

<sup>1</sup> When easy is not preferred: A discounting paradigm to assess load-independent task  
<sup>2</sup> preference

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16

## Abstract

17 When individuals set goals, they consider the subjective value (SV) of the anticipated  
18 reward and the required effort, a trade-off that is of great interest to psychological research.  
19 One approach to quantify the SVs of levels of difficulty of a cognitive task is the Cognitive  
20 Effort Discounting Paradigm by Westbrook and colleagues (2013). However, it fails to  
21 acknowledge the highly individual nature of effort, as it assumes a unidirectional, inverse  
22 relationship between task load and SVs. Therefore, it cannot map differences in effort  
23 perception that arise from traits like Need for Cognition, since individuals who enjoy  
24 effortful cognitive activities likely do not prefer the easiest level. We replicated the analysis  
25 of Westbrook and colleagues with an adapted version, the Cognitive and Affective  
26 Discounting (CAD) Paradigm. It quantifies SVs without assuming that the easiest level is  
27 preferred, thereby enabling the assessment of SVs for tasks without objective order of task  
28 load. Results show that many participants preferred a more or the most difficult level.  
29 Variance in SVs was best explained by a declining logistic contrast of the  $n$ -back levels and  
30 by the accuracy of responses, while reaction time as a predictor was highly volatile  
31 depending on the preprocessing pipeline. Participants with higher Need for Cognition  
32 scores perceived higher  $n$ -back levels as less effortful and found them less aversive. Effects  
33 of Need for Cognition on SVs in lower levels did not reach significance, as group differences  
34 only emerged in higher levels. The CAD Paradigm appears to be well suited for assessing  
35 and analysing task preferences independent of the supposed objective task difficulty.

36       *Keywords:* effort discounting, registered report, specification curve analysis, need for  
37 cognition,  $n$ -back

38       Word count: 7000

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40 preference

41 **Introduction**

42 In everyday life, effort and reward are closely intertwined<sup>1</sup>. With each decision a  
43 person makes, they have to evaluate whether the effort required to reach a goal is worth  
44 being exerted, given the reward they receive when reaching the goal. A reward is  
45 subjectively more valuable if it is obtained with less effort, so the required effort is used as  
46 a reference point for estimating the reward value<sup>1</sup>. However, the cost of the effort itself is  
47 also subjective, and research has not yet established which function best describes the  
48 relationship between effort and cost<sup>2</sup>. Investigating effort and cost is challenging because  
49 “effort is not a property of the target task alone, but also a function of the individual’s  
50 cognitive capacities, as well as the degree of effort voluntarily mobilized for the task, which  
51 in turn is a function of the individual’s reward sensitivity” (p. 209)<sup>2</sup>.

52 One task that is often used to investigate effort is the *n*-back task, a working memory  
53 task in which a continuous stream of stimuli, e.g. letters, is presented on screen.  
54 Participants indicate via button press whether the current stimulus is the same as *n* stimuli  
55 before, with *n* being the level of difficulty between one and six<sup>3</sup>. The *n*-back task is well  
56 suited to investigate effort because it is an almost continuous manipulation of task load as  
57 has been shown by monotonic increases in error rates, reaction times<sup>4</sup>, and brain activity in  
58 areas associated with working memory<sup>5,6</sup>. However, its reliability measures are mixed, and  
59 associations of *n*-back performance and measures such as executive functioning and fluid  
60 intelligence are often inconsistent<sup>4</sup>.

61 A way to quantify the subjective cost of each *n*-back level has been developed by  
62 Westbrook, Kester, and Braver<sup>7</sup>, called the Cognitive Effort Discounting Paradigm  
63 (COG-ED). First, the participants complete the *n*-back levels to familiarize themselves  
64 with the task. Then, 1-back is compared with each more difficult level by asking the

65 participants to decide between receiving a fixed 2\$ for the more difficult level or the flexible  
66 starting value of 1\$ for 1-back. If they choose the more difficult level, the reward for 1-back  
67 increases by 0.50\$, if they choose 1-back, it decreases by 0.50\$. This is repeated five more  
68 times, with each adjustment of the 1-back reward being half of the previous step, while the  
69 reward for the more difficult level remains fixed at 2\$. The idea is to estimate the point of  
70 subjective equivalence, i.e., the monetary ratio at which both offers are equally preferred<sup>7</sup>.  
71 The subjective value (SV) of each more difficult level is then calculated by dividing the  
72 final reward value of 1-back by the fixed 2\$ reward. Westbrook et al.<sup>7</sup> used these SVs to  
73 investigate inter-individual differences in effort discounting. Younger participants showed  
74 lower effort discounting, i.e., they needed a lower monetary incentive for choosing the more  
75 difficult levels over 1-back.

76 The individual degree of effort discounting in the study by Westbrook et al.<sup>7</sup> was also  
77 associated with the participants' scores in Need for Cognition (NFC), a personality trait  
78 describing an individual's tendency to actively seek out and enjoy effortful cognitive  
79 activities<sup>8</sup>. Westbrook et al.<sup>7</sup> conceptualized NFC as a trait measure of effortful task  
80 engagement, providing a subjective self-report of effort discounting for each participant  
81 which could then be related to the SVs as an objective measure of effort discounting. On  
82 the surface, this association stands to reason, as individuals with higher NFC are more  
83 motivated to mobilize cognitive effort because they perceive it as intrinsically rewarding.  
84 Additionally, it has been shown that individuals avoid cognitive effort only to a certain  
85 degree, possibly to retain a sense of self-control<sup>9</sup>, a trait more prominent in individuals  
86 with high NFC<sup>10–12</sup>. However, the relation of NFC and SVs might be confounded, since  
87 other studies utilizing the COG-ED paradigm found the association of NFC and SVs to  
88 disappear after correcting for performance<sup>13</sup> or found no association of NFC and SVs at  
89 all<sup>14</sup>. On the other hand, task load has been shown to be a better predictor of SVs than  
90 task performance<sup>7,15,16</sup>, so more research is needed to shed light on this issue.

91 With the present study, we alter one fundamental assumption of the original

92 COG-ED paradigm: That the easiest  $n$ -back level has the highest SV. We therefore  
93 adapted the COG-ED paradigm in a way that allows the computation of SVs for different  
94  $n$ -back levels without presuming that all individuals inherently prefer the easiest level.  
95 Since we also aim to establish this paradigm for the assessment of tasks with no objective  
96 task load, e.g., emotion regulation tasks<sup>17</sup>, we call it the Cognitive and Affective  
97 Discounting Paradigm (CAD). In the present study, we validated the CAD paradigm by  
98 conceptually replicating the findings of Westbrook et al.<sup>7</sup>. Additionally, we compared the  
99 effort discounting behavior of participants regarding the  $n$ -back task and an emotion  
100 regulation task. The full results of the latter are published in a second Registered Report<sup>17</sup>.  
101 The COG-ED paradigm has been applied to tasks in different domains before, showing  
102 that SVs across task domains correlate<sup>14</sup>, but these tasks had an objective order of task  
103 load, which is not the case for the choice of emotion regulation strategies or other  
104 paradigms where there is no objective order of task load.

105 Our hypotheses were derived from the results of Westbrook et al.<sup>7</sup>. As a manipulation  
106 check, we hypothesized that with increasing  $n$ -back level the (1a) the signal detection  
107 parameter  $d'$  declines, while (1b) reaction time and (1c) perceived task load increase.  
108 Regarding the associations of task load and effort discounting we hypothesized that (2a)  
109 SVs decline with increasing  $n$ -back level, and (2b) they do so even after controlling for  
110 declining task performance. And finally, we hypothesized that the CAD paradigm can show  
111 inter-individual differences in effort discounting, such that participants with higher NFC  
112 have (3a) lower SVs for 1-back but higher SVs for 2- and 3-back, (3b) lower perceived task  
113 load across all levels, and (3c) higher aversion against 1-back but lower aversion against 2-  
114 and 3-back. Each hypothesis is detailed in the Design Table in the Supplementary Material.

## 115 Methods

116 We report how we determined our sample size, all data exclusions (if any), all  
117 manipulations, and all measures in the study<sup>cf. 18</sup>. The paradigm was written and

<sup>118</sup> presented using *Psychopy*<sup>19</sup>. We used *R*<sup>20</sup> with *R Studio*<sup>21</sup> with the main packages *aferx*<sup>22</sup>  
<sup>119</sup> and *BayesFactor*<sup>23</sup> for all our analyses.

<sup>120</sup> **Ethics information**

<sup>121</sup> The study protocol complies with all relevant ethical regulations and was approved  
<sup>122</sup> by the ethics committee of the Technische Universität Dresden (reference number  
<sup>123</sup> SR-EK-50012022). Prior to testing, written informed consent was obtained. Participants  
<sup>124</sup> received 24€ in total or course credit for participation.

<sup>125</sup> **Design**

<sup>126</sup> **CAD Paradigm.** Figure 1 illustrates how different modifications of the COG-ED  
<sup>127</sup> paradigm<sup>7</sup> return SVs that do or do not reflect the true preference of a hypothetical  
<sup>128</sup> participant, who likes 2-back most, 3-back less, and 1-back least (for reasons of clarity  
<sup>129</sup> there are only three levels in the example). The COG-ED paradigm, which compares every  
<sup>130</sup> more difficult level with 1-back sets the SV of 1-back to 1, regardless of the response  
<sup>131</sup> pattern. Adding a comparison of the more difficult levels with each other allows the SVs of  
<sup>132</sup> those two levels to be more differentiated, but leaves the SV of 1-back unchanged. Adding  
<sup>133</sup> those same pairs again, but with the opposite assignment of fixed and flexible level, does  
<sup>134</sup> approach the true preference, but has two disadvantages. First, the SVs are still quite alike  
<sup>135</sup> across levels due to the fact that every more difficult level has only been compared with the  
<sup>136</sup> easiest level, and second, having more task levels than just three would lead to an  
<sup>137</sup> exponential increase in comparisons. Therefore, the solution lies in reducing the number of  
<sup>138</sup> necessary comparisons by presenting only one effort discounting round for each possible  
<sup>139</sup> pair of levels after determining for each pair which level should be fixed and which should  
<sup>140</sup> be flexible. This is determined by presenting each possible pair of levels on screen with the  
<sup>141</sup> question “Would you prefer 1€ for level A or 1€ for level B?”. Participants respond by  
<sup>142</sup> clicking the respective on-screen button. Each pair is presented three times, resulting in 18

143 presented pairs, which are fully randomized in order and in the assignment of which level is  
144 on the left or right of the screen. For each pair, the level that was chosen by the participant  
145 at least two out of three times will be used as the level with a flexible value, which starts at  
146 1€ and changes in every iteration. The other level in the pair will be set to a fixed value of  
147 2€. Then, the effort discounting sensu Westbrook et al.<sup>7</sup> begins, but with all possible pairs  
148 and with the individually determined assignment of fixed and flexible level. The order in  
149 which the pairs are presented is fully randomized, and each pair goes through all iteration  
150 steps of adding/subtracting 0.50€, 0.25€, 0.13€, 0.06€, 0.03€, 0.02€ to/from the flexible  
151 level's reward (each adjustment half of the previous one, rounded to two decimals) before  
152 moving on to the next one. This procedure allows to compute SVs based on actual  
153 individual preference instead of objective task load. For each pair, the SV of the flexible  
154 level is 1, as it was preferred when faced with equal rewards, and the SV of the fixed level  
155 is the final reward of the flexible level divided by 2€. Each level's "global" SV is calculated  
156 as the mean of this level's SVs from all pairs in which it appeared. If the participant has a  
157 clear preference for one level, this level's SV will be 1. If not, then no level's SV will be 1,  
158 but each level's SV can still be interpreted as an absolute and relative value, so each  
159 participant's effort discounting behaviour can still be quantified. The interpretation of SVs  
160 in Westbrook et al.<sup>7</sup> was "The minimum relative reward required for me to choose 1-back  
161 over this level". So if the SV of 3-back was 0.6, the participant would need to be rewarded  
162 with at least 60 % of what they are being offered for doing 3-back to do 1-back instead,  
163 forgoing the higher reward for 3-back. In this study, the SV can be interpreted as "The  
164 minimum relative reward required for me to choose any other level over this level".  
165 Therefore, an SV of 1 indicates that this level is preferred over all others, while SVs lower  
166 than 1 indicate that in at least one pair, a different level was preferred over this one.

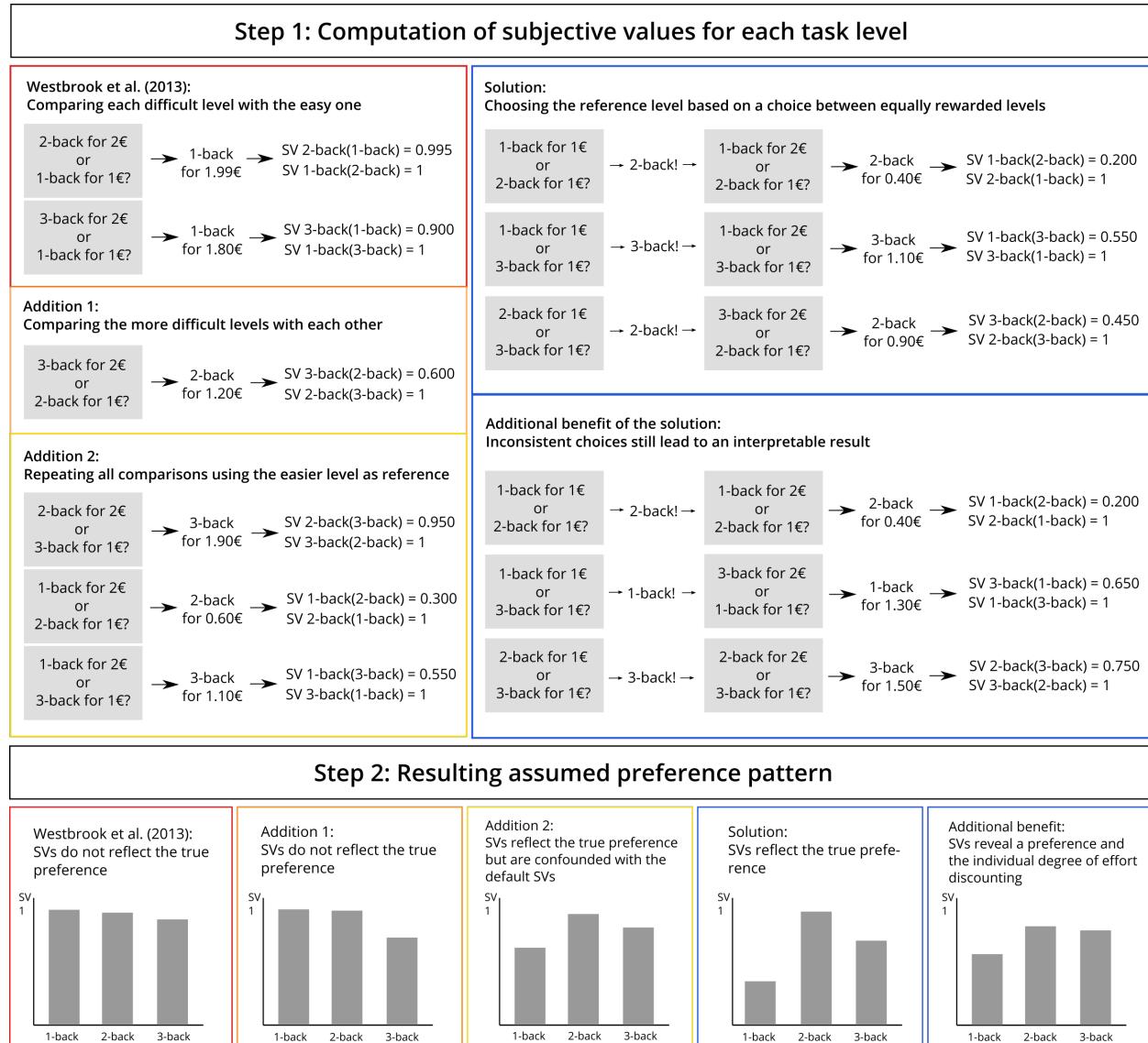


Figure 1. An example for subjective values for an  $n$ -back task with three levels, returned by different modifications of the COG-ED paradigm for a hypothetical participant with the true preference  $2\text{-back} > 3\text{-back} > 1\text{-back}$ . The grey boxes are the choice options shown to the participant. The participant's final reward value of the flexible level is displayed after the first arrow. The resulting subjective value of each level is displayed after the second arrow, in the notation "SV 3-back(1-back)" for the subjective value of 3-back when 1-back is the other choice. The Solution and Additional Benefit panel follow the same logic, but are preceded by a choice between equal rewards, and the participant's first choice indicated by an exclamation mark. Figure available at [osf.io/vnj8x/](https://osf.io/vnj8x/), under a CC-BY-4.0 license.

167      **Study procedure.** Healthy participants aged 18 to 30 years were recruited using  
 168      the software *ORSEE*<sup>24</sup>. Participants completed the personality questionnaires online and

then visited the lab for two sessions one week apart. NFC was assessed using the 16-item short form of the Need for Cognition Scale<sup>25,26</sup>. Responses to each item (e.g., “Thinking is not my idea of fun”, recoded) were recorded on a 7-point Likert scale. The NFC scale shows comparably high internal consistency (Cronbach’s  $\alpha > .80$ )<sup>26,27</sup>. Several other personality questionnaires were used in this study but are the topic of the Registered Report for the second lab session<sup>17</sup>. A full list of measures can be found in our Github repository. In the first session, participants provided informed consent and demographic data before completing the computer-based paradigm. The paradigm started with the *n*-back levels one to four, presented sequentially with two runs per level, consisting of 64 consonants (16 targets, 48 non-targets) per run. The levels were referred to by color (1-back: black, 2-back: red, 3-back: blue, 4-back: green) to avoid anchor effects in the effort discounting procedure. To assess perceived task load, we used the 6-item NASA Task Load Index (NASA-TLX)<sup>28</sup>, where participants evaluate their subjective perception of mental load, physical load, effort, frustration, performance, and time pressure during the task on a 20-point scale. At the end of each level, participants filled out the NASA-TLX on a tablet, plus an item with the same response scale, asking them how aversive they found this *n*-back level. After the *n*-back task, participants completed the CAD paradigm on screen and were instructed to do so as realistically as possible, even though the displayed rewards were not paid out on top of their compensation. They were told that one of their choices would be randomly picked for the final run of *n*-back. However, this data was not analyzed as it only served to incentivise truthful behavior and to stay close to the design of Westbrook et al.<sup>7</sup>. After the CAD paradigm, participants filled out a short questionnaire on the tablet, indicating whether they adhered to the instructions (yes/no) and what the primary motivation for their decisions during the effort discounting procedure was (avoid boredom/relax/avoid effort/seek challenge/other).

The second session consisted of an emotion regulation task with negative pictures and the instruction to suppress facial reactions, detach cognitively from the picture content,

and distract oneself, respectively. The paradigm followed the same structure of task and effort discounting procedure, but participants could decide which strategy they wanted to reapply in the last block. Study data was collected and managed using REDCap electronic data capture tools hosted at Technische Universität Dresden<sup>29,30</sup>.

## Sampling plan

Sample size determination was mainly based on the results of the analyses of Westbrook et al.<sup>7</sup> (see Design Table in the Supplementary Material). The hypothesis that yielded the largest necessary sample size was a repeated measures ANOVA with within-between interaction of NFC and *n*-back level influencing SVs. Sample size analysis with *G\*Power*<sup>31,32</sup> indicated that we should collect data from at least 72 participants, assuming  $\alpha = .05$  and  $\beta = .95$ . However, the sample size analysis for the hypotheses of the second lab session revealed a larger necessary sample size of 85 participants to find an effect of  $d = -0.32$  of emotion regulation on facial muscle activity with  $\alpha = .05$  and  $\beta = .95$ . To account for technical errors, noisy physiological data, or participants who indicate that they did not follow the instructions, we aimed to collect about 50% more data sets than necessary,  $N = 120$  in total.

## Analysis plan

Data collection and analysis were not performed blind to the conditions of the experiments. We excluded the data of a participant from all analyses, if the participant stated that they did not follow the instructions, if the investigator noted that the participant misunderstood the instructions, or if the participant withdrew their consent. No data was replaced. The performance measure  $d'$  was computed as the difference of the *z*-transformed hit rate and the *z*-transformed false alarm rate<sup>33</sup>. Reaction time (RT) data was trimmed by excluding all trials with responses faster than 100 ms, as the relevant cognitive processes cannot have been completed before<sup>34,35</sup>. Aggregated RT values were

described using the median and the median of absolute deviation (*MAD*) as robust estimates of center and variability, respectively<sup>36</sup>. Error- and post-error trials were excluded, because RT in the latter is longer due to more cautious behavior<sup>37,38</sup>. To test our hypotheses, we performed a series of rmANOVAs and an MLM with orthogonal sum-to-zero contrasts in order to meaningfully interpret results<sup>39</sup>.

*Manipulation check.* Declining performance was investigated by calculating an rmANOVA with six paired contrasts comparing  $d'$  between two levels of 1- to 4-back at a time. Another rmANOVA with six paired contrasts was computed to compare the median RT between two levels of 1- to 4-back at a time. To investigate changes in NASA-TLX ratings, six rmANOVAs were computed, one for each NASA-TLX subscale, and each with six paired contrasts comparing the ratings between two levels of 1- to 4-back at a time.

*Subjective values.* For each effort discounting round, the SV of the fixed level was calculated by adding or subtracting the last adjustment of 0.02€ from the last monetary value of the flexible level, depending on the participant's last choice, and dividing this value by 2€. This yielded an SV between 0 and 1 for the fixed compared with the flexible level, while the SV of the flexible level was 1. The closer the SV of the fixed level is to 0, the stronger the preference for the flexible level. All SVs of each level were averaged to compute one "global" SV for each level. An rmANOVA with four different contrasts were computed to investigate the association of SVs and the  $n$ -back levels: Declining linear (3,1,-1,-3), ascending quadratic (-1,1,1,-1), declining logistic (3,2,-2,-3), and positively skewed normal (1,2,-1,-2). Depending on whether the linear or one of the other three contrasts fit the curve best, we applied a linear or nonlinear multi-level model in the next step, respectively.

To determine the influence of task performance on the association of SVs and  $n$ -back level, we performed MLM. We applied restricted maximum likelihood (REML) to fit the model. As an effect size measure for random effects we first calculated the intraclass correlation (ICC), which displays the proportion of variance that is explained by differences

247 between persons. Second, we estimated a random slopes model of  $n$ -back level (level 1,  
248 fixed, and random factor: 0-back, 1-back, 2-back, 3-back) predicting SV nested within  
249 subjects. As Mussel et al.<sup>40</sup> could show, participants with high versus low NFC not only  
250 have a more shallow decline in performance with higher  $n$ -back levels, but show a  
251 demand-specific increase in EEG theta oscillations, which has been associated with mental  
252 effort. We controlled for performance, i.e.,  $d'$  (level 1, fixed factor, continuous), median RT  
253 (level 1, fixed factor, continuous) in order to eliminate a possible influence of declining  
254 performance on SV ratings.

$$SV \sim level + d' + medianRT + (level|subject)$$

255 Level-1-predictors were centered within cluster as recommended by Enders & Tofighi<sup>41</sup>. By  
256 this, the model yields interpretable parameter estimates. If necessary, we adjusted the  
257 optimization algorithm to improve model fit. We visually inspected the residuals of the  
258 model for evidence to perform model criticism. This was done by excluding all data points  
259 with absolute standardized residuals above 3 SD. As effect size measures, we calculated  
260 pseudo  $R^2$  for our model and  $f^2$  to estimate the effect of  $n$ -back level according to Lorah<sup>42</sup>.

261 The association of SVs and NFC was examined with an rmANOVA. We subtracted  
262 the SV of 1- from 2-back and 2- from 3-back, yielding two SV difference scores per  
263 participant. The sample was divided into participants with low and high NFC using a  
264 median split. We then computed an rmANOVA with the within-factor  $n$ -back level and the  
265 between-factor NFC group to determine whether there is a main effect of level and/or  
266 group, and/or an interaction between level and group on the SV difference scores. Post-hoc  
267 tests were computed depending on which effect reached significance at  $p < .01$ . To ensure  
268 the validity of this association, we conducted a specification curve analysis<sup>43</sup>, which  
269 included 63 possible preprocessing pipelines of the RT data. These pipelines specify which  
270 transformation was applied (none, log, inverse, or square-root), which outliers were

271 excluded (none, 2, 2.5, or 3 *MAD* from the median, RTs below 100 or 200 ms), and across  
272 which dimensions the transformations and exclusions were applied (across/within subjects  
273 and across/within *n*-back levels). The rmANOVA was run with each of the 63 pipelines,  
274 which also included our main pipeline (untransformed data, exclusion of RTs below  
275 100 ms). The ratio of pipelines that lead to significant versus non-significant effects  
276 provides an indication of how robust the effect actually is.

277 The association of subjective task load with NFC was examined similarly. We  
278 calculated NASA-TLX sum scores per participant per level, computed an rmANOVA with  
279 the within-factor *n*-back level and the between-factor NFC group, and applied post-hoc  
280 tests based on which effect reached significance at  $p < .01$ . And the association of  
281 subjective aversiveness of the task with NFC was examined with difference scores as well,  
282 since we expected this curve to mirror the SV curve, i.e. as the SV rises, the aversiveness  
283 declines, and vice versa. We subtracted the aversiveness ratings of 1- from 2-back and 2-  
284 from 3-back, yielding two aversiveness difference scores per participant. Then, we  
285 computed an rmANOVA with the within-factor *n*-back level and the between-factor NFC  
286 group, and applied post-hoc tests based on which effect reached significance at  $p < .01$ .

287 The results of each analysis was assessed on the basis of both *p*-value and the Bayes  
288 factor  $BF_{10}$ , calculated with the *BayesFactor* package<sup>23</sup> using the default prior widths of  
289 the functions *anovaBF*, *lmBF* and *ttestBF*. We considered a  $BF_{10}$  close to or above 3/10 as  
290 moderate/strong evidence for the alternative hypothesis, and a  $BF_{10}$  close to or below  
291 .33/.10 as moderate/strong evidence for the null hypothesis<sup>44</sup>.

## 292 Pilot data

293 The sample of the pilot study consisted of  $N = 15$  participants (53.3% female,  
294  $M = 24.43$  ( $SD = 3.59$ ) years old). One participant's data was removed because they  
295 misunderstood the instruction. Due to a technical error the subjective task load data of

296 one participant was incomplete, so the hypotheses involving the NASA-TLX were analyzed  
297 with  $n = 14$  data sets. The results showed increases in subjective and objective task load  
298 measures with higher  $n$ -back level. Importantly, SVs were lower for higher  $n$ -back levels,  
299 but not different between 1- and 2-back, which shows that the easiest level is not  
300 universally preferred. The MLM revealed  $n$ -back level as a reliable predictor of SV, even  
301 after controlling for declining task performance ( $d'$  and median RT). NASA-TLX scores  
302 were higher with higher  $n$ , and lower for the group with lower NFC scores, but NFC and  
303  $n$ -back level did not interact. All results are detailed in the Supplementary Material.

### 304 **Data availability**

305 The data of this study can be downloaded from [osf.io/vnj8x/](https://osf.io/vnj8x/).

### 306 **Code availability**

307 The paradigm code, the R script for analysis, and the R Markdown file used to  
308 compile this document are available at [osf.io/vnj8x/](https://osf.io/vnj8x/).

### 309 **Protocol registration**

310 The Stage 1 Registered Report protocol has been approved and is available at  
311 [osf.io/qa2bg/](https://osf.io/qa2bg/).

## 312 **Results**

### 313 **Adjustments for Stage 2**

314 There were two necessary adjustments of the methods. First, we failed to update the  
315 necessary sample size after the analyses changed with the first review round. Instead of the  
316 72 subjects stated above, the largest minimum sample size was actually 53 subjects (see

317 hypothesis 1b in the Design Table in the Supplementary Material). And secondly, we  
318 changed to which hypothesis we applied the specification curve analysis (SCA). In the  
319 initial Stage 1 submission, we had applied it to the MLM of hypothesis 2b, which at this  
320 point included NFC as a predictor. Following the advice of the reviewers, we removed NFC  
321 from the MLM, and analyzed NFC in an rmANOVA (hypothesis 3a) instead. Since NFC  
322 was of great interest to us, we decided to apply the SCA to hypothesis 3a rather than 2b to  
323 provide a measure of robustness. However, hypothesis 3a does not contain any RT data, so  
324 the SCA is only useful for the MLM in hypothesis 2b. Therefore, we applied it to the MLM.

### 325 **Sample**

326 Data was collected between the 16th of August 2022 and the 3rd of February 2023.  
327 Of the  $N = 176$  participants who filled out the NFC questionnaire,  $n = 124$  completed the  
328 first lab session. Based on the experimenters' notes, we excluded the data of seven  
329 participants from analysis for misunderstanding the instruction of the  $n$ -back task, and the  
330 data of one participant who reported that they confused the colours of the levels during  
331 effort discounting. Our final data set therefore included  $N = 116$  participants (83.60%  
332 female,  $M \pm SD = 22.4 \pm 3$ ) years old), which is 2.2 times more than what the highest  
333 sample size calculation required.

### 334 **Manipulation checks**

335 We used rmANOVAs to investigate whether objective performance measures and  
336 subjective task load measures changed across  $n$ -back levels. For each rmANOVA we report  
337 the generalized eta squared  $\hat{\eta}_G^2$ , which estimates the effect size in analyses that contain  
338 both manipulated and non-manipulated terms. The performance measure  $d'$  did not  
339 change across  $n$ -back levels ( $F(2.85, 327.28) = 0.01, p = .999, \hat{\eta}_G^2 = .000, 90\% \text{ CI}$   
340 [.000, .000],  $\text{BF}_{10} = 3.31 \times 10^{-3}$ ), but the median RT did ( $F(2.46, 283.05) = 98.67,$   
341  $p < .001, \hat{\eta}_G^2 = .192, 90\% \text{ CI } [.130, .248], \text{BF}_{10} = 2.28 \times 10^{34}$ ), evidence was not in favour of

<sup>342</sup> H1a but in favour of H1b. Specifically, the median RT was higher for the more difficult  
<sup>343</sup> level in every contrast, with two exceptions: It did not differ between 2- and 4-back, and it  
<sup>344</sup> was higher for 3- than for 4-back (Table 1).

Table 1

*Paired contrasts for the rmANOVA comparing the median reaction time between n-back levels*

Contrast	Estimate	SE	df	t	p	BF <sub>10</sub>	$\eta_p^2$	95%CI
1 - 2	-0.11	0.01	345.00	-11.76	<.001	$1.75 \times 10^{30}$	0.29	[0.22, 1.00]
1 - 3	-0.16	0.01	345.00	-16.23	<.001	$8.80 \times 10^{45}$	0.43	[0.37, 1.00]
1 - 4	-0.12	0.01	345.00	-12.47	<.001	$4.79 \times 10^{34}$	0.31	[0.25, 1.00]
2 - 3	-0.04	0.01	345.00	-4.47	<.001	5,538.45	0.05	[0.02, 1.00]
2 - 4	-0.01	0.01	345.00	-0.71	0.894	0.10	1.45e-03	[0.00, 1.00]
3 - 4	0.04	0.01	345.00	3.76	0.001	$6.35 \times 10^6$	0.04	[0.01, 1.00]

*Note.* The column Contrast contains the  $n$  of the  $n$ -back levels. SE = standard error, df = degrees of freedom, t = t-statistic, p = p-value, CI = confidence interval.

<sup>345</sup> All NASA-TLX subscale scores increased across  $n$ -back levels, so evidence was in  
<sup>346</sup> favour of H1c. Ratings on the effort subscale ( $F(2.20, 253.06) = 203.82, p < .001$ ,  
<sup>347</sup>  $\hat{\eta}_G^2 = .316$ , 90% CI [.250, .375],  $BF_{10} = 2.47 \times 10^{34}$ ) increased across all levels, but the  
<sup>348</sup> magnitude of change decreased from 1- to 2-back ( $t(345) = -12.35, p_{Tukey(4)} < .001$ ,  
<sup>349</sup>  $BF_{10} = 4.24 \times 10^{19}$ ) to 3- to 4-back ( $t(345) = -2.72, p_{Tukey(4)} = .035, BF_{10} = 174.38$ ).  
<sup>350</sup> Three subscales had significant differences between all contrasts except for 3- versus  
<sup>351</sup> 4-back: While ratings on the frustration and time subscales were higher for more difficult  
<sup>352</sup> levels ( $F(2.50, 287.66) = 68.06, p < .001$ ,  $\hat{\eta}_G^2 = .172$ , 90% CI [.112, .227],  
<sup>353</sup>  $BF_{10} = 5.26 \times 10^{15}$ , and  $F(2.21, 254.65) = 51.08, p < .001, \hat{\eta}_G^2 = .117$ , 90% CI [.065, .168],  
<sup>354</sup>  $BF_{10} = 3.94 \times 10^9$ , respectively), ratings on the performance subscale decreased with higher  
<sup>355</sup>  $n$  ( $F(2.49, 285.97) = 95.33, p < .001, \hat{\eta}_G^2 = .241$ , 90% CI [.176, .299],  $BF_{10} = 1.55 \times 10^{24}$ ).  
<sup>356</sup> Ratings on the mental subscale consistently increased across all levels  
<sup>357</sup> ( $F(1.99, 228.35) = 274.47, p < .001, \hat{\eta}_G^2 = .375$ , 90% CI [.309, .432],  $BF_{10} = 1.64 \times 10^{43}$ ).  
<sup>358</sup> Ratings on the physical subscale were higher for more difficult levels

<sup>359</sup> ( $F(1.68, 192.93) = 15.91, p < .001, \hat{\eta}_G^2 = .041, 90\% \text{ CI } [.009, .075], \text{BF}_{10} = 60.54$ ), apart  
<sup>360</sup> from the contrasts 2- versus 3-back ( $\text{BF}_{10} = 10.45$ ) and 3- versus 4-back ( $\text{BF}_{10} = 0.47$ ).  
<sup>361</sup> The full results of these manipulation checks are listed in Table S.1 to S.8 in the  
<sup>362</sup> Supplementary Material.

<sup>363</sup> **Decline of subjective values**

<sup>364</sup> When asking participants what motivated their decisions in the cognitive effort  
<sup>365</sup> discounting paradigm, 11.2% stated that they wanted to avoid boredom, 22.4% stated that  
<sup>366</sup> they wanted a challenge, 34.5% stated that they wanted to avoid effort, and 4.3% stated  
<sup>367</sup> that they wanted to relax. The remaining 27.6% of participants used the free text field and  
<sup>368</sup> provided reasons such as “I wanted a fair relation of effort and reward.”, “I wanted the fun  
<sup>369</sup> that I had in the more challenging levels.”, “I wanted to maximize reward first and  
<sup>370</sup> minimize effort second.”, or “I did not want to perform poorly when I was being paid for  
<sup>371</sup> it.”. Figure S.1 in the Supplementary Material shows the different motivations in the  
<sup>372</sup> context of the SVs per  $n$ -back level.

<sup>373</sup> The rmANOVA showed a significant difference between the SVs across  $n$ -back levels  
<sup>374</sup> ( $F(1.98, 227.98) = 65.65, p < .001, \hat{\eta}_G^2 = .288, 90\% \text{ CI } [.222, .347], \text{BF}_{10} = 1.58 \times 10^{64}$ ), so  
<sup>375</sup> evidence was in favour of H2a. All four pre-defined contrasts reached significance (Table 2),  
<sup>376</sup> so a purely linear contrast can be rejected.

Table 2  
*Contrasts for the rmANOVA comparing the subjective values between  $n$ -back levels*

Contrast	Estimate	SE	df	t	p	$\eta_p^2$	95%CI
Declining Linear	1.11	0.08	345.00	13.41	<.001	0.34	[0.28, 1.00]
Ascending Quadratic	0.15	0.04	345.00	4.14	<.001	0.05	[0.02, 1.00]
Declining Logistic	1.22	0.09	345.00	12.97	<.001	0.33	[0.26, 1.00]
Positively Skewed Normal	0.75	0.06	345.00	12.74	<.001	0.32	[0.26, 1.00]

*Note.* SE = standard error, df = degrees of freedom, t = t-statistic, p = p-value, CI = confidence interval.

<sup>377</sup> The declining logistic contrast had the highest effect estimate ( $t(345) = 12.97$ ,  
<sup>378</sup>  $p < .001$ ), suggesting a shallow decline of SVs between 1- and 2-back, and 3- and 4-back,  
<sup>379</sup> respectively, and a steeper decline of SVs between 2- and 3-back.

<sup>380</sup> Consequently, we had to adapt the MLM to incorporate this non-linear trend. To  
<sup>381</sup> apply the contrast to the  $n$ -back levels, we had to turn the variables into a factor, with two  
<sup>382</sup> consequences: Centered variables cannot be turned into factors, so we entered the variable  
<sup>383</sup> level in its raw form, and factors cannot be used as random slopes, so the model is now  
<sup>384</sup> defined as:

$$SV \sim level + d' + medianRT + (1|subject)$$

<sup>385</sup> This means that the intercept still varied between subjects, but there were no random  
<sup>386</sup> slopes anymore. To provide more than one observation per factor level, we used the two  
<sup>387</sup> rounds per  $n$ -back level per subject, rather than  $n$ -back levels per subject. The ICC of the  
<sup>388</sup> null model indicated that there was a correlation of  $r = .096$  between the SVs of a subject,  
<sup>389</sup> i.e. that 9.59% of variance in SVs could be explained by differences between participants.  
<sup>390</sup> We did not use an optimization algorithm to improve the fit of the random intercept  
<sup>391</sup> model. A total of 9 data points from 6 participants were excluded, because the residuals  
<sup>392</sup> exceeded 3 SD above the mean. The results of the final model are displayed in Table 3.

Table 3

*Results of the multi level model on the influence of n-back level (as a declining logistic contrast) and task performance on subjective values.*

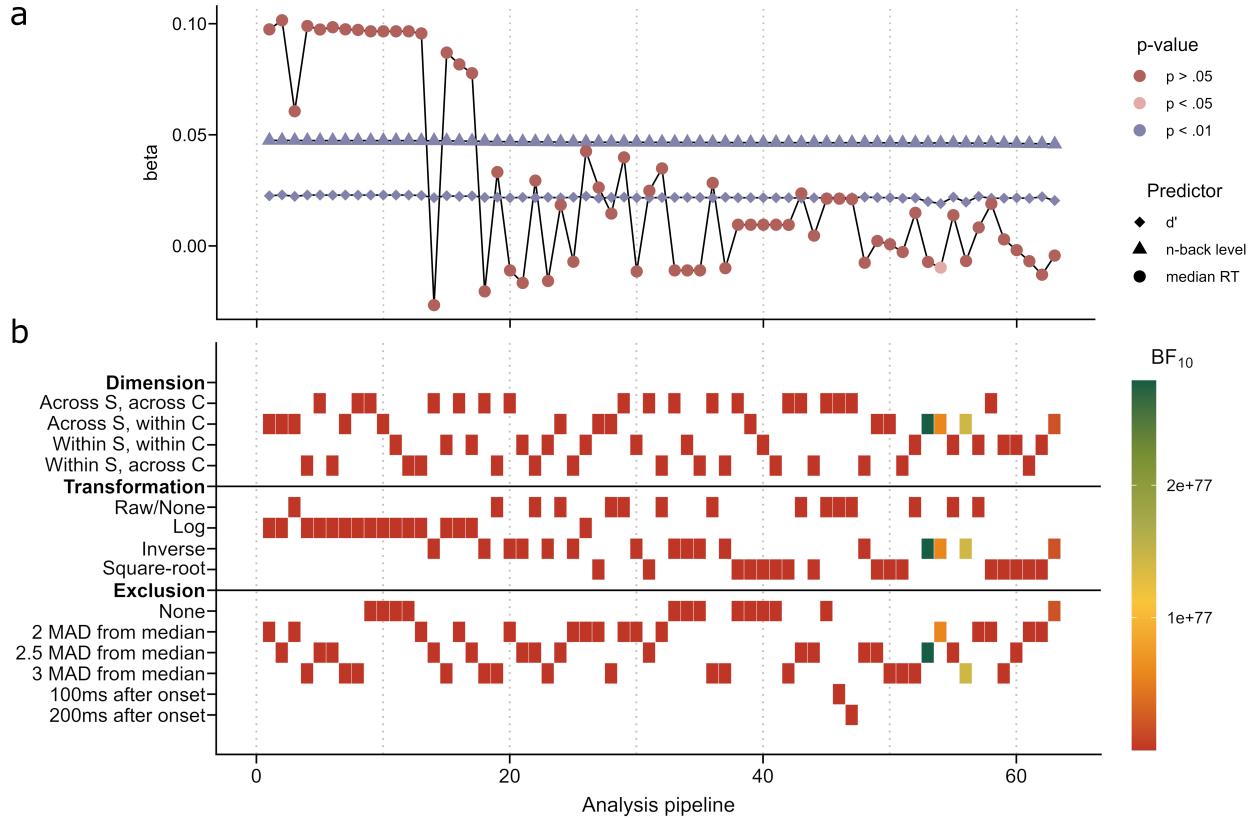
Parameter	Beta	SE	df	t-value	p-value	$f^2$	Random Effects (SD)
Intercept	0.81	0.01	114.82	78.34	<.001		0.09
n-back level	0.05	0.00	799.38	18.22	<.001	0.64	
d'	0.02	0.00	798.75	5.60	<.001	0.04	
median RT	0.02	0.07	798.58	0.30	0.768	0.00	

*Note.* SE = standard error, df = degrees of freedom, SD = standard deviation.

<sup>393</sup> An exploratory ANOVA was used to compare the fit of the final model with a linear

random intercept model, confirming that the two models were different from each other ( $\chi^2(2) = 34.48, p < .001$ ), and with an Akaike Information Criterion of  $AIC = -492.61$  and a Bayesian Information Criterion of  $BIC = -454.02$  the declining logistic model was superior to the linear model ( $AIC = -462.12, BIC = -433.18$ ). Both AIC and BIC subtract the likelihood of the model from the number of parameters and/or data points, so lower values indicate better model fit. The final model had an effect size of  $f^2 = 0.64$  for the  $n$ -back levels and  $f^2 = 0.04$  for  $d'$ , which are considered large and small, respectively<sup>45</sup>. This means that the  $n$ -back level explained 64.20% and  $d'$  explained 3.95% of variance in SVs relative to the unexplained variance, respectively. The beta coefficient indicated that with every 1-unit increase in  $d'$ , the SV increased by 0.02. Due to the coding scheme of the logistic contrast, the beta coefficient of the  $n$ -back level has to be interpreted inversely, so SVs decline with increasing  $n$ -back level. The effect size of the median RT was  $f^2 = 0.00$ . Since SVs decline with increasing level, beyond the variance explained by  $d'$ , evidence was in favour of H2b.

To investigate the dependency of the model results on the RT preprocessing, we conducted a specification curve analysis (Figure 2).

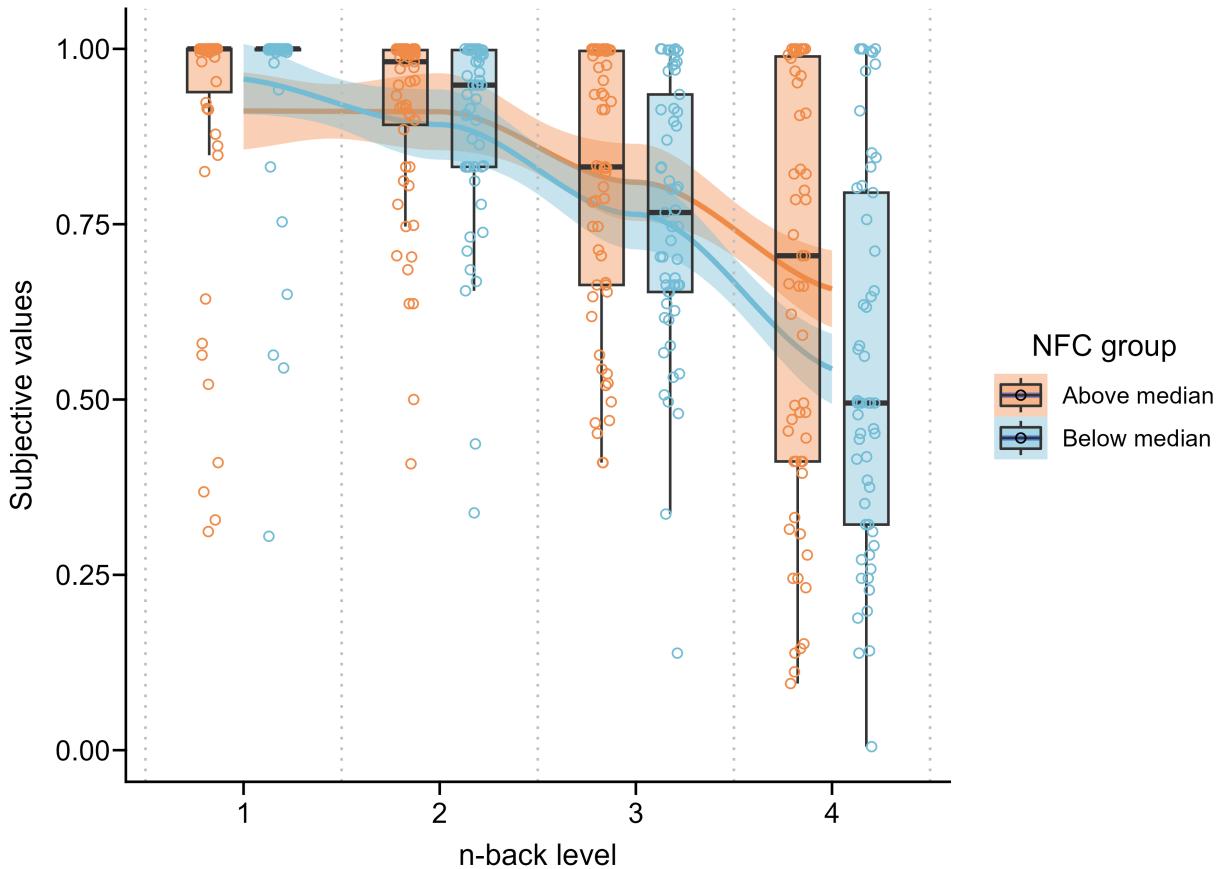


*Figure 2.* Results of the multi level model for each of the 63 preprocessing pipelines. Drawing a vertical through both panels indicates the type of preprocessing (panel b) of the pipeline and the resulting beta estimates of the three predictors in the model (panel a). The colourbar in panel b indicates the  $BF_{10}$  of each multi level model compared to a model in which the n-back level has no effect. The pipelines in both panels are sorted left to right in descending order of the magnitude of the beta estimate of the predictor n-back level. Figure available at [osf.io/vnj8x/](https://osf.io/vnj8x/), under a CC-BY-4.0 license.

410        Regardless of the preprocessing pipeline,  $n$ -back level and  $d'$  were significant  
 411        predictors of SVs, and had stable effect estimates across all pipelines. There was only one  
 412        pipeline in which the median RT was a significant predictor of SVs. This pipeline contained  
 413        data that had been inverse transformed across subjects but within conditions, i.e. within  
 414        the round of an  $n$ -back level, and RTs beyond 2 *MAD* from the median had been excluded.

<sup>415</sup> **Differences between NFC groups**

<sup>416</sup> Figure 3 shows the SVs per  $n$ -back level for participants with NFC scores above and  
<sup>417</sup> below the median. There is a concentration of participants who have assigned their highest  
<sup>418</sup> SV to 1-back, and this concentration fades across  $n$ -back levels. At the same time, there is  
<sup>419</sup> a subtle separation of SVs across  $n$ -back levels, depending on the participant's NFC score:  
<sup>420</sup> While the SVs of those with higher NFC scores remain elevated, the SVs of those with  
<sup>421</sup> lower NFC scores decline more strongly. Specifically,  $n = 71$  participants had an absolute  
<sup>422</sup> preference for 1-back,  $n = 18$  for 2-back,  $n = 9$  for 3-back, and  $n = 13$  for 4-back. There  
<sup>423</sup> were  $n = 5$  participants who did not have an absolute preference for any  $n$ -back level,  
<sup>424</sup> i.e. none of their SVs was 1.



*Figure 3.* Subjective values per n-back level for participants with Need for Cognition (NFC) scores above and below the median.  $N = 116$ . The scatter has a horizontal jitter of 0.2. Smoothing of conditional means with Loess method. Figure available at [osf.io/vnj8x/](https://osf.io/vnj8x/), under a CC-BY-4.0 license.

425 The median NFC was 16, with  $n = 57$  subjects below and  $n = 59$  above the median.

426 We used an rmANOVA to investigate whether the difference between the SVs of 1- and

427 2-back, and 2- and 3-back, respectively, depended on whether a participant's NFC score

428 was above or below the median. There was a main effect of the  $n$ -back level

429 ( $F(1, 114) = 9.13, p = .003, \hat{\eta}_G^2 = .040, 90\% \text{ CI } [.002, .115], \text{BF}_{10} = 12.68$ ), but neither a

430 main effect of the NFC group ( $F(1, 114) = 3.18, p = .077, \hat{\eta}_G^2 = .013, 90\% \text{ CI } [.000, .068]$ ,

431  $\text{BF}_{10} = 0.56$ ) nor an interaction of NFC group and  $n$ -back level ( $F(1, 114) = 0.46, p = .499$ ,

432  $\hat{\eta}_G^2 = .002, 90\% \text{ CI } [.000, .037]$ ), so evidence was not in favour of H3a. Post-hoc tests

433 showed that the difference between the SVs of 2- and 3-back is slightly more negative than

434 the difference between 1- and 2-back ( $t(114) = -3.02, p = .003$ ), but there were large  
 435 inter-individual differences (Figure 4a). This means that across the whole sample, there  
 436 was a steeper decline in SVs from 2- to 3-back than from 1- to 2-back, again resembling the  
 437 declining logistic function.

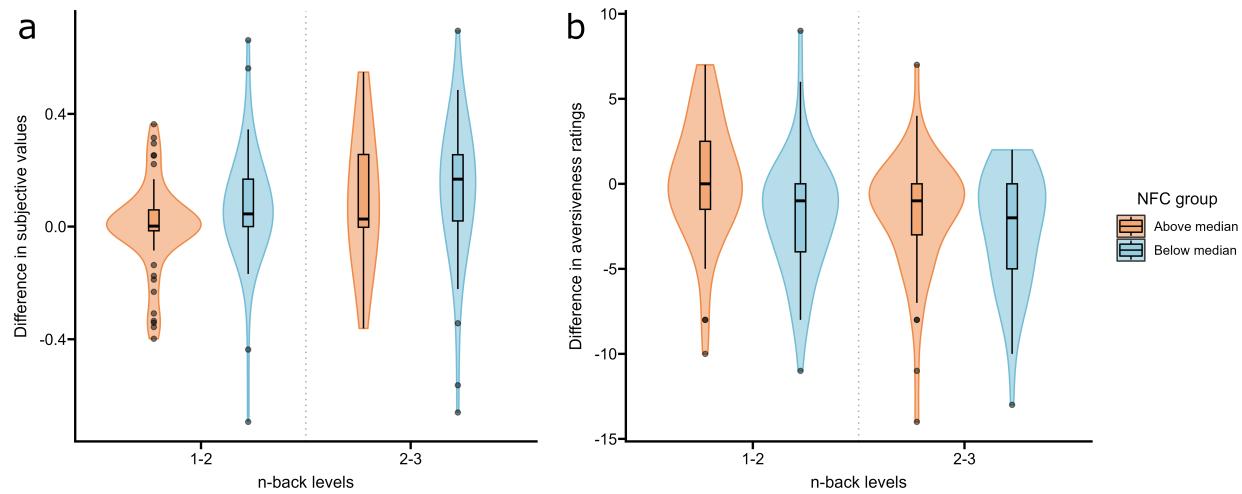
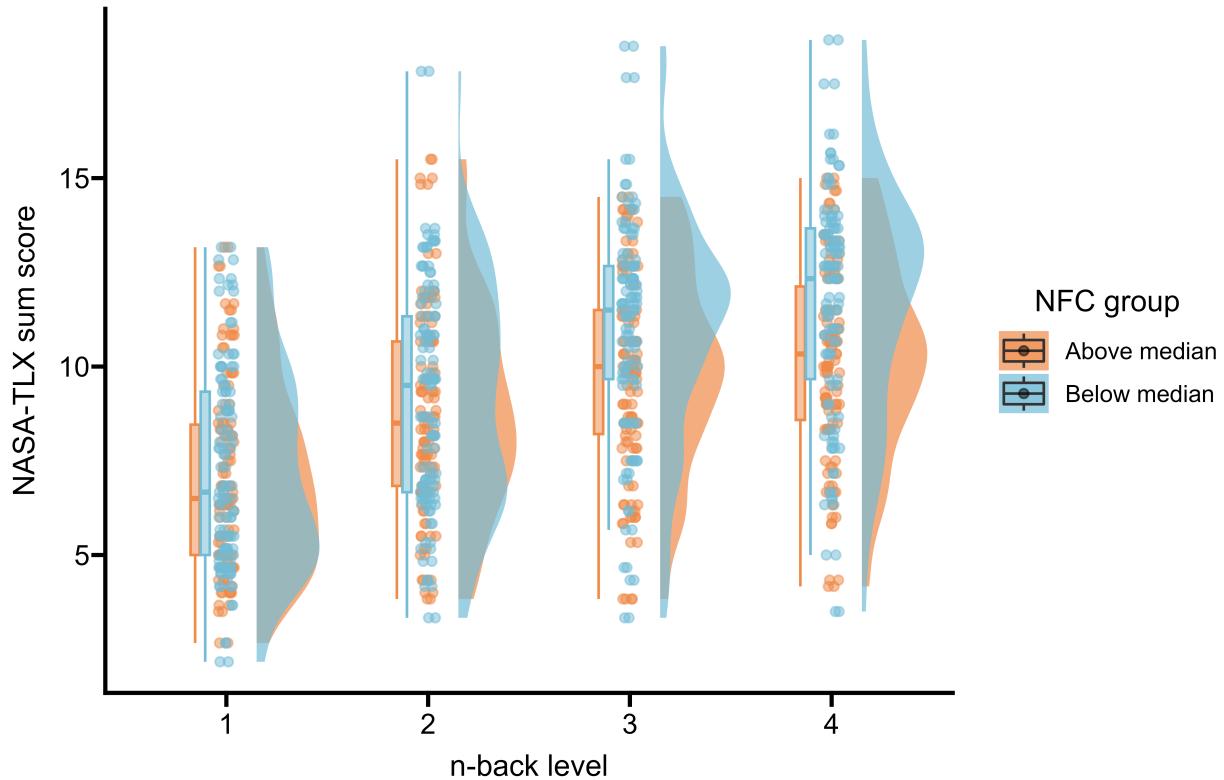


Figure 4. Difference scores for subjective values (a) and aversiveness ratings (b) when subtracting 2- from 1-back and 3- from 2-back. Horizontal lines of the boxplots represent the median per group, whiskers represent 1.5 interquartile ranges. NFC = Need for Cognition score.  $N = 116$ . Figure available at [osf.io/vnj8x/](https://osf.io/vnj8x/), under a CC-BY-4.0 license.

438 The rmANOVA on the association between NFC scores and NASA-TLX scores  
 439 revealed a main effect of  $n$ -back level ( $F(2.10, 239.56) = 154.50, p < .001, \hat{\eta}_G^2 = .223, 90\%$   
 440 CI [.159, .282],  $BF_{10} = 2.22 \times 10^{45}$  }\$) and an interaction between  $n$ -back level and NFC  
 441 scores ( $F(2.10, 239.56) = 4.93, p = .007, \hat{\eta}_G^2 = .009, 90\% \text{ CI } [.000, .025]$ ), but no main effect  
 442 of NFC scores ( $F(1, 114) = 3.22, p = .075, \hat{\eta}_G^2 = .022, 90\% \text{ CI } [.000, .084]$ ,  
 443  $BF_{10} = 1.75 \times 10^2$  }). Post –  
 444 *hoc* tests showed that the participants with NFC scores below the median had higher NASA –  
 445 TLX scores for 3 – back ( $t(114) = -2.15\$, p = .033, BF_{10} = 11.15$ ) and for 4-back  
 446 ( $t(114) = -2.89, p = .005, BF_{10} = 336.88$ ) than those with NFC scores above the median,  
 447 so evidence was in favour of H3b. Regardless of NFC scores, NASA-TLX scores were  
 448 higher for the more difficult level in each pair of  $n$ -back levels (Figure 5).



*Figure 5.* NASA-TLX sum scores for each  $n$ -back level. Colours indicate Need for Cognition (NFC) score above or below the median.  $N = 116$ . Figure available at [osf.io/vnj8x/](https://osf.io/vnj8x/), under a CC-BY-4.0 license.

With another rmANOVA we investigated whether the difference between the aversiveness scores of 1- and 2-back, and 2- and 3-back, respectively, depended on whether a participant's NFC score was above or below the median. There was a main effect of NFC group ( $F(1, 114) = 8.43, p = .004, \hat{\eta}_G^2 = .043, 90\% \text{ CI } [.003, .119], \text{BF}_{10} = 14.26$ ) and a main effect of the  $n$ -back level ( $F(1, 114) = 10.21, p = .002, \hat{\eta}_G^2 = .034, 90\% \text{ CI } [.000, .105]$ ), but no interaction ( $F(1, 114) = 2.59, p = .110, \hat{\eta}_G^2 = .009, 90\% \text{ CI } [.000, .058]$ ). In favour of H3c, post-hoc tests revealed that participants with NFC scores below the median reported higher aversiveness than participants with NFC scores above the median ( $t(114) = 2.90, p = .004$ ) (Figure 4b). Regardless of NFC, the difference of the aversiveness scores of 2- and 3-back was more negative than that of 1- and 2-back ( $t(114) = 3.20, p = .002$ ), indicating that in the same way in which the SVs decreased more strongly from 2- to 3-back than

460 from 1- to 2-back, the aversion increased more strongly. The full results of these analyses of  
461 NFC group differences can be found in Table S.11 to S.15 in the Supplementary Material.

462 **Exploratory analysis**

463 To investigate the apparent group difference between the SVs of participants with  
464 NFC scores below and above the median in higher  $n$ -back levels, we computed an  
465 rmANOVA with the within-factor level (1 to 4) and the between-factor NFC group  
466 (below/above median). There was no main effect of NFC group ( $F(1, 114) = 2.63$ ,  
467  $p = .108$ ,  $\hat{\eta}_G^2 = .007$ , 90% CI [.000, .053],  $2.95 \times 10^{-1}$ ), but a main effect of the  $n$ -back level  
468 ( $F(2.01, 229.39) = 67.39$ ,  $p < .001$ ,  $\hat{\eta}_G^2 = .295$ , 90% CI [.228, .354],  $2.70 \times 10^{30}$ ) and an  
469 interaction ( $F(2.01, 229.39) = 3.24$ ,  $p = .041$ ,  $\hat{\eta}_G^2 = .020$ , 90% CI [.000, .044]). Post-hoc  
470 tests for the main effect of level showed that SVs were lower for the more difficult  $n$ -back  
471 level in each paired contrast except for 1- versus 2-back. Post-hoc tests for the interaction  
472 effect showed that the NFC groups only had a significant difference in SVs for 4-back,  
473 where participants below the NFC median had lower scores ( $\Delta M = 0.11$ , 95% CI  
474 [0.01, 0.22],  $t(114) = 2.13$ ,  $p = .036$ ). Despite not reaching significance, 1-back was the only  
475 level in which participants with NFC scores above the median seemed to have lower SVs  
476 than those with scores below the median ( $\Delta M = -0.05$ , 95% CI [-0.11, 0.01],  
477  $t(114) = -1.50$ ,  $p = .136$ ). The full results of this exploratory analysis of NFC group  
478 differences can be found in Table S.16 and S.17 in the Supplementary Material.

479 **Discussion**

480 This Registered Report aimed to adapt the Cognitive Effort Discounting (COG-ED)  
481 paradigm by Westbrook et al.<sup>7</sup>, which estimates subjective values of different  $n$ -back levels,  
482 into the Cognitive and Affective Discounting (CAD) paradigm to estimate SVs of tasks  
483 without defaulting to the assumed objective task load as a benchmark. For this purpose,  
484 we adapted the way in which the discounting options are presented to the participants,

485 based the anchor on their own choices, and computed SVs across multiple combinations of  
486 task levels. The analyses were closely aligned with those in Westbrook et al.<sup>7</sup> to  
487 demonstrate the changes in SVs brought about by the new paradigm. This study also  
488 applied the CAD paradigm to an emotion regulation task, the results of which are detailed  
489 in a second Registered Report<sup>17</sup>.

490 **Manipulation checks**

491 The performance measure  $d'$  did not differ across  $n$ -back levels, but the RT increased  
492 from 1- to 2- to 3-back and then remained on a high level for 4-back. This points to three  
493 important characteristics of the  $n$ -back task in this context. Firstly, RT as a valid  
494 group-level indicator of performance might only be useful for levels up to  $n = 3$ , and could  
495 be used to investigate inter-individual differences for  $n > 3$ . Secondly, there is a  
496 speed-accuracy tradeoff in the first three levels, that might even re-emerge in higher levels,  
497 where  $d'$  would decline and RT would remain stable. And lastly, the fact that neither  
498 accuracy nor speed is an informative performance measure by itself has been observed  
499 before<sup>46</sup> and both show different associations with various measures of intelligence<sup>4</sup>,  
500 suggesting that they should always be reported as separate indices. Additionally,  $d'$  might  
501 not have differed across  $n$ -back levels because the manipulation of task load is not strictly  
502 continuous. Several participants said that they perceived 3-back as more difficult than  
503 4-back because they found it is easier to remember chunks of stimuli when  $n$  was an even  
504 number than when  $n$  was an odd number.

505 All NASA-TLX subscales differed across  $n$ -back levels, but the effort and mental load  
506 subscales were the only ones to consistently increase across all levels. This would support  
507 the notion of the  $n$ -back task offering a continuous manipulation of task load, at least  
508 subjectively. Ratings on the frustration and time subscales increased and ratings on the  
509 performance subscale decreased until 3-back and then remained stable. This pattern is  
510 akin to the RT, which also increased and then remained stable. Ratings on the physical

511 load subscale increased with  $n$ -back levels, but not between 2- and 3-back and 3- and  
512 4-back, respectively.

513 **Decline of subjective values**

514 The rmANOVA with different pre-defined contrasts showed that all fit the SVs to a  
515 different degree, and that the SVs do not simply decline linearly across  $n$ -back levels. The  
516 best fit was a declining logistic curve, reflecting that the majority of participants preferred  
517 1-back and that SVs for 2-back were also high, before having more inter-individual variance  
518 for 3- and 4-back. Thomson and Oppenheimer<sup>47</sup> argue that the different effort curves that  
519 have been observed for different tasks are likely due to the fact that we still understand  
520 quite little about how and why different manipulations of effort work. For example, the  
521  $n$ -back task is likely not a continuous manipulation of task load, as discussed above.

522 However, the declining logistic curve is similar to the sigmoidal curve that had the best fit  
523 in a different effort paradigm<sup>48</sup>, which the authors explained with the low effect of low  
524 energy costs, suggesting there are still common features of effort across different tasks and  
525 domains. The MLM with the logistic contrast showed that the  $n$ -back level explained the  
526 majority of variance in SVs, while the performance measure  $d'$  also explained some variance  
527 in SVs, albeit less. With increasing  $n$ -back level and decreasing  $d'$ , the SV decreased. The  
528 median RT was not a significant predictor in this model, which was somewhat surprising  
529 because RT but not  $d'$  yielded significant differences across levels in the manipulation  
530 checks. However, participants might have deliberately or subconsciously used the feedback  
531 they received at the end of each round, i.e. twice per  $n$ -back level, as an anchor during the  
532 effort discounting. This feedback was based on correct responses and not on RT, so if  
533 participants based their effort discounting choices at least partly on this feedback, they  
534 were either motivated to repeat a task in which they performed well and/or they were  
535 reluctant to accept a larger reward for a task in which they did not perform well. Since  
536 more participants reported effort avoidance as their motivation in the effort discounting

537 than those who reported seeking a challenge, we can assume that they were more  
538 motivated to repeat a task in which they performed well because their good performance  
539 coincided with low effort.

540 The declining logistic  $n$ -back levels and  $d'$  remained significant predictors of SVs  
541 throughout all 63 preprocessing pipelines in the specification curve analysis, with betas  
542 that varied by less than 0.01. In contrast to this stood the variability of the median RT  
543 betas, which ranged from about 0.10 to -0.03, and reached significance in only one pipeline.  
544 This pipeline was among the three pipelines with the highest  $BF_{10}$ , and applied inverse  
545 transformation to the RT data, across subjects but within conditions, and excluded data  
546 beyond 2  $MAD$  from the median. Interestingly, the curve of median RT betas in Figure 2a  
547 mirrored the rectangular pipeline indicators in the transformation rows of Figure 2b, so the  
548 transformation choice influenced the median RT much more than the dimension or the  
549 exclusion choice did. As Fernandez et al.<sup>49</sup> found, applying more than one preprocessing  
550 step to the reaction time data of a Stroop task increased the risk of false positives beyond  
551  $\alpha = .05$ , and transformation choices inflated this risk more than outlier exclusion or  
552 aggregation choices did. Our data seems to corroborate this finding for  $n$ -back tasks as  
553 well. Surprisingly, the  $d'$  betas appear almost unaffected by the preprocessing pipeline,  
554 even though  $d'$  was computed after the outlier exclusion. This indicates that researchers  
555 who are interested in the correctness rather than the speed of responses can choose a simple  
556 preprocessing pipeline without risking false positives through elaborate transformations.

### 557 Differences between NFC groups

558 The majority of participants (61.20 %) had an absolute preference for 1-back over the  
559 other levels, but that also means that there were 34.50 % who had an absolute preference  
560 for 2-, 3-, or 4-back, and 4.30 % who preferred no specific level over all others. It shows that  
561 when given the choice, there is a large number of participants who do not prefer the easiest  
562 level, confirming the necessity of an effort discounting paradigm that works independent of

563 the objective task load. The CAD paradigm provides the means to depict these preferences.

564 In the analysis of SV difference scores, the NFC group did not reach significance as a  
565 predictor. This was likely due to the bandwidth of SVs of participants with NFC scores  
566 around the median, and due to the fact that the difference appeared most pronounced for  
567 4-back, and we only analyzed the difference scores between 1- and 2-back and 2- and  
568 3-back. As the exploratory analysis showed, only 4-back yielded a significant group  
569 difference, and SVs of participants with NFC scores above the median were higher for 2- to  
570 4-back and lower for 1-back. The analysis of NASA-TLX scores showed that the sum score  
571 increased with every *n*-back level, and that participants with NFC scores below the median  
572 had higher NASA-TLX scores for 3- and 4-back than those below the median. This  
573 demonstrates that higher *n*-back levels have a higher discriminatory power regarding  
574 inter-individual differences in subjective effort perception. This was also supported by the  
575 fact that higher *n*-back levels were perceived as more aversive, and participants with NFC  
576 scores below the median reported higher aversion than those with NFC scores above the  
577 median. Our data supports the notion of a nonlinear interaction between person and  
578 situation that has also been described by Schmitt et al. (2013)<sup>50</sup> and Blum et al. (2018)<sup>51</sup>  
579 in the same-named NIPS model. The NIPS model describes behaviour as a function of  
580 situational affordance which is mediated by personality traits. The behavioural variability  
581 follows an s-shaped curve, such that “strong” situations with low or high situational  
582 affordance elicit the least behavioural variability, while “weak” situations with moderate  
583 affordance maximize individual differences. These differences are caused by a person’s  
584 expression of a certain trait, which shifts the curve along the y-axis. In our study, the  
585 situational affordance is the *n*-back level and the behaviour is the SV, following a declining  
586 logistic curve, i.e. a mirrored s-shape. Hence, the variability in SVs increased from 1- to  
587 4-back, and participants with higher NFC showed a more shallow decline in SVs as the  
588 situational affordance approached moderate values. According to the NIPS model, we can  
589 expect the SVs of participants with higher and lower NFC to converge again in levels of

590  $n > 4$ , since behavioural variability decreases when situational affordance is high. An  
591 investigation of this relationship using the COG-ED paradigm<sup>7</sup> had been encouraged by  
592 Strobel et al.<sup>52</sup> based on their findings on demand avoidance and cognitive effort  
593 investment. With the CAD paradigm, the declining logistic contrast of SVs across levels  
594 resembles the ascending logistic curve of the NIPS model<sup>50,51</sup> and should be tested further  
595 in a setting with  $n$ -back levels exceeding  $n = 4$ .

596 **Limitations**

597 When developing a new paradigm, it is challenging to decide on the optimal analysis  
598 strategy, as every hypothesis is based on expected data patterns rather than previous  
599 findings. While the Stage 1 review process made the analyses as robust as possible, there  
600 were still unknown factors that should be addressed by future studies. For instance, the  
601 differences between participants with higher and lower NFC should be investigated with  
602 extreme groups rather than a median split, or even more promising, as a continuous  
603 measure, especially in academic samples where NFC can be expected to be higher on  
604 average and more narrow in range. To arrive at a sample with more balanced NFC scores,  
605 recruitment efforts should be focused on representative population samples and/or  
606 collecting data with an NFC-based stop rule. Additionally, we expected the SVs of  
607 participants with lower NFC scores to peak at 1-back and the SVs of those with higher  
608 scores to peak at 2-back, but the way the SVs of both groups appeared to drift apart in the  
609 higher  $n$ -back levels suggests that an analysis of those levels would be more fruitful in  
610 determining group differences. Future studies could create a stronger separation between  
611 the concepts investigated in this study (discounting curve, effort perception, performance,  
612 SV computation, NFC), and model the SVs and their task-related influencing factors first,  
613 before looking at (non-linear) associations with personality. Another important point is the  
614 instruction, not just for the  $n$ -back task, but for the effort discounting as well. We had to  
615 exclude several participants for misunderstanding the task instruction, so we will add a

616 visual instruction or a training next time. And even though the participants were  
617 instructed to do the effort discounting with the aim to be satisfied with their choices  
618 instead of trying to increase the rewards, we cannot be sure that they did so. One might  
619 also argue that the 2€ reward range was not large enough to be an incentive for effort  
620 expenditure. However, findings by Bialaszek et al.<sup>53</sup> suggest that participants are actually  
621 more sensitive to effort when the reward is small. Nevertheless, we exceeded the largest  
622 required sample size by 2.20 times, which gives our analyses high statistical power.

## 623 Conclusion

624 Effort and reward are relevant in everyday life, yet these constructs vary in their  
625 conceptualization across individuals and even studies. With each decision an individual  
626 makes, they must weigh the required effort against the expected reward to decide if and  
627 how to behave in that situation. So far, effort discounting paradigms have relied on the  
628 assumption that the task that is objectively easiest is the one that is preferred by everyone,  
629 and each more difficult task is simply being devalued compared to the easy one. However,  
630 effort-related traits such as Need for Cognition suggest that this is not the case. Therefore,  
631 we developed a paradigm that allows to examine effort discounting independent of  
632 objective task load, which we tested using an *n*-back task. The results showed that many  
633 participants indeed preferred a more or even the most difficult *n*-back level. Spanning the  
634 entire sample, these preferences took the shape of a declining logistic curve across *n*-back  
635 levels. While the subjective value declined with increasing levels, it increased with better  
636 performance as measured in  $d'$ , and was unaffected by the reaction time. Participants with  
637 Need for Cognition scores above the median reported lower subjective task load in and less  
638 aversion to more difficult levels. However, they did not have higher subjective values per  
639 se, which was likely due to our choice of median split and our assumption that these group  
640 differences would emerge in lower levels. In fact, the reaction time and self-report data  
641 suggest that individual differences emerge especially from 3-back upwards, emphasizing the

642 need for tasks with high discriminatory power and effort discounting paradigms with  
643 flexible, participant-centered mechanisms. The CAD paradigm offers this flexibility, and we  
644 encourage future studies to question traditional assumptions in the field of effort  
645 discounting in the light of these findings, and to re-use this data set for exploratory  
646 analyses.

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761

### Author Contributions

762 JZ and CS contributed equally to this work. JZ, CS, and AS conceptualized the  
763 study and acquired funding. JZ and CS developed the methodology, investigated,  
764 administered the project, and wrote the software. JZ, CS, and CK did the formal analysis.  
765 JZ visualized the results. JZ and CK prepared the original draft. All authors reviewed,  
766 edited, and approved the final version of the manuscript.

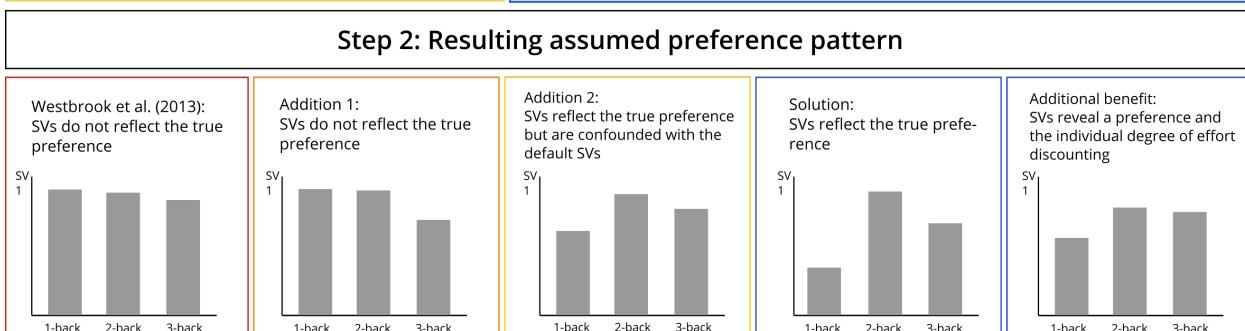
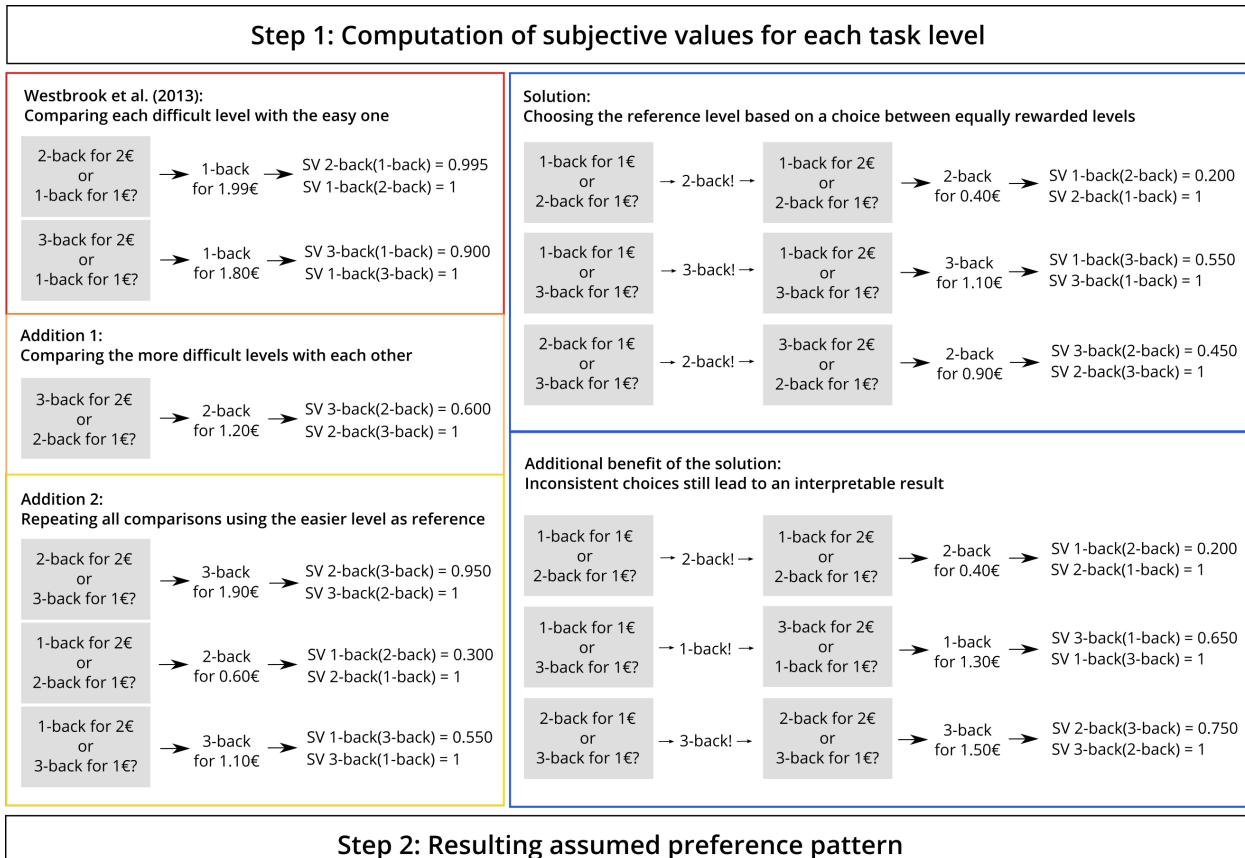
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### Competing Interests

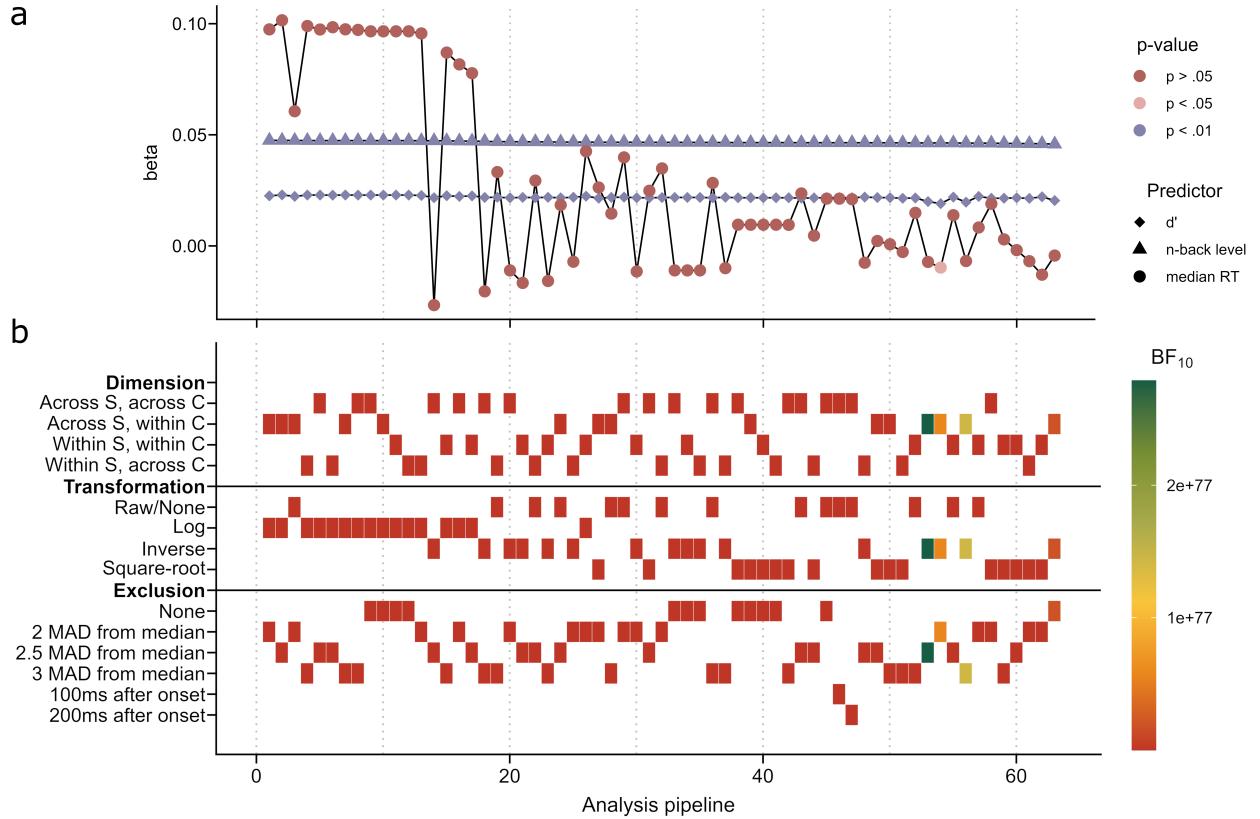
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The authors declare no competing interests.

## Figures



*Figure 1.* An example for subjective values for an  $n$ -back task with three levels, returned by different modifications of the COG-ED paradigm for a hypothetical participant with the true preference  $2\text{-back} > 3\text{-back} > 1\text{-back}$ . The grey boxes are the choice options shown to the participant. The participant's final reward value of the flexible level is displayed after the first arrow. The resulting subjective value of each level is displayed after the second arrow, in the notation "SV 3-back(1-back)" for the subjective value of 3-back when 1-back is the other choice. The Solution and Additional Benefit panel follow the same logic, but are preceded by a choice between equal rewards, and the participant's first choice indicated by an exclamation mark. Figure available at [osf.io/vnj8x/](https://osf.io/vnj8x/), under a CC-BY-4.0 license.



*Figure 2.* Results of the multi level model for each of the 63 preprocessing pipelines. Drawing a vertical through both panels indicates the type of preprocessing (panel b) of the pipeline and the resulting beta estimates of the three predictors in the model (panel a). The colourbar in panel b indicates the  $BF_{10}$  of each multi level model compared to a model in which the n-back level has no effect. The pipelines in both panels are sorted left to right in descending order of the magnitude of the beta estimate of the predictor n-back level. Figure available at [osf.io/vnj8x/](https://osf.io/vnj8x/), under a CC-BY-4.0 license.

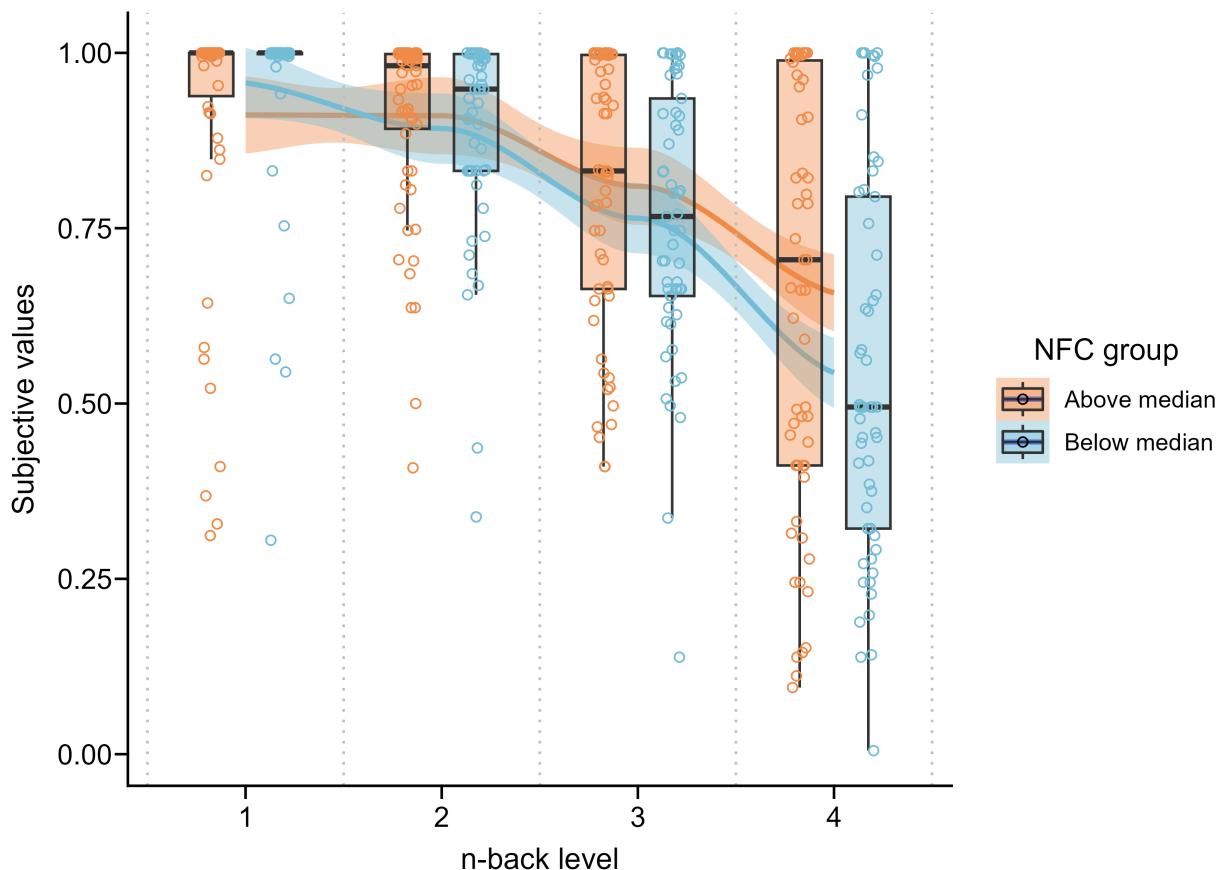


Figure 3. Subjective values per n-back level for participants with Need for Cognition (NFC) scores above and below the median.  $N = 116$ . The scatter has a horizontal jitter of 0.2. Smoothing of conditional means with Loess method. Figure available at [osf.io/vnj8x/](https://osf.io/vnj8x/), under a CC-BY-4.0 license.

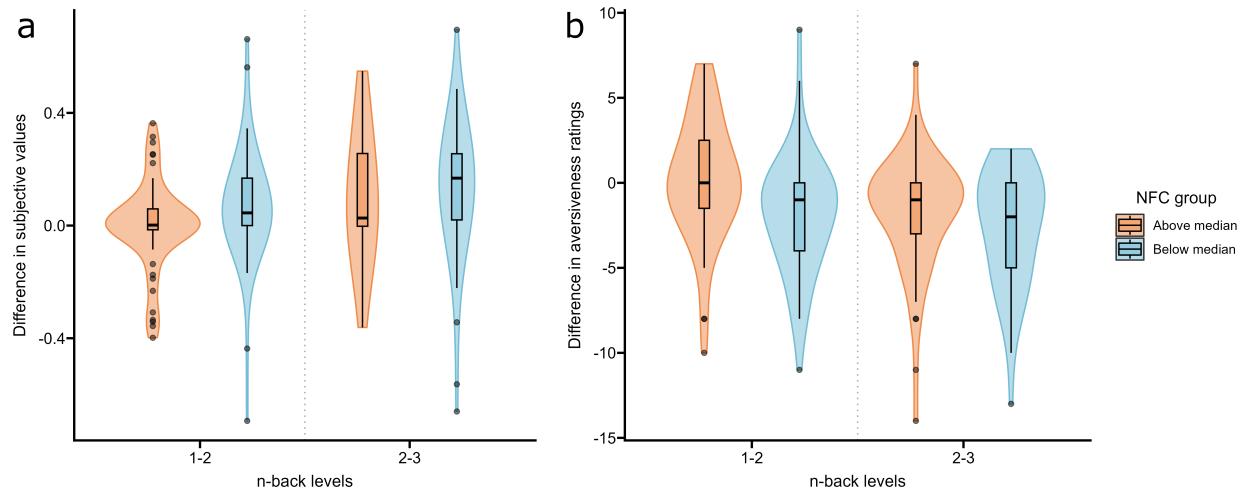


Figure 4. Difference scores for subjective values (a) and aversiveness ratings (b) when subtracting 2- from 1-back and 3- from 2-back. Horizontal lines of the boxplots represent the median per group, whiskers represent 1.5 interquartile ranges. NFC = Need for Cognition score.  $N = 116$ . Figure available at [osf.io/vnj8x/](https://osf.io/vnj8x/), under a CC-BY-4.0 license.

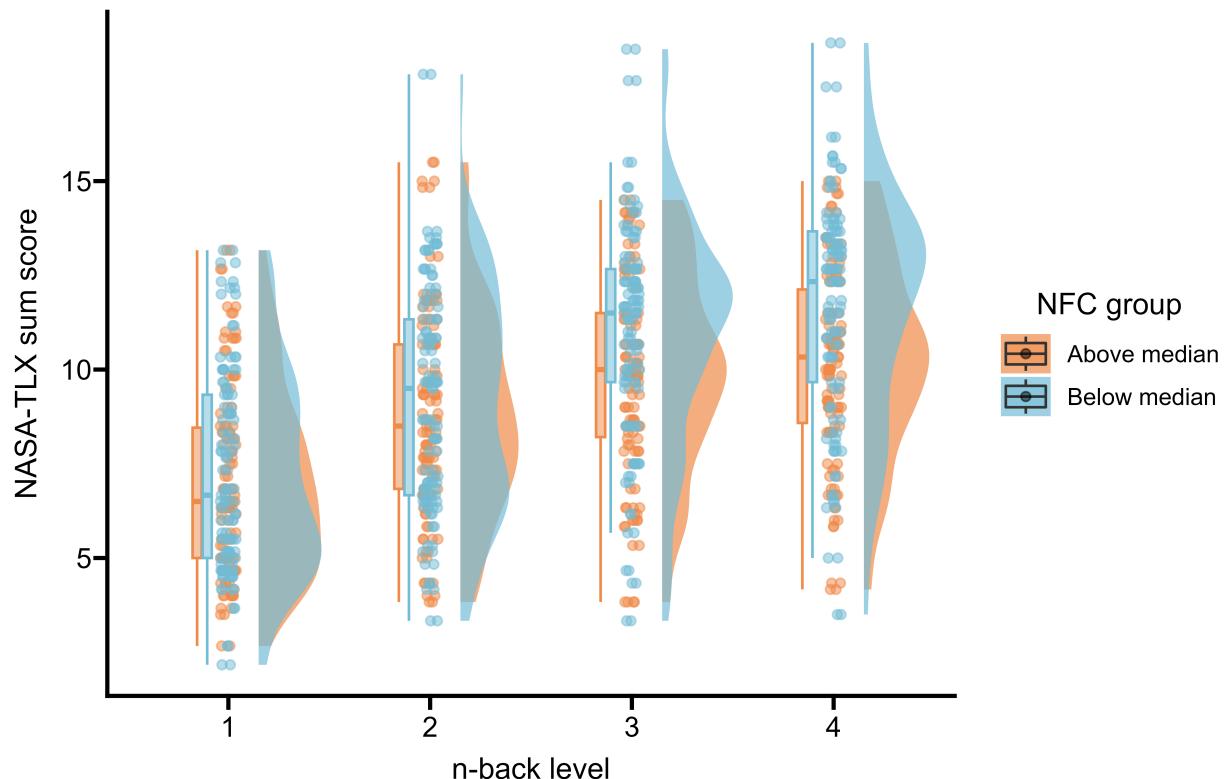


Figure 5. NASA-TLX sum scores for each  $n$ -back level. Colours indicate Need for Cognition (NFC) score above or below the median.  $N = 116$ . Figure available at [osf.io/vnj8x/](https://osf.io/vnj8x/), under a CC-BY-4.0 license.