

¹ When easy is not preferred: A discounting paradigm to assess load-independent task
² 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 of the 116 participants preferred a more or the most difficult
29 level. Variance in SVs was best explained by a declining logistic contrast of the n -back
30 levels and by the accuracy of responses, while reaction time as a predictor was highly
31 volatile depending on the preprocessing pipeline. Participants with higher Need for
32 Cognition scores perceived higher n -back levels as less effortful and found them less
33 aversive. Effects of Need for Cognition on SVs in lower levels did not reach significance, as
34 group differences only emerged in higher levels. The CAD Paradigm appears to be well
35 suited for assessing and analysing task preferences independent of the supposed objective
36 task difficulty.

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

39 Word count: 7000

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42 **Introduction**

43 In everyday life, effort and reward are closely intertwined¹. With each decision a
44 person makes, they have to evaluate whether the effort required to reach a goal is worth
45 being exerted, given the reward they receive when reaching the goal. A reward is
46 subjectively more valuable if it is obtained with less effort, so the required effort is used as
47 a reference point for estimating the reward value¹. However, the cost of the effort itself is
48 also subjective, and research has not yet established which function best describes the
49 relationship between effort and cost². Investigating effort and cost is challenging because
50 “effort is not a property of the target task alone, but also a function of the individual’s
51 cognitive capacities, as well as the degree of effort voluntarily mobilized for the task, which
52 in turn is a function of the individual’s reward sensitivity” (p. 209)².

53 One task that is often used to investigate effort is the *n*-back task, a working memory
54 task in which a continuous stream of stimuli, e.g. letters, is presented on screen.
55 Participants indicate via button press whether the current stimulus is the same as *n* stimuli
56 before, with *n* being the level of difficulty between one and six³. The *n*-back task is well
57 suited to investigate effort because it is an almost continuous manipulation of task load as
58 has been shown by monotonic increases in error rates, reaction times⁴, and brain activity in
59 areas associated with working memory^{5,6}. However, its reliability measures are mixed, and
60 associations of *n*-back performance and measures such as executive functioning and fluid
61 intelligence are often inconsistent⁴.

62 A way to quantify the subjective cost of each *n*-back level has been developed by
63 Westbrook, Kester, and Braver⁷, called the Cognitive Effort Discounting Paradigm
64 (COG-ED). First, the participants complete the *n*-back levels to familiarize themselves
65 with the task. Then, 1-back is compared with each more difficult level by asking the

66 participants to decide between receiving a fixed 2\$ for the more difficult level or the flexible
67 starting value of 1\$ for 1-back. If they choose the more difficult level, the reward for 1-back
68 increases by 0.50\$, if they choose 1-back, it decreases by 0.50\$. This is repeated five more
69 times, with each adjustment of the 1-back reward being half of the previous step, while the
70 reward for the more difficult level remains fixed at 2\$. The idea is to estimate the point of
71 subjective equivalence, i.e., the monetary ratio at which both offers are equally preferred⁷.
72 The subjective value (SV) of each more difficult level is then calculated by dividing the
73 final reward value of 1-back by the fixed 2\$ reward. Westbrook et al.⁷ used these SVs to
74 investigate inter-individual differences in effort discounting. Younger participants showed
75 lower effort discounting, i.e., they needed a lower monetary incentive for choosing the more
76 difficult levels over 1-back.

77 The individual degree of effort discounting in the study by Westbrook et al.⁷ was also
78 associated with the participants' scores in Need for Cognition (NFC), a personality trait
79 describing an individual's tendency to actively seek out and enjoy effortful cognitive
80 activities⁸. Westbrook et al.⁷ conceptualized NFC as a trait measure of effortful task
81 engagement, providing a subjective self-report of effort discounting for each participant
82 which could then be related to the SVs as an objective measure of effort discounting. On
83 the surface, this association stands to reason, as individuals with higher NFC are more
84 motivated to mobilize cognitive effort because they perceive it as intrinsically rewarding.
85 Additionally, it has been shown that individuals avoid cognitive effort only to a certain
86 degree, possibly to retain a sense of self-control⁹, a trait more prominent in individuals
87 with high NFC^{10–12}. However, the relation of NFC and SVs might be confounded, since
88 other studies utilizing the COG-ED paradigm found the association of NFC and SVs to
89 disappear after correcting for performance¹³ or found no association of NFC and SVs at
90 all¹⁴. On the other hand, task load has been shown to be a better predictor of SVs than
91 task performance^{7,15,16}, so more research is needed to shed light on this issue.

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

93 COG-ED paradigm: That the easiest n -back level has the highest SV. We therefore
94 adapted the COG-ED paradigm in a way that allows the computation of SVs for different
95 n -back levels without presuming that all individuals inherently prefer the easiest level.
96 Since we also aim to establish this paradigm for the assessment of tasks with no objective
97 task load, e.g., emotion regulation tasks¹⁷, we call it the Cognitive and Affective
98 Discounting Paradigm (CAD). In the present study, we validated the CAD paradigm by
99 conceptually replicating the findings of Westbrook et al.⁷. Additionally, we compared the
100 effort discounting behavior of participants regarding the n -back task and an emotion
101 regulation task. The full results of the latter are published in a second Registered Report¹⁷.
102 The COG-ED paradigm has been applied to tasks in different domains before, showing
103 that SVs across task domains correlate¹⁴, but these tasks had an objective order of task
104 load, which is not the case for the choice of emotion regulation strategies or other
105 paradigms where there is no objective order of task load.

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

116

Methods

117 We report how we determined our sample size, all data exclusions (if any), all
118 manipulations, and all measures in the study^{cf. 18}. The paradigm was written and

¹¹⁹ presented using *Psychopy*¹⁹. We used *R*²⁰ with *R Studio*²¹ with the main packages *aferx*²²
¹²⁰ and *BayesFactor*²³ for all our analyses.

¹²¹ **Ethics information**

¹²² The study protocol complies with all relevant ethical regulations and was approved
¹²³ by the ethics committee of the Technische Universität Dresden (reference number
¹²⁴ SR-EK-50012022). Prior to testing, written informed consent was obtained. Participants
¹²⁵ received 24€ in total or course credit for participation.

¹²⁶ **Design**

¹²⁷ **CAD Paradigm.** Figure 1 illustrates how different modifications of the COG-ED
¹²⁸ paradigm⁷ return SVs that do or do not reflect the true preference of a hypothetical
¹²⁹ participant, who likes 2-back most, 3-back less, and 1-back least (for reasons of clarity
¹³⁰ there are only three levels in the example). The COG-ED paradigm, which compares every
¹³¹ more difficult level with 1-back sets the SV of 1-back to 1, regardless of the response
¹³² pattern. Adding a comparison of the more difficult levels with each other allows the SVs of
¹³³ those two levels to be more differentiated, but leaves the SV of 1-back unchanged. Adding
¹³⁴ those same pairs again, but with the opposite assignment of fixed and flexible level, does
¹³⁵ approach the true preference, but has two disadvantages. First, the SVs are still quite alike
¹³⁶ across levels due to the fact that every more difficult level has only been compared with the
¹³⁷ easiest level, and second, having more task levels than just three would lead to an
¹³⁸ exponential increase in comparisons. Therefore, the solution lies in reducing the number of
¹³⁹ necessary comparisons by presenting only one effort discounting round for each possible
¹⁴⁰ pair of levels after determining for each pair which level should be fixed and which should
¹⁴¹ be flexible. This is determined by presenting each possible pair of levels on screen with the
¹⁴² question “Would you prefer 1€ for level A or 1€ for level B?”. Participants respond by
¹⁴³ clicking the respective on-screen button. Each pair is presented three times, resulting in 18

¹⁴⁴ presented pairs, which are fully randomized in order and in the assignment of which level is
¹⁴⁵ on the left or right of the screen. For each pair, the level that was chosen by the participant
¹⁴⁶ at least two out of three times will be used as the level with a flexible value, which starts at
¹⁴⁷ 1€ and changes in every iteration. The other level in the pair will be set to a fixed value of
¹⁴⁸ 2€. Then, the effort discounting sensu Westbrook et al.⁷ begins, but with all possible pairs
¹⁴⁹ and with the individually determined assignment of fixed and flexible level. The order in
¹⁵⁰ which the pairs are presented is fully randomized, and each pair goes through all iteration
¹⁵¹ steps of adding/subtracting 0.50€, 0.25€, 0.13€, 0.06€, 0.03€, 0.02€ to/from the flexible
¹⁵² level's reward (each adjustment half of the previous one, rounded to two decimals) before
¹⁵³ moving on to the next one. This procedure allows to compute SVs based on actual
¹⁵⁴ individual preference instead of objective task load. For each pair, the SV of the flexible
¹⁵⁵ level is 1, as it was preferred when faced with equal rewards, and the SV of the fixed level
¹⁵⁶ is the final reward of the flexible level divided by 2€. Each level's "global" SV is calculated
¹⁵⁷ as the mean of this level's SVs from all pairs in which it appeared. If the participant has a
¹⁵⁸ clear preference for one level, this level's SV will be 1. If not, then no level's SV will be 1,
¹⁵⁹ but each level's SV can still be interpreted as an absolute and relative value, so each
¹⁶⁰ participant's effort discounting behaviour can still be quantified. The interpretation of SVs
¹⁶¹ in Westbrook et al.⁷ was "The minimum relative reward required for me to choose 1-back
¹⁶² over this level". So if the SV of 3-back was 0.6, the participant would need to be rewarded
¹⁶³ with at least 60 % of what they are being offered for doing 3-back to do 1-back instead,
¹⁶⁴ forgoing the higher reward for 3-back. In this study, the SV can be interpreted as "The
¹⁶⁵ minimum relative reward required for me to choose any other level over this level".
¹⁶⁶ Therefore, an SV of 1 indicates that this level is preferred over all others, while SVs lower
¹⁶⁷ than 1 indicate that in at least one pair, a different level was preferred over this one.

¹⁶⁸ [FIGURE 1 HERE]

¹⁶⁹ **Study procedure.** Healthy participants aged 18 to 30 years were recruited using

¹⁷⁰ the software *ORSEE*²⁴. 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^{25,26}. 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 $\alpha > .80$)^{26,27}. Several other personality questionnaires were used in this study but are the topic of the Registered Report for the second lab session¹⁷. 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)²⁸, 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.⁷. 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^{29,30}.

Sampling plan

Sample size determination was mainly based on the results of the analyses of Westbrook et al.⁷ (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*^{31,32} 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 rate³³. 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^{34,35}. Aggregated RT values were

described using the median and the median of absolute deviation (*MAD*) as robust estimates of center and variability, respectively³⁶. Error- and post-error trials were excluded, because RT in the latter is longer due to more cautious behavior^{37,38}. To test our hypotheses, we performed a series of rmANOVAs and an MLM with orthogonal sum-to-zero contrasts in order to meaningfully interpret results³⁹.

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

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

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

257 Level-1-predictors were centered within cluster as recommended by Enders & Tofighi⁴¹. By
 258 this, the model yields interpretable parameter estimates. If necessary, we adjusted the
 259 optimization algorithm to improve model fit. We visually inspected the residuals of the
 260 model for evidence to perform model criticism. This was done by excluding all data points
 261 with absolute standardized residuals above 3 SD. As effect size measures, we calculated
 262 pseudo R^2 for our model and f^2 to estimate the effect of n -back level according to Lorah⁴².

263 The association of SVs and NFC was examined with an rmANOVA. We subtracted
 264 the SV of 1- from 2-back and 2- from 3-back, yielding two SV difference scores per
 265 participant. The sample was divided into participants with low and high NFC using a
 266 median split. We then computed an rmANOVA with the within-factor n -back level and the
 267 between-factor NFC group to determine whether there is a main effect of level and/or
 268 group, and/or an interaction between level and group on the SV difference scores. Post-hoc
 269 tests were computed depending on which effect reached significance at $p < .01$. To ensure
 270 the validity of this association, we conducted a specification curve analysis⁴³, which
 271 included 63 possible preprocessing pipelines of the RT data. These pipelines specify which
 272 transformation was applied (none, log, inverse, or square-root), which outliers were

273 excluded (none, 2, 2.5, or 3 *MAD* from the median, RTs below 100 or 200 ms), and across
274 which dimensions the transformations and exclusions were applied (across/within subjects
275 and across/within *n*-back levels). The rmANOVA was run with each of the 63 pipelines,
276 which also included our main pipeline (untransformed data, exclusion of RTs below
277 100 ms). The ratio of pipelines that lead to significant versus non-significant effects
278 provides an indication of how robust the effect actually is.

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

289 The results of each analysis was assessed on the basis of both *p*-value and the Bayes
290 factor BF_{10} , calculated with the *BayesFactor* package²³ using the default prior widths of
291 the functions *anovaBF*, *lmBF* and *ttestBF*. We considered a BF_{10} close to or above 3/10 as
292 moderate/strong evidence for the alternative hypothesis, and a BF_{10} close to or below
293 .33/.10 as moderate/strong evidence for the null hypothesis⁴⁴.

294 Pilot data

295 The sample of the pilot study consisted of $N = 15$ participants (53.3% female,
296 $M = 24.43$ ($SD = 3.59$) years old). One participant's data was removed because they
297 misunderstood the instruction. Due to a technical error the subjective task load data of

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

306 **Data availability**

307 The data of this study can be downloaded from osf.io/vnj8x/.

308 **Code availability**

309 The paradigm code, the R script for analysis, and the R Markdown file used to
310 compile this document are available at osf.io/vnj8x/.

311 **Protocol registration**

312 The Stage 1 Registered Report protocol has been approved and is available at
313 osf.io/cpxth/.

314 **Results**

315 **Adjustments for Stage 2**

316 There were two necessary adjustments of the methods. First, we failed to update the
317 necessary sample size after the analyses changed with the first review round. Instead of the
318 72 subjects stated above, the largest minimum sample size was actually 53 subjects (see

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

327 Sample

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

336 Manipulation checks

337 We used rmANOVAs to investigate whether objective performance measures and
338 subjective task load measures changed across n -back levels. For each rmANOVA we report
339 the generalized eta squared $\hat{\eta}_G^2$, which estimates the effect size in analyses that contain
340 both manipulated and non-manipulated terms. The performance measure d' did not
341 change across n -back levels ($F(2.85, 327.28) = 0.01, p = .999, \hat{\eta}_G^2 = .000, 90\% \text{ CI}$
342 [.000, .000], $\text{BF}_{10} = 3.31 \times 10^{-3}$), but the median RT did ($F(2.46, 283.05) = 98.67,$
343 $p < .001, \hat{\eta}_G^2 = .192, 90\% \text{ CI } [.130, .248], \text{BF}_{10} = 2.28 \times 10^{34}$), evidence was not in favour of

³⁴⁴ H1a but in favour of H1b. Specifically, the median RT was higher for the more difficult
³⁴⁵ level in every contrast, with two exceptions: It did not differ between 2- and 4-back, and it
³⁴⁶ 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 ₁₀	η_p^2	95%CI
1 - 2	-0.11	0.01	345.00	-11.76	<.001	1.75×10^{30}	0.29	[0.22, 1.00]
1 - 3	-0.16	0.01	345.00	-16.23	<.001	8.80×10^{45}	0.43	[0.37, 1.00]
1 - 4	-0.12	0.01	345.00	-12.47	<.001	4.79×10^{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	6.35×10^6	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.

³⁴⁷ All NASA-TLX subscale scores increased across n -back levels, so evidence was in
³⁴⁸ favour of H1c. Ratings on the effort subscale ($F(2.20, 253.06) = 203.82, p < .001$,
³⁴⁹ $\hat{\eta}_G^2 = .316$, 90% CI [.250, .375], $BF_{10} = 2.47 \times 10^{34}$) increased across all levels, but the
³⁵⁰ magnitude of change decreased from 1- to 2-back ($t(345) = -12.35, p_{Tukey(4)} < .001$,
³⁵¹ $BF_{10} = 4.24 \times 10^{19}$) to 3- to 4-back ($t(345) = -2.72, p_{Tukey(4)} = .035, BF_{10} = 174.38$).
³⁵² Three subscales had significant differences between all contrasts except for 3- versus
³⁵³ 4-back: While ratings on the frustration and time subscales were higher for more difficult
³⁵⁴ levels ($F(2.50, 287.66) = 68.06, p < .001, \hat{\eta}_G^2 = .172$, 90% CI [.112, .227],
³⁵⁵ $BF_{10} = 5.26 \times 10^{15}$, and $F(2.21, 254.65) = 51.08, p < .001, \hat{\eta}_G^2 = .117$, 90% CI [.065, .168],
³⁵⁶ $BF_{10} = 3.94 \times 10^9$, respectively), ratings on the performance subscale decreased with higher
³⁵⁷ n ($F(2.49, 285.97) = 95.33, p < .001, \hat{\eta}_G^2 = .241$, 90% CI [.176, .299], $BF_{10} = 1.55 \times 10^{24}$).
³⁵⁸ Ratings on the mental subscale consistently increased across all levels
³⁵⁹ ($F(1.99, 228.35) = 274.47, p < .001, \hat{\eta}_G^2 = .375$, 90% CI [.309, .432], $BF_{10} = 1.64 \times 10^{43}$).
³⁶⁰ Ratings on the physical subscale were higher for more difficult levels

³⁶¹ ($F(1.68, 192.93) = 15.91, p < .001, \hat{\eta}_G^2 = .041, 90\% \text{ CI } [.009, .075], \text{BF}_{10} = 60.54$), apart
³⁶² from the contrasts 2- versus 3-back ($\text{BF}_{10} = 10.45$) and 3- versus 4-back ($\text{BF}_{10} = 0.47$).
³⁶³ The full results of these manipulation checks are listed in Table S.1 to S.8 in the
³⁶⁴ Supplementary Material.

³⁶⁵ **Decline of subjective values**

³⁶⁶ When asking participants what motivated their decisions in the cognitive effort
³⁶⁷ discounting paradigm, 11.2% stated that they wanted to avoid boredom, 22.4% stated that
³⁶⁸ they wanted a challenge, 34.5% stated that they wanted to avoid effort, and 4.3% stated
³⁶⁹ that they wanted to relax. The remaining 27.6% of participants used the free text field and
³⁷⁰ provided reasons such as “I wanted a fair relation of effort and reward.”, “I wanted the fun
³⁷¹ that I had in the more challenging levels.”, “I wanted to maximize reward first and
³⁷² minimize effort second.”, or “I did not want to perform poorly when I was being paid for
³⁷³ it.”. Figure S.1 in the Supplementary Material shows the different motivations in the
³⁷⁴ context of the SVs per n -back level.

³⁷⁵ The rmANOVA showed a significant difference between the SVs across n -back levels
³⁷⁶ ($F(1.98, 227.98) = 65.65, p < .001, \hat{\eta}_G^2 = .288, 90\% \text{ CI } [.222, .347], \text{BF}_{10} = 1.58 \times 10^{64}$), so
³⁷⁷ evidence was in favour of H2a. All four pre-defined contrasts reached significance (Table 2),
³⁷⁸ 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	η_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.

379 The declining logistic contrast had the highest effect estimate ($t(345) = 12.97$,

380 $p < .001$), suggesting a shallow decline of SVs between 1- and 2-back, and 3- and 4-back,

381 respectively, and a steeper decline of SVs between 2- and 3-back.

382 Consequently, we had to adapt the MLM to incorporate this non-linear trend. To

383 apply the contrast to the n -back levels, we had to turn the variables into a factor, with two

384 consequences: Centered variables cannot be turned into factors, so we entered the variable

385 level in its raw form, and factors cannot be used as random slopes, so the model is now

386 defined as:

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

387 This means that the intercept still varied between subjects, but there were no random

388 slopes anymore. To provide more than one observation per factor level, we used the two

389 rounds per n -back level per subject, rather than n -back levels per subject. The ICC of the

390 null model indicated that there was a correlation of $r = .096$ between the SVs of a subject,

391 i.e. that 9.59% of variance in SVs could be explained by differences between participants.

392 We did not use an optimization algorithm to improve the fit of the random intercept

393 model. A total of 9 data points from 6 participants were excluded, because the residuals

394 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.

395 An exploratory ANOVA was used to compare the fit of the final model with a linear

396 random intercept model, confirming that the two models were different from each other
397 ($\chi^2(2) = 34.48, p < .001$), and with an Akaike Information Criterion of $AIC = -492.61$
398 and a Bayesian Information Criterion of $BIC = -454.02$ the declining logistic model was
399 superior to the linear model ($AIC = -462.12, BIC = -433.18$). Both AIC and BIC
400 subtract the likelihood of the model from the number of parameters and/or data points, so
401 lower values indicate better model fit. The final model had an effect size of $f^2 = 0.64$ for
402 the n -back levels and $f^2 = 0.04$ for d' , which are considered large and small, respectively⁴⁵.
403 This means that the n -back level explained 64.20% and d' explained 3.95% of variance in
404 SVs relative to the unexplained variance, respectively. The beta coefficient indicated that
405 with every 1-unit increase in d' , the SV increased by 0.02. Due to the coding scheme of the
406 logistic contrast, the beta coefficient of the n -back level has to be interpreted inversely, so
407 SVs decline with increasing n -back level. The effect size of the median RT was $f^2 = 0.00$.
408 Since SVs decline with increasing level, beyond the variance explained by d' , evidence was
409 in favour of H2b.

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

412 [FIGURE 2 HERE]

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

418 **Differences between NFC groups**

419 Figure 3 shows the SVs per n -back level for participants with NFC scores above and
420 below the median. There is a concentration of participants who have assigned their highest

421 SV to 1-back, and this concentration fades across n -back levels. At the same time, there is
 422 a subtle separation of SVs across n -back levels, depending on the participant's NFC score:
 423 While the SVs of those with higher NFC scores remain elevated, the SVs of those with
 424 lower NFC scores decline more strongly. Specifically, $n = 71$ participants had an absolute
 425 preference for 1-back, $n = 18$ for 2-back, $n = 9$ for 3-back, and $n = 13$ for 4-back. There
 426 were $n = 5$ participants who did not have an absolute preference for any n -back level,
 427 i.e. none of their SVs was 1.

428 [FIGURE 3 HERE]

429 The median NFC was 16, with $n = 57$ subjects below and $n = 59$ above the median.
 430 We used an rmANOVA to investigate whether the difference between the SVs of 1- and
 431 2-back, and 2- and 3-back, respectively, depended on whether a participant's NFC score
 432 was above or below the median. There was a main effect of the n -back level
 433 ($F(1, 114) = 9.13, p = .003, \hat{\eta}_G^2 = .040, 90\% \text{ CI } [.002, .115], \text{BF}_{10} = 12.68$), but neither a
 434 main effect of the NFC group ($F(1, 114) = 3.18, p = .077, \hat{\eta}_G^2 = .013, 90\% \text{ CI } [.000, .068]$,
 435 $\text{BF}_{10} = 0.56$) nor an interaction of NFC group and n -back level ($F(1, 114) = 0.46, p = .499$,
 436 $\hat{\eta}_G^2 = .002, 90\% \text{ CI } [.000, .037]$), so evidence was not in favour of H3a. Post-hoc tests
 437 showed that the difference between the SVs of 2- and 3-back is slightly more negative than
 438 the difference between 1- and 2-back ($t(114) = -3.02, p = .003$), but there were large
 439 inter-individual differences (Figure 4a). This means that across the whole sample, there
 440 was a steeper decline in SVs from 2- to 3-back than from 1- to 2-back, again resembling the
 441 declining logistic function.

442 [FIGURE 4 HERE]

443 The rmANOVA on the association between NFC scores and NASA-TLX scores
 444 revealed a main effect of n -back level ($F(2.10, 239.56) = 154.50, p < .001, \hat{\eta}_G^2 = .223, 90\%$
 445 $\text{CI } [.159, .282], \text{BF}_{10} = 2.22 \times 10^{45}$) and an interaction between n -back level and NFC scores
 446 ($F(2.10, 239.56) = 4.93, p = .007, \hat{\eta}_G^2 = .009, 90\% \text{ CI } [.000, .025]$), but no main effect of

447 NFC scores ($F(1, 114) = 3.22, p = .075, \hat{\eta}_G^2 = .022, 90\% \text{ CI } [.000, .084], \text{BF}_{10} = 1.75 \times 10^2$).
448 Post-hoc tests showed that the participants with NFC scores below the median had higher
449 NASA-TLX scores for 3-back ($t(114) = -2.15, p = .033, \text{BF}_{10} = 11.15$) and for 4-back
450 ($t(114) = -2.89, p = .005, \text{BF}_{10} = 336.88$) than those with NFC scores above the median,
451 so evidence was in favour of H3b. Regardless of NFC scores, NASA-TLX scores were
452 higher for the more difficult level in each pair of n -back levels (Figure 5).

453 [FIGURE 5 HERE]

454 With another rmANOVA we investigated whether the difference between the
455 aversiveness scores of 1- and 2-back, and 2- and 3-back, respectively, depended on whether
456 a participant's NFC score was above or below the median. There was a main effect of NFC
457 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
458 effect of the n -back level ($F(1, 114) = 10.21, p = .002, \hat{\eta}_G^2 = .034, 90\% \text{ CI } [.000, .105]$,), but
459 no interaction ($F(1, 114) = 2.59, p = .110, \hat{\eta}_G^2 = .009, 90\% \text{ CI } [.000, .058]$). In favour of
460 H3c, post-hoc tests revealed that participants with NFC scores below the median reported
461 higher aversiveness than participants with NFC scores above the median ($t(114) = 2.90,$
462 $p = .004$) (Figure 4b). Regardless of NFC, the difference of the aversiveness scores of 2- and
463 3-back was more negative than that of 1- and 2-back ($t(114) = 3.20, p = .002$), indicating
464 that in the same way in which the SVs decreased more strongly from 2- to 3-back than
465 from 1- to 2-back, the aversion increased more strongly. The full results of these analyses of
466 NFC group differences can be found in Table S.11 to S.15 in the Supplementary Material.

467 Exploratory analysis

468 To investigate the apparent group difference between the SVs of participants with
469 NFC scores below and above the median in higher n -back levels, we computed an
470 rmANOVA with the within-factor level (1 to 4) and the between-factor NFC group
471 (below/above median). There was no main effect of NFC group ($F(1, 114) = 2.63,$

⁴⁷² $p = .108$, $\hat{\eta}_G^2 = .007$, 90% CI [.000, .053], 2.95×10^{-1}), but a main effect of the n -back level
⁴⁷³ ($F(2.01, 229.39) = 67.39$, $p < .001$, $\hat{\eta}_G^2 = .295$, 90% CI [.228, .354], 2.70×10^{30}) and an
⁴⁷⁴ interaction ($F(2.01, 229.39) = 3.24$, $p = .041$, $\hat{\eta}_G^2 = .020$, 90% CI [.000, .044]). Post-hoc
⁴⁷⁵ tests for the main effect of level showed that SVs were lower for the more difficult n -back
⁴⁷⁶ level in each paired contrast except for 1- versus 2-back. Post-hoc tests for the interaction
⁴⁷⁷ effect showed that the NFC groups only had a significant difference in SVs for 4-back,
⁴⁷⁸ where participants below the NFC median had lower scores ($\Delta M = 0.11$, 95% CI
⁴⁷⁹ [0.01, 0.22], $t(114) = 2.13$, $p = .036$). Despite not reaching significance, 1-back was the only
⁴⁸⁰ level in which participants with NFC scores above the median seemed to have lower SVs
⁴⁸¹ than those with scores below the median ($\Delta M = -0.05$, 95% CI [-0.11, 0.01],
⁴⁸² $t(114) = -1.50$, $p = .136$). The full results of this exploratory analysis of NFC group
⁴⁸³ differences can be found in Table S.16 and S.17 in the Supplementary Material.

484

Discussion

⁴⁸⁵ This Registered Report aimed to adapt the Cognitive Effort Discounting (COG-ED)
⁴⁸⁶ paradigm by Westbrook et al.⁷, which estimates subjective values of different n -back levels,
⁴⁸⁷ into the Cognitive and Affective Discounting (CAD) paradigm to estimate SVs of tasks
⁴⁸⁸ without defaulting to the assumed objective task load as a benchmark. For this purpose,
⁴⁸⁹ we adapted the way in which the discounting options are presented to the participants,
⁴⁹⁰ based the anchor on their own choices, and computed SVs across multiple combinations of
⁴⁹¹ task levels. The analyses were closely aligned with those in Westbrook et al.⁷ to
⁴⁹² demonstrate the changes in SVs brought about by the new paradigm. This study also
⁴⁹³ applied the CAD paradigm to an emotion regulation task, the results of which are detailed
⁴⁹⁴ in a second Registered Report¹⁷.

495 Manipulation checks

496 The performance measure d' did not differ across n -back levels, but the RT increased
497 from 1- to 2- to 3-back and then remained on a high level for 4-back. This points to three
498 important characteristics of the n -back task in this context. Firstly, RT as a valid
499 group-level indicator of performance might only be useful for levels up to $n = 3$, and could
500 be used to investigate inter-individual differences for $n > 3$. Secondly, there is a
501 speed-accuracy tradeoff in the first three levels, that might even re-emerge in higher levels,
502 where d' would decline and RT would remain stable. And lastly, the fact that neither
503 accuracy nor speed is an informative performance measure by itself has been observed
504 before⁴⁶ and both show different associations with various measures of intelligence⁴,
505 suggesting that they should always be reported as separate indices. Additionally, d' might
506 not have differed across n -back levels because the manipulation of task load is not strictly
507 continuous. Several participants said that they perceived 3-back as more difficult than
508 4-back because they found it is easier to remember chunks of stimuli when n was an even
509 number than when n was an odd number.

510 All NASA-TLX subscales differed across n -back levels, but the effort and mental load
511 subscales were the only ones to consistently increase across all levels. This would support
512 the notion of the n -back task offering a continuous manipulation of task load, at least
513 subjectively. Ratings on the frustration and time subscales increased and ratings on the
514 performance subscale decreased until 3-back and then remained stable. This pattern is
515 akin to the RT, which also increased and then remained stable. Ratings on the physical
516 load subscale increased with n -back levels, but not between 2- and 3-back and 3- and
517 4-back, respectively.

518 **Decline of subjective values**

519 The rmANOVA with different pre-defined contrasts showed that all fit the SVs to a
520 different degree, and that the SVs do not simply decline linearly across n -back levels. The
521 best fit was a declining logistic curve, reflecting that the majority of participants preferred
522 1-back and that SVs for 2-back were also high, before having more inter-individual variance
523 for 3- and 4-back. Thomson and Oppenheimer⁴⁷ argue that the different effort curves that
524 have been observed for different tasks are likely due to the fact that we still understand
525 quite little about how and why different manipulations of effort work. For example, the
526 n -back task is likely not a continuous manipulation of task load, as discussed above.
527 However, the declining logistic curve is similar to the sigmoidal curve that had the best fit
528 in a different effort paradigm⁴⁸, which the authors explained with the low effect of low
529 energy costs, suggesting there are still common features of effort across different tasks and
530 domains. The MLM with the logistic contrast showed that the n -back level explained the
531 majority of variance in SVs, while the performance measure d' also explained some variance
532 in SVs, albeit less. With increasing n -back level and decreasing d' , the SV decreased. The
533 median RT was not a significant predictor in this model, which was somewhat surprising
534 because RT but not d' yielded significant differences across levels in the manipulation
535 checks. However, participants might have deliberately or subconsciously used the feedback
536 they received at the end of each round, i.e. twice per n -back level, as an anchor during the
537 effort discounting. This feedback was based on correct responses and not on RT, so if
538 participants based their effort discounting choices at least partly on this feedback, they
539 were either motivated to repeat a task in which they performed well and/or they were
540 reluctant to accept a larger reward for a task in which they did not perform well. Since
541 more participants reported effort avoidance as their motivation in the effort discounting
542 than those who reported seeking a challenge, we can assume that they were more
543 motivated to repeat a task in which they performed well because their good performance
544 coincided with low effort.

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

Differences between NFC groups

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

In the analysis of SV difference scores, the NFC group did not reach significance as a predictor. This was likely due to the bandwidth of SVs of participants with NFC scores

571 around the median, and due to the fact that the difference appeared most pronounced for
572 4-back, and we only analyzed the difference scores between 1- and 2-back and 2- and
573 3-back. As the exploratory analysis showed, only 4-back yielded a significant group
574 difference, and SVs of participants with NFC scores above the median were higher for 2- to
575 4-back and lower for 1-back. The analysis of NASA-TLX scores showed that the sum score
576 increased with every n -back level, and that participants with NFC scores below the median
577 had higher NASA-TLX scores for 3- and 4-back than those below the median. This
578 demonstrates that higher n -back levels have a higher discriminatory power regarding
579 inter-individual differences in subjective effort perception. This was also supported by the
580 fact that higher n -back levels were perceived as more aversive, and participants with NFC
581 scores below the median reported higher aversion than those with NFC scores above the
582 median. Our data supports the notion of a nonlinear interaction between person and
583 situation that has also been described by Schmitt et al. (2013)⁵⁰ and Blum et al. (2018)⁵¹
584 in the same-named NIPS model. The NIPS model describes behaviour as a function of
585 situational affordance which is mediated by personality traits. The behavioural variability
586 follows an s-shaped curve, such that “strong” situations with low or high situational
587 affordance elicit the least behavioural variability, while “weak” situations with moderate
588 affordance maximize individual differences. These differences are caused by a person’s
589 expression of a certain trait, which shifts the curve along the y-axis. In our study, the
590 situational affordance is the n -back level and the behaviour is the SV, following a declining
591 logistic curve, i.e. a mirrored s-shape. Hence, the variability in SVs increased from 1- to
592 4-back, and participants with higher NFC showed a more shallow decline in SVs as the
593 situational affordance approached moderate values. According to the NIPS model, we can
594 expect the SVs of participants with higher and lower NFC to converge again in levels of
595 $n > 4$, since behavioural variability decreases when situational affordance is high. An
596 investigation of this relationship using the COG-ED paradigm⁷ had been encouraged by
597 Strobel et al.⁵² based on their findings on demand avoidance and cognitive effort

598 investment. With the CAD paradigm, the declining logistic contrast of SVs across levels
599 resembles the ascending logistic curve of the NIPS model^{50,51} and should be tested further
600 in a setting with n -back levels exceeding $n = 4$.

601 **Limitations**

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

624 also argue that the 2€ reward range was not large enough to be an incentive for effort
625 expenditure. However, findings by Bialaszek et al.⁵³ suggest that participants are actually
626 more sensitive to effort when the reward is small. Nevertheless, we exceeded the largest
627 required sample size by 2.20 times, which gives our analyses high statistical power.

628 Conclusion

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

650 discounting in the light of these findings, and to re-use this data set for exploratory
651 analyses.

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Author Contributions

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

772

Competing Interests

773

The authors declare no competing interests.

Figures

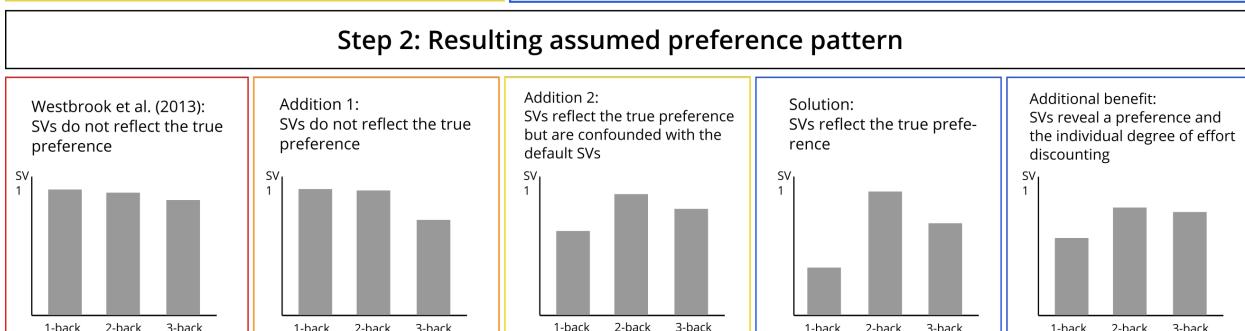
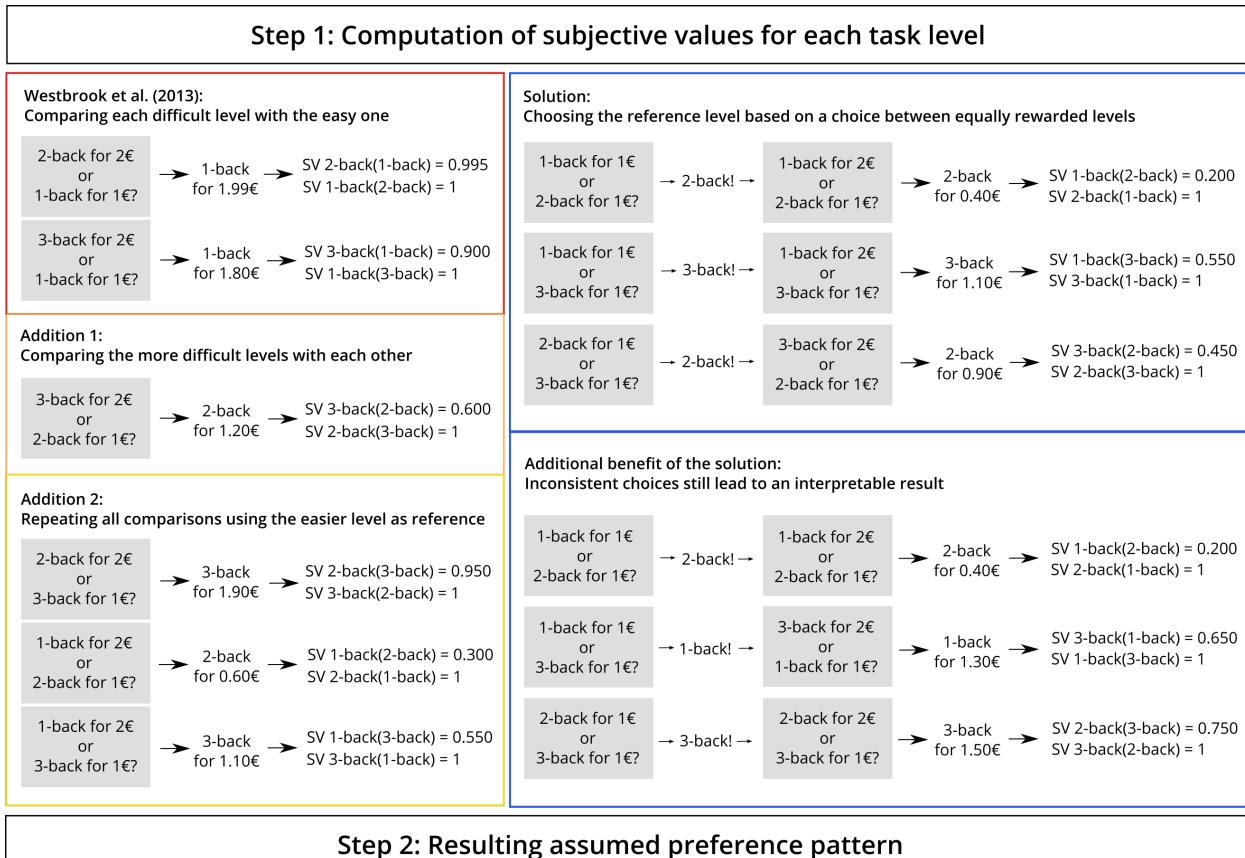


Figure 1. An example for subjective values for an n -back task with three levels, returned by different modifications of the COG-ED paradigm for a hypothetical participant with the true preference $2\text{-back} > 3\text{-back} > 1\text{-back}$. The grey boxes are the choice options shown to the participant. 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/, under a CC-BY-4.0 license.

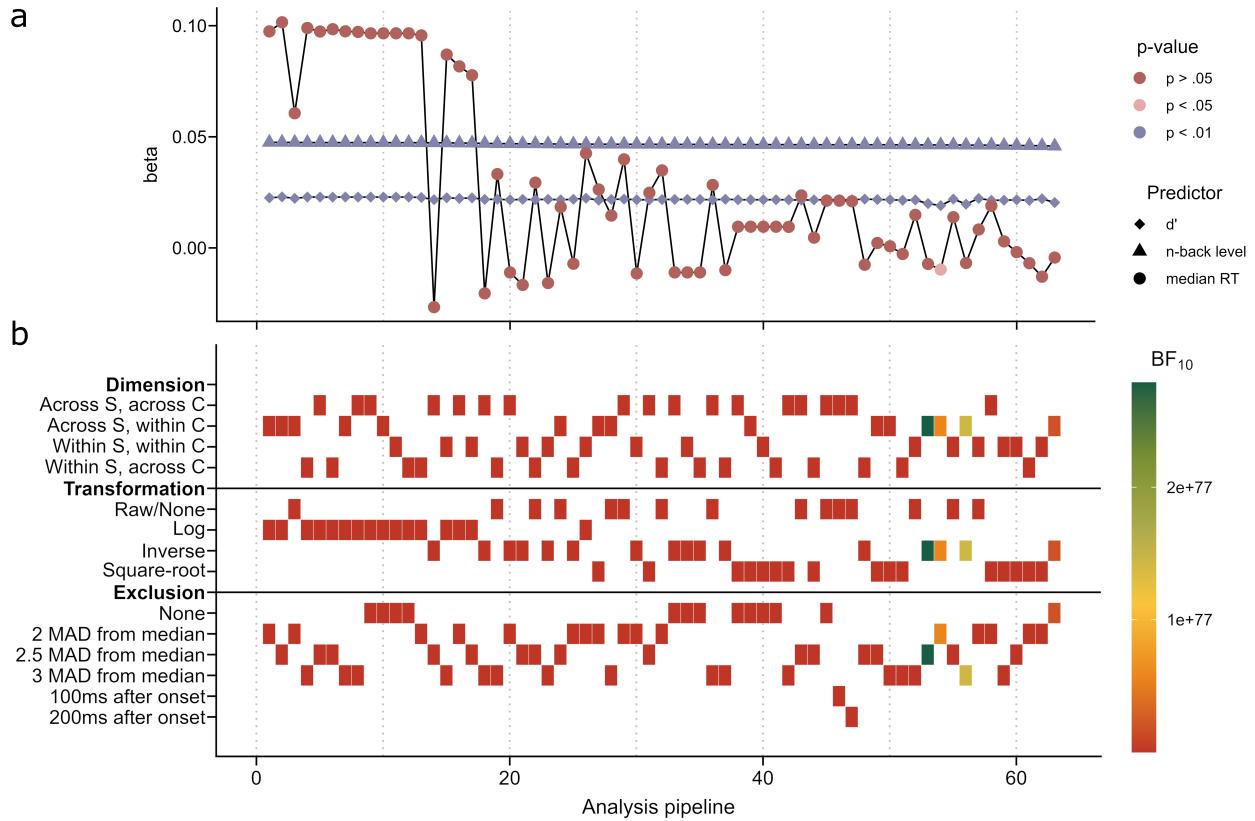


Figure 2. Results of the multi level model for each of the 63 preprocessing pipelines. Drawing a vertical through both panels indicates the type of preprocessing (panel b) of the pipeline and the resulting beta estimates of the three predictors in the model (panel a). The colourbar in panel b indicates 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/, under a CC-BY-4.0 license.

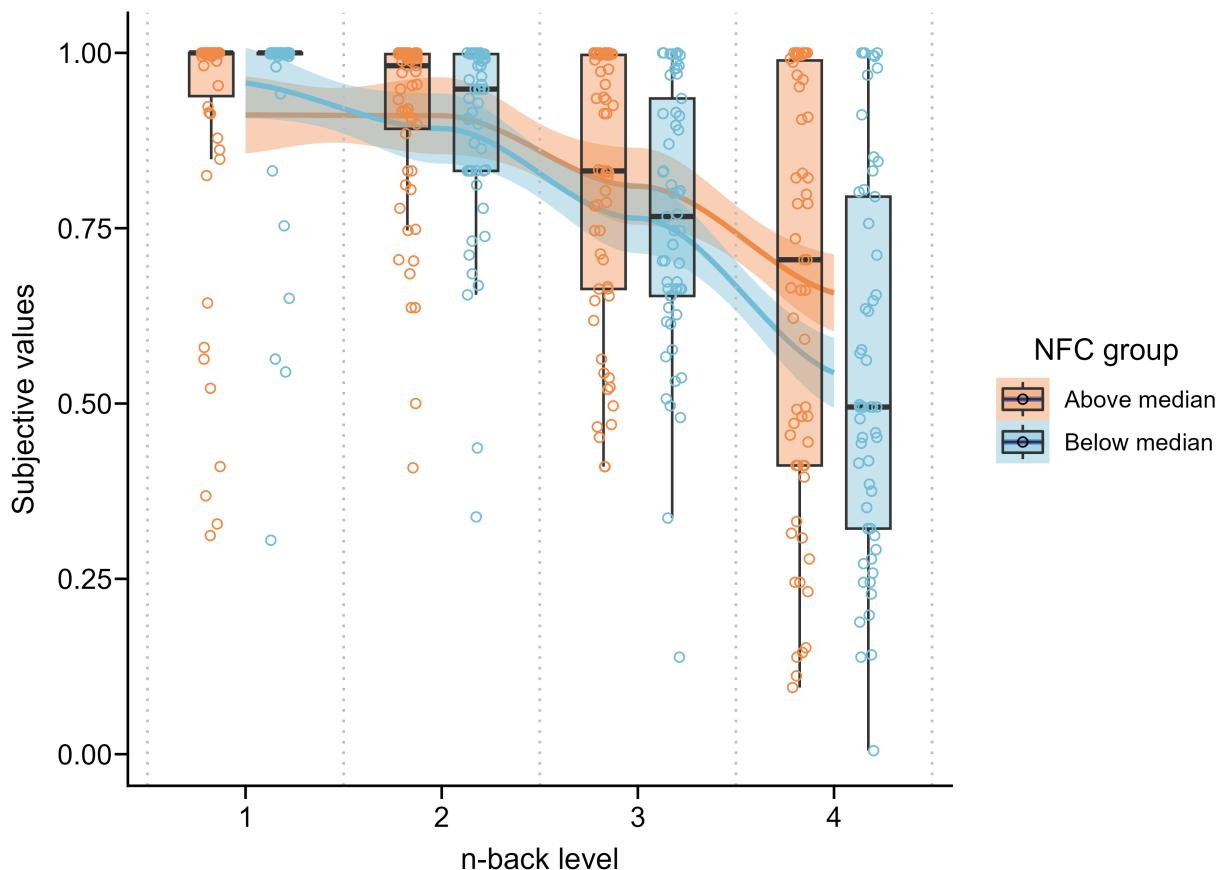


Figure 3. Subjective values per n-back level for participants with Need for Cognition (NFC) scores above and below the median. $N = 116$. The scatter has a horizontal jitter of 0.2. Smoothing of conditional means with Loess method. Figure available at osf.io/vnj8x/, under a CC-BY-4.0 license.

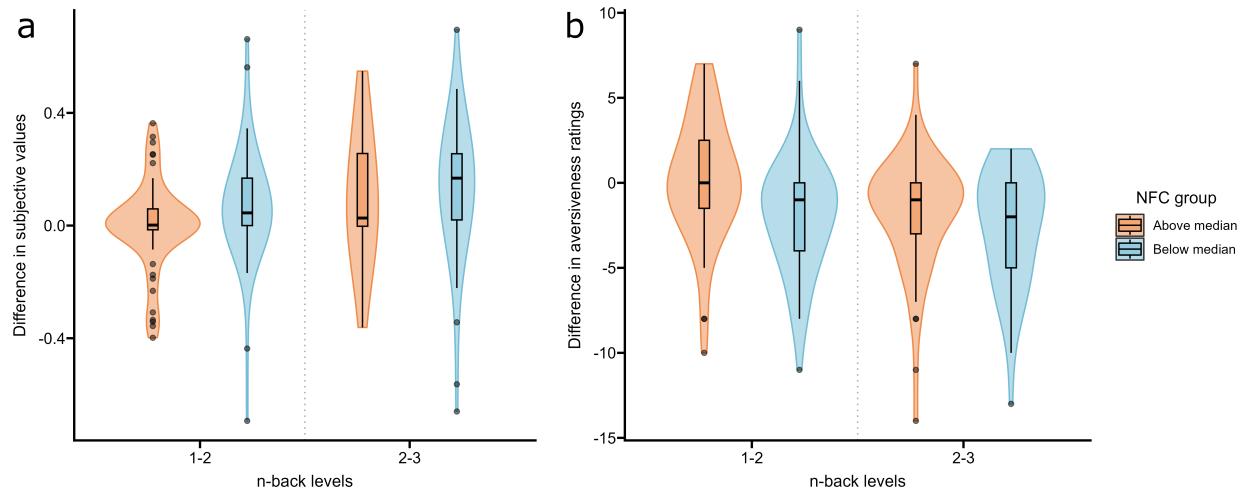


Figure 4. Difference scores for subjective values (a) and aversiveness ratings (b) when subtracting 2- from 1-back and 3- from 2-back. Horizontal lines of the boxplots represent the median per group, whiskers represent 1.5 interquartile ranges. NFC = Need for Cognition score. $N = 116$. Figure available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

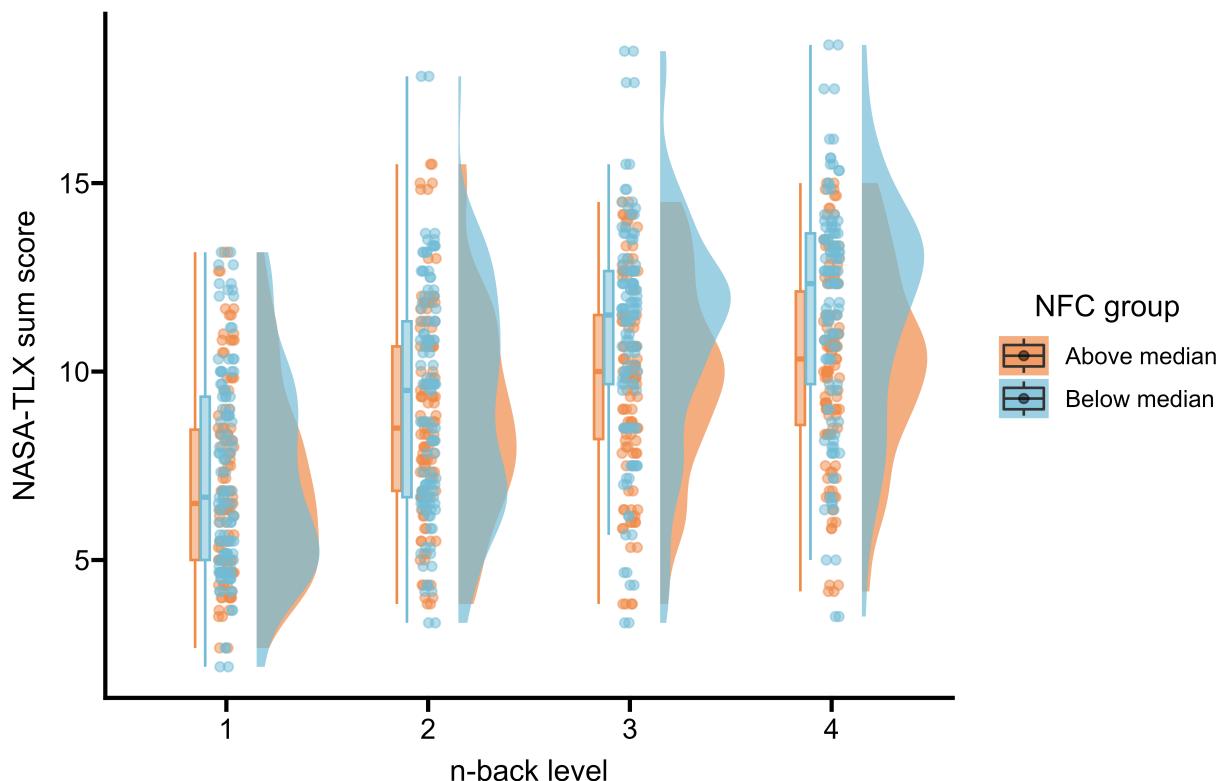


Figure 5. NASA-TLX sum scores for each n -back level. Colours indicate Need for Cognition (NFC) score above or below the median. $N = 116$. Figure available at osf.io/vnj8x/, under a CC-BY-4.0 license.