traits (i.e., autism spectrum symptoms, apathy, impulsivity, and reward responsiveness). All hypotheses and corresponding results can be found in Table 1. In sum, we did not find evidence for any of our hypotheses related to personality traits.

Table 1
Relationship between personality traits and our behavioral measures.

Trait	Behavioral measure	Predicted	*r*	*p*	BF_{10}
Autism Spectrum Symptoms (AQ)	Negative priming	+	0.069	0.545	0.30
	Switch Rate	−	−0.019	0.870	0.26
	Switch Cost	0	0.153	0.174	0.61
Apathy (AMI)	Negative priming	+	−0.174	0.121	0.78
	Switch Rate	−	0.140	0.213	0.53
	Switch Cost	+	−0.178	0.115	0.81
Impulsivity (UPPS-P)	Negative priming	0	−0.115	0.308	0.42
	Switch Rate	+	−0.183	0.104	0.88
	Switch Cost	+	0.090	0.428	0.34
Reward Responsiveness (BIS/BAS)	Negative priming	+	−0.073	0.522	0.31
	Switch Rate	−	0.086	0.447	0.34
	Switch Cost	+	0.122	0.280	0.44

4. Discussion

In this pre-registered study, we set out to investigate the relationship between the subjective evaluation of task switching cues and objective voluntary task switching behavior. We expected that a more negative evaluation of task switching cues would be related to a lower switch rate in a voluntary task switching context. Participants started the experiment by performing a cued task switching paradigm. Next, these cues were used in an affective priming paradigm to assess their affective value. Finally, participants performed a voluntary task switching paradigm. In line with prior observations, we replicated the traditional switch costs in the cued task switching context and switch avoidance (often also referred to as a repetition bias) in the voluntary task switching context (Arrington & Logan, 2004; Monsell, 2003), as well as recent findings that task alternation cues are evaluated as more negative than task repetition cues (Van Dessel, Liefooghe, & De Houwer, 2020; Vermeylen et al., 2019). Moreover, we are the first to show that participants with more negative evaluation of task alternation cues also show a lower probability to switch between tasks (or a higher probability to repeat tasks), thereby explicitly demonstrating a link between effort evaluation and effort allocation (or effort avoidance) during task switching.

Our results are in line with value-based decision-making accounts of cognitive control posing that control processes themselves are considered to be costly, which through avoidance learning steers us away from applying these costly control processes (Botvinick, 2007). Although our correlational approach does not allow for causal interpretations, our results bring first support that the evaluation and allocation of control processes are at least related. Yet, people still engage in control-demanding situations. The Expected Value of Control account therefore proposes that people allocate control proportional to the costs of control, the potential benefits, and the amount of control necessary to achieve those benefits (Shenhav et al., 2013, 2017, see also cognitive labor/leisure tradeoff, Kool & Botvinick, 2014). The results can also be explained by accounts that view cognitive control as a form of emotion regulation (Dignath, Eder, Steinhauser, & Kiesel, 2020; Dreisbach & Fischer, 2015; Saunders, Milyavskaya, & Inzlicht, 2015). For example, the Affective Alarm framework (Saunders et al., 2015) proposes that people aim to maximize cognitive comfort – a state dominated by pleasant rather than unpleasant stimulation. Here, events or contexts that signal the need for cognitive control (e.g., task switching cues) are assumed to lead to a negative state. People will aim to upregulate this negative state into a positive state in order to achieve cognitive comfort. This can be achieved by either increasing control (leading to control adaptations; Dignath et al., 2020) or, when there is a choice, to simply avoid contexts or tasks in which those signals appear frequently.

Arguably, these accounts would also predict that the negative value of control is related to how resource-demanding a given task is (which in turn would affect the degree to which one avoids spending cognitive control resources). The switch costs are often thought to provide an index for individual differences in the demanding or effortful nature of task switching, and Vermeylen et al. (2019) indeed found that higher switch costs (more demanding nature of task switching) were related to a more negative evaluation of task switching cues. In the current study, however, we failed to replicate this finding. On the other hand, a follow-up mixed effects model revealed that the negative value was related to the probability to switch in a task-specific manner: A more negative experience of task switching mainly affected task alternations on the relatively easy task (i.e., animacy task). This result seems to support the idea that the negative value of control was related to how resource-demanding the tasks were.

Van Dessel, Liefooghe, & De Houwer, 2020 more directly replicated the finding that higher switch costs were related to more negative affective ratings of task switch cues. However, their study featured explicit affective ratings in addition to implicit affective ratings. Notably, the correlation was only found using the explicit affective ratings. One explanation for the current failed replication might be that the implicit affective ratings have low reliability and might only reflect the affective nature of the prime in a subset of participants that are aware of the prime's influence on their judgment (Hughes, Cummins, & Hussey, 2019; Van Dessel, Liefooghe, & De Houwer, 2020). Future studies might consider using explicit ratings, physiological measures (facial EMG, e.g., Berger, Mitschke, Dignath, Eder, & van Steenbergen, 2020), or other behavioral paradigms that are developed to quantify the costs of effort (e.g., cognitive effort discounting paradigms, COGED, Westbrook, Kester, & Braver, 2013). In addition, quantifying individual variation of cognitive control processes in terms of RT indices also suffers from low reliability (see also Haines et al., 2020; Hedge, Powell, & Sumner, 2018; Whitehead, Brewer, & Blais, 2019). It has been proposed that (hierarchical) model-based measures of cognitive control might be more promising to quantify individual variation in cognitive control performance (Haines et al., 2020; Hedge et al., 2018). Therefore, follow-up studies could exploit (hierarchical) cognitive modeling to quantify individual differences in terms of cognitive control processes. Another (not mutually exclusive) explanation for not finding a relationship between switch costs and evaluation of task switching cues might be our relatively small sample size for investigating individual differences. Although our sample size was chosen to detect small-to-medium unidirectional correlations (in line with the pre-registered hypotheses), a larger sample would likely be more sensitive to find potential (moderation or mediation) effects between task switching performance, evaluation, and avoidance.

The above-mentioned limitations of the current study, together with the homogeneous nature of our sample (first year psychology students), might also explain why we did not find any of our hypothesized correlations between personality traits and the performance or evaluation measures. Nevertheless, the relationship between clinically relevant personality traits on the one hand, and task switching performance, evaluation, and avoidance on the other hand, might be a promising avenue for future investigations. It might be especially promising to investigate these relationships in clinical populations rather than healthy populations as deficits in effortful decision making and cognitive control are present in a variety of mental disorders such as addiction, eating disorders, anxiety, depression, and schizophrenia (Goschke, 2014; Moran, Culbreth, & Barch, 2017; Wittchen et al., 2011) next to clinically related traits such as anhedonia and apathy (Le Heron et al., 2018). The transdiagnostic nature of these deficits call for a more nuanced investigation of the subprocesses that support and guide effortful cognitive control behavior in these populations, i.e., disturbances in the evaluation of control processes and how this evaluation relates to the avoidance of control. For example, in depression, increased effort costs (together with disturbed reward sensitivity and a decrease in perceived controllability) are proposed to explain decreased effort investment (for a review see Grahek, Shenhav, Musslick, Krebs, & Koster, 2019). It has also been found that lack of perseverance (high impulsivity) is related to increased effort avoidance (Patzelt et al., 2019).

To conclude, the present study demonstrates for the first time that a more negative evaluation of task switching cues is related to lower switch rates in a voluntary task switching context. This suggests that the negative affective value of task switching (Vermeylen et al., 2019) supports a form of avoidance learning in which effort is minimized proportional to the degree to which one evaluates said task switching as costlier. Although we did not find any relationships between clinically related personality traits and task switching performance, evaluation, or avoidance, disturbance in terms of evaluation and allocation could be promising transdiagnostic markers for clinical disorders that show deficits in effortful cognitive control behavior.

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References

Ang, Y.-S., Lockwood, P., Apps, M. A. J., Muhammed, K., & Husain, M. (2017). Distinct subtypes of apathy revealed by the apathy motivation index. *PLoS One, 12*(1), 1–15. https://doi.org/10.1371/journal.pone.0169938

Arrington, C. M., & Logan, G. D. (2004). The cost of a voluntary task switch. *Psychological Science, 15*(9), 610–615. https://doi.org/10.1111/j.0956-7976.2004.00728.x

Arrington, C. M., & Logan, G. D. (2005). Voluntary task switching: Chasing the elusive homunculus. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 31*(4), 683–702. https://doi.org/10.1037/0278-7393.31.4.683

Bakeman, R. (2005). Recommended effect size statistics for repeated measures designs. *Behavior Research Methods, 37*(3), 379–384. https://doi.org/10.3758/BF03192707

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5–17. https://doi.org/10.1023/A:1005653411471

Berger, A., Mitschke, V., Dignath, D., Eder, A., & van Steenbergen, H. (2020). The face of control: Corrugator Supercilii tracks aversive conflict signals in the service of adaptive cognitive control. *Psychophysiology, 57*(4), Article e13524. https://doi.org/10.1111/psyp.13524

Botvinick, M. M. (2007). Conflict monitoring and decision making: Reconciling two perspectives on anterior cingulate function. *Cognitive, Affective, & Behavioral Neuroscience, 7*(4), 356–366. https://doi.org/10.3758/CABN.7.4.356

Bousardt, A. M. C., Noorthoorn, E. O., Hoogendoorn, A. W., Nijman, H. L. I., & Hummelen, J. W. (2018). On the link between emotionally driven impulsivity and aggression: Evidence from a validation study on the Dutch UPPS-P. *International Journal of Offender Therapy and Comparative Criminology, 62*(8), 2329–2344. https://doi.org/10.1177/0306624X17711879

Braem, S. (2017). Conditioning task switching behavior. *Cognition, 166*, 272–276. https://doi.org/10.1016/j.cognition.2017.05.037

Braun, D. A., & Arrington, C. M. (2018). Assessing the role of reward in task selection using A reward-based voluntary task switching paradigm. *Psychological Research, 82*(1), 54–64. https://doi.org/10.1007/s00426-017-0919-x

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), 319–333. https://doi.org/10.1037/0022-3514.67.2.319

Diamond, A. (2013). Executive functions. *Annual review of psychology, 64*, 135–168.

Dignath, D., Eder, A. B., Steinhauser, M., & Kiesel, A. (2020). Conflict monitoring and the affective-signaling hypothesis—An integrative review. *Psychonomic Bulletin & Review, 27*(2), 193–216. https://doi.org/10.3758/s13423-019-01668-9

Dreisbach, G., & Fischer, R. (2012). Conflicts as aversive signals. *Brain and Cognition, 78*(2), 94–98. https://doi.org/10.1016/j.bandc.2011.12.003

Dreisbach, G., & Fischer, R. (2015). Conflicts as aversive signals for control adaptation. *Current Directions in Psychological Science, 24*, 255–260.

Fazio, R. H. (2001). On the automatic activation of associated evaluations: An overview. *Cognition & Emotion, 15*(2), 115–141. https://doi.org/10.1080/02699930125908

Franken, I. H. A., Muris, P., & Rassin, E. (2005). Psychometric properties of the Dutch BIS/BAS scales. *Journal of Psychopathology and Behavioral Assessment, 27*(1), 25–30. https://doi.org/10.1007/s10862-005-3262-2

Fritz, J., & Dreisbach, G. (2013). Conflicts as aversive signals: Conflict priming increases negative judgments for neutral stimuli. *Cognitive, Affective, & Behavioral Neuroscience, 13*(2), 311–317. https://doi.org/10.3758/s13415-012-0147-1

Fritz, J., & Dreisbach, G. (2015). The time course of the aversive conflict signal. *Experimental Psychology, 62*(1), 30–39. https://doi.org/10.1027/1618-3169/a000271

Geurts, H. M., Corbett, B., & Solomon, M. (2009). The paradox of cognitive flexibility in autism. *Trends in Cognitive Sciences, 13*(2), 74–82. https://doi.org/10.1016/j.tics.2008.11.006

Goschke, T. (2014). Dysfunctions of decision-making and cognitive control as transdiagnostic mechanisms of mental disorders: Advances, gaps, and needs in current research. *International Journal of Methods in Psychiatric Research, 23*(Suppl. 1), 41–57. https://doi.org/10.1002/mpr.1410

Grahek, I., Shenhav, A., Musslick, S., Krebs, R. M., & Koster, E. H. W. (2019). Motivation and cognitive control in depression. *Neuroscience and Biobehavioral Reviews, 102*, 371–381. https://doi.org/10.1016/j.neubiorev.2019.04.011

Haines, N., Kvam, P. D., Irving, L. H., Smith, C., Beauchaine, T. P., Pitt, M. A., … Turner, B. (2020). Theoretically informed generative models can advance the psychological and brain sciences: Lessons from the reliability paradox. *PsyArXiv.*. https://doi.org/10.31234/osf.io/xr7y3

Hedge, C., Powell, G., & Sumner, P. (2018). The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences. *Behavior Research Methods, 50*(3), 1166–1186. https://doi.org/10.3758/s13428-017-0935-1

Hoekstra, R. A., Bartels, M., Cath, D. C., Boomsma, D. I., & Biological Psychology. (2008). Factor structure, reliability and criterion validity of the autism-Spectrum quotient (AQ): A study in Dutch population and patient groups. *Journal of Autism and Developmental Disorders, 38*(8), 1555–1566. https://doi.org/10.1007/s10803-008-0538-x

Hoofs, V., Princen, M. M., Poljac, E., Stolk, A., & Poljac, E. (2018). Task switching in autism: An EEG study on intentions and actions. *Neuropsychologia, 117*, 398–407. https://doi.org/10.1016/j.neuropsychologia.2018.07.008

Hughes, S., Cummins, J., & Hussey, I. (2019). Effects on the affect misattribution procedure are strongly moderated by awareness. *PsyArXiv.*. https://doi.org/10.31234/osf.io/d5zn8

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching—A review. *Psychological Bulletin, 136*(5), 849–874. https://doi.org/10.1037/a0019842

Kool, W., & Botvinick, M. (2014). A labor/leisure tradeoff in cognitive control. *Journal of Experimental Psychology. General, 143*(1), 131–141. https://doi.org/10.1037/a0031048

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

Le Heron, C., Apps, M. A. J., & Husain, M. (2018). The anatomy of apathy: A neurocognitive framework for Amotivated behaviour. *Neuropsychologia, 118*, 54–67. https://doi.org/10.1016/j.neuropsychologia.2017.07.003

de Leeuw, J. R. (2015). jsPsych: A Javascript library for creating behavioral experiments in A web browser. *Behavior Research Methods, 47*(1), 1–12. https://doi.org/10.3758/s13428-014-0458-y

Mertens, G., Dessel, P. V., & Houwer, J. D. (2018). The contextual malleability of approach-avoidance training effects: Approaching or avoiding fear conditioned stimuli modulates effects of approach-avoidance training. *Cognition & Emotion, 32* (2), 341–349. https://doi.org/10.1080/02699931.2017.1308315

Mittelstädt, V., Miller, J., & Kiesel, A. (2018). Trading off switch costs and stimulus availability benefits: An investigation of voluntary task-switching behavior in A predictable dynamic multitasking environment. *Memory and Cognition, 46*(5), 699–715. https://doi.org/10.3758/s13421-018-0802-z

Mittelstädt, V., Miller, J., & Kiesel, A. (2019). Linking task selection to task performance: Internal and predictable external processing constraints jointly influence voluntary task switching behavior. *Journal of Experimental Psychology. Human Perception and Performance, 45*(12), 1529–1548. https://doi.org/10.1037/xhp0000690

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7*(3), 134–140. https://doi.org/10.1016/S1364-6613(03)00028-7

Moran, E. K., Culbreth, A. J., & Barch, D. M. (2017). Ecological momentary assessment of negative symptoms in schizophrenia: Relationships to effort-based decision making and reinforcement learning. *Journal of Abnormal Psychology, 126*(1), 96–105. https://doi.org/10.1037/abn0000240

Orr, J. M., Carp, J., & Weissman, D. H. (2012). The influence of response conflict on voluntary task switching: A novel test of the conflict monitoring model. *Psychological Research, 76*(1), 60–73. https://doi.org/10.1007/s00426-011-0324-9

Patzelt, E. H., Kool, W., Millner, A. J., & Gershman, S. J. (2019). Incentives boost model-based control across a range of severity on several psychiatric constructs. *Biological Psychiatry, 85*(5), 425–433. https://doi.org/10.1016/j.biopsych.2018.06.018

Poljac, E., Hoofs, V., Princen, M. M., & Poljac, E. (2017). Understanding Behavioural rigidity in autism spectrum conditions: The role of intentional control. *Journal of Autism and Developmental Disorders, 47*(3), 714–727. https://doi.org/10.1007/s10803-016-3010-3

Poljac, E., Poljac, E., & Yeung, N. (2012). Cognitive control of intentions for voluntary actions in individuals with a high level of autistic traits. *Journal of Autism and Developmental Disorders, 42*(12), 2523–2533. https://doi.org/10.1007/s10803-012-1509-9

Saunders, B., Milyavskaya, M., & Inzlicht, M. (2015). Variation in cognitive control as emotion regulation. *Psychological Inquiry, 26*(1), 108–115. https://doi.org/10.1080/1047840X.2015.962396

Schneider, D. W. (2015). Isolating a mediated route for response congruency effects in task switching. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 41*(1), 235–245. https://doi.org/10.1037/xlm0000049

Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: An integrative theory of anterior cingulate cortex function. *Neuron, 79*(2), 217–240. https://doi.org/10.1016/j.neuron.2013.07.007

Shenhav, A., Musslick, S., Lieder, F., Kool, W., Griffiths, T. L., Cohen, J. D., & Botvinick, M. M. (2017). Toward a rational and mechanistic account of mental effort. *Annual Review of Neuroscience, 40*(1), 99–124. https://doi.org/10.1146/annurev-neuro-072116-031526

Van Dessel, P., Liefooghe, B., & De Houwer, J. (2020). The instructed task-switch evaluation effect: Is the instruction to switch tasks sufficient to dislike task switch cues? *Journal of Cognition, 3*(1), 1. https://doi.org/10.5334/joc.90

Vandierendonck, A., Liefooghe, B., & Verbruggen, F. (2010). Task switching: Interplay of reconfiguration and interference control. *Psychological Bulletin, 136*(4), 601–626. https://doi.org/10.1037/a0019791

Vermeylen, L., Braem, S., & Notebaert, W. (2019). The affective twitches of task switches: Task switch cues are evaluated as negative. *Cognition, 183*, 124–130. https://doi.org/10.1016/j.cognition.2018.11.002

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), Article e68210. https://doi.org/10.1371/journal.pone.0068210

Whitehead, P. S., Brewer, G. A., & Blais, C. (2019). Are cognitive control processes reliable? *Journal of Experimental Psychology. Learning, Memory, and Cognition, 45*(5), 765–778. https://doi.org/10.1037/xlm0000632

Wittchen, H. U., Jacobi, F., Rehm, J., Gustavsson, A., Svensson, M., Jönsson, B., … Steinhausen, H.-C. (2011). The size and burden of mental disorders and other disorders of the brain in Europe 2010. *European Neuropsychopharmacology, 21*(9), 655–679. https://doi.org/10.1016/j.euroneuro.2011.07.018

Zipf, G. K. (1949), 1902–1950. *Human behavior and the principle of least effort: An introduction to human ecology.* Addison-Wesley Press.