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Information about task progress modulates cognitive demand avoidance

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ABSTRACT

People tend to avoid engaging in cognitively demanding tasks unless it is 'worth our while'—that is, if the benefits outweigh the costs of effortful action. Yet, we seemingly partake in a variety of effortful mental activities (e.g. playing chess, completing Sudoku puzzles) because they impart a sense of progress. Here, we examine the possibility that information about progress—specifically, the number of trials completed of a demanding cognitive control task, relative to the total number of trials to be completed—reduces individuals' aversion to cognitively effort activity, across four experiments. In Experiment 1, we provide an initial demonstration that presenting progress information reduces individuals' avoidance of cognitively demanding activity avoidance using a variant of the well-characterized Demand Selection Task (DST). The subsequent experiments buttress this finding using a more sophisticated within-subjects versions of the DST, independently manipulating progress information and demand level to further demonstrate that, 1) people prefer receiving information about temporal progress in a task, and 2) all else being equal, individuals will choose to engage in tasks that require greater levels of cognitive effort when the more demanding option confers information about their progress in a task. Together, these results suggest that progress information can motivate cognitive effort expenditure and, in some cases, override individuals' default bias towards demand avoidance.

1. Introduction

Owing to the limited-capacity nature of human cognitive processing, we tend to avoid engagement in cognitively demanding behaviors unless this effort expenditure is "worth our while" (Kool & Botvinick, 2018). Highlighting this point, a body of work finds that people consistently choose tasks that require less mental effort over those that are more mentally taxing (Kool, McGuire, Rosen, & Botvinick, 2010; Vogel, Savelson, Otto, & Roy, 2020; Westbrook, Kester, & Braver, 2013). This notion is perhaps formalized most famously by Hull (1943) who remarked that, all else being equal, humans and animals have a natural preference for the least demanding course of action—reflected by *the law of least effort* (Hull, 1943) and later revisited, in the domain of cognitive effort, as the law of least mental effort (Balle, 2002). One recent and influential account of effort views cognitive effort as an economic resource—or an 'effort cost'—and proposes that an individual's decision to allocate cognitive effort is governed by tradeoff between the costs of a cost-benefit tradeoff (Shenhav et al., 2017). On this view, people allocate effort to a particular task when the benefits of effort exertion (e.g., reward incentives) outweigh its costs.

At the same time, people do not prefer, in all circumstances, the course of least effort— that is, there are a variety of cognitively effortful activities that humans engage in *because* they are effortful, rather than *in spite* of the effort they require (Inzlicht, Shenhav, & Olivola, 2018). For example, mountaineers derive a sense of enjoyment from the arduous challenge of scaling a mountain—a sense that would be undercut if the task was trivially easy to accomplish (Loewenstein, 1999). Similarly, video game players often seek out demanding and/or challenging games—if the game does not sufficiently tax players' abilities, it will not be enjoyed as much: "difficulty is part of the fun" (Aponte, Levieux, & Natkin, 2011). Less anecdotally, the degree to which an individual intrinsically values cognitive effort—operationalized by the Need for Cognition scale—has been found to predict effort aversion as well as reward-induced adjustments in cognitive control, suggesting that the subjective costs of cognitive effort vary considerably from individual to individual (Bogdanov, Renault, Loparco, Weinberg, & Otto, 2022; Sandra & Otto, 2018; Sayalı & Badre, 2019; Westbrook et al., 2013). Supporting the more general idea that effort expenditure can be intrinsically rewarding, past work reveals that consumers place a larger value on items when they assemble these items themselves compared to when consumers are given the same items pre-assembled, a phenomenon termed the 'IKEA effect' (Norton, Mochon, & Ariely, 2012). These apparent anomalies, in the view of the law of least effort, suggest that the perceived costs—and possible intrinsic benefits—of effort exertion might be contextually dependent (Inzlicht et al., 2018).

One commonality shared between these examples of apparent effort-seeking behavior is that these contexts often convey an acute sense of perceived progress. In the examples of mountain-climbing and furniture assembly, people may be motivated to engage in these effortful tasks because they convey a sense of task progress: the summit's incremental

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approach over the horizon or the table's gradual ability to stand on its own. Here, we examine the possibility that explicit information about task progress might, under certain circumstances, modulate—or even reverse—an individuals' avoidance of cognitively effortful activities.

Interestingly, the idea that perceived progress motivates effort expenditure dovetails with classic animal work. The goal-gradient hypothesis, which posits that organisms exert more effort as they approach a goal, is supported by the observation that rats' running speed down a straight alley is proportional to their progress towards a goal (Hull, 1934). Extending this idea to human behavior, a line of research finds that the ease of visualization of a goal increases physical effort (Cheema & Bagchi, 2011), and in the context of consumer behavior, finds that individuals are more willing to effortfully engage with an incentives system (for example, rating music) when they are nearing some kind of reward (Kivetz, Urminsky, & Zheng, 2006). More recently, Katzir, Emanuel, and Liberman (2020) observed that information about trial-wise progress— i.e., how many trials of the task they had completed and how many trials remained—improved participants' performance in a long and demanding cognitive control task, compared to participants who received no progress information of any sort.

Taken together, these lines of work suggest that information about an individual's temporal progress in completing a task might play an important role in mobilizing cognitive effort investment. Through the lens of cost-benefit effort decision-making (Shenhav et al., 2017), it is possible that progress information could offset effort costs—either by decreasing perceived effort costs, increasing the perceived benefits conferred by effort exertion, or both— which would effectively increase an individual's inclination to engage in tasks that require more effort. However, the question of whether information about progress might influence explicit choices about cognitive effort exertion—for example, the choice between completing a more demanding versus less demanding task—remains unexplored.

Here, we examine the possibility that that information about progress—specifically, the number of trials completed of a demanding cognitive control task, relative to the total number of trials to be completed—reduces individuals' aversion to cognitively effort activity. In other words, are people more willing to engage in cognitively demanding activities when effort explicitly confers progress? To do so, we employed variants of the Demand Selection Task (DST; Kool et al., 2010; Sayalı & Badre, 2019) modified to include information about participants' progress in the task. In the original DST paradigm, participants make repeated choices between two options associated with different cognitive demand levels, operationalized as a higher versus lower probability of switching between two simple cognitive tasks. Critically, more frequent switches between these tasks require participants to flexibly adapt to new changes and increases demand for cognitive processing resources (Kool et al., 2010; Liu & Yeung, 2020). Because the level of demand depends upon the rate at which the task rules switch, which in turn is controlled by participants' choice, this design allows for a relatively pure measurement of participants' demand preference. Past work using the DST has consistently demonstrated a tendency for individuals to select the low-demand option (Bogdanov, Nitschke, LoParco, Bartz, & Otto, 2021; Kool et al., 2010; Patzelt, Kool, Millner, & Gershman, 2019), indicating a general or 'default' preference for less cognitively effortful courses of action.

Across four experiments, we explore the conditions under which information about temporal progress in a task—conferred via a progress bar that indicated how many trials participants had to complete to finish a block (Fig. 1)—bears upon decisions to engage on cognitively effortful behavior. And, following Katzir et al. (2020), we also probe the extent to which progress information might enhance cognitive performance, over and above demand selection behavior (see Supplemental Materials). To foreshadow, in Experiment 1, we provide an initial demonstration that presenting progress information reduces cognitive demand avoidance in a between-subjects variant of the DST. Experiments 2A, 2B, and 3 buttress this finding using a more sophisticated within-subjects variant of the DST, independently manipulating progress information and demand level, and demonstrate that, all else being equal, individuals prefer progress information even when greater levels of cognitive effort are required to obtain it.

2. Experiment 1

As an initial exploration of the effects of perceived progress on demand avoidance, we modified the basic DST (Kool et al., 2010; Experiment 2), in which participants are asked to choose between low and high demand cues dictating the difficulty (i.e., task switch probability) of a subsequent task-switching block, to incorporate progress feedback in a between-subjects fashion (see Fig. 1). Half of participants were given feedback about their progress throughout each block of trials and through the entire experiment, while the other half received no progress information. We predicted that participants who received progress feedback would select high demand tasks more often than those who did not receive progress feedback, who in turn we expected to exhibit a pattern of demand avoidance consistent with past work (Kool et al., 2010; Patzelt et al., 2019)—avoiding high demand options significantly more than chance. With respect to task-switching performance, we predicted on the basis of previous work (Bogdanov, Nitschke, LoParco, Bartz, & Otto, 2021; Bogdanov, Renault, Loparco, Weinberg, & Otto, 2022; Liu & Yeung, 2020) that participants would exhibit slower RTs and reduced accuracy on high-demand versus low-demand blocks, irrespective of progress information. Prior to data collection, we pre-registered our design and predictions with the Open Science Foundation (see https://osf.io/gfrsh).

2.1. Method

2.1.1. Participants

We recruited 502 participants from Amazon Mechanical Turk (AMT; Crump, McDonnell, & Gureckis, 2013): 251 in each progress condition (age range = [19, 72], M_{age} = 37.63 (11.20), 69% men). Participants were assigned to one of two progress groups: one group completed a version of the task with progress feedback and another completed a version without progress feedback. An a priori power analyses reported in our pre-registration indicated that 500 participants would yield greater than 80% power to detect an effect size of minimal interest. We excluded participants who missed greater than 25 response deadlines or performed at or below chance on task repetition trials, which left 386 participants in our analysis ($N_{\text{No Progress}}$ = 189, N_{Progress} = 197, $M_{\text{age No Progress}}$ = 38.70 (11.90), 49% men, $M_{\text{age Progress}}$ = 36.80 (10.90), 50% male). The exclusion of the above participants does not affect the patterns of significance of our key results.[1]

2.1.2. Modified Demand Selection Task (DST)

We used a modified version of the DST (Kool et al., 2010; Patzelt et al., 2019) that incorporated progress feedback. This task consisted of 300 task-switching trials, divided into 4 blocks of 75 trials, each of which was preceded by a choice of whether to complete a low- or high-demand block. In the task-switching paradigm, participants had to judge a numeric digit that appeared on the screen which appeared in one of two colors (green or orange) which indicated the to-be-completed subtask. If the digit was green, participants needed to perform a magnitude judgment and indicate whether the digit was greater or smaller than 5. If the digit was orange, participants needed to make a parity judgment and

[1] We originally preregistered to exclude participants who missed 9 or more timeout deadlines and/or who were less than 75% accurate on repeat trials. This turned out to be a vast overestimate of participants' abilities, which would have resulted in the loss of 280 participants (56% of our total sample). As such, we used the more lenient exclusion criteria detailed in the text. Importantly, our results remain largely unaffected regardless of which exclusion criteria we use.

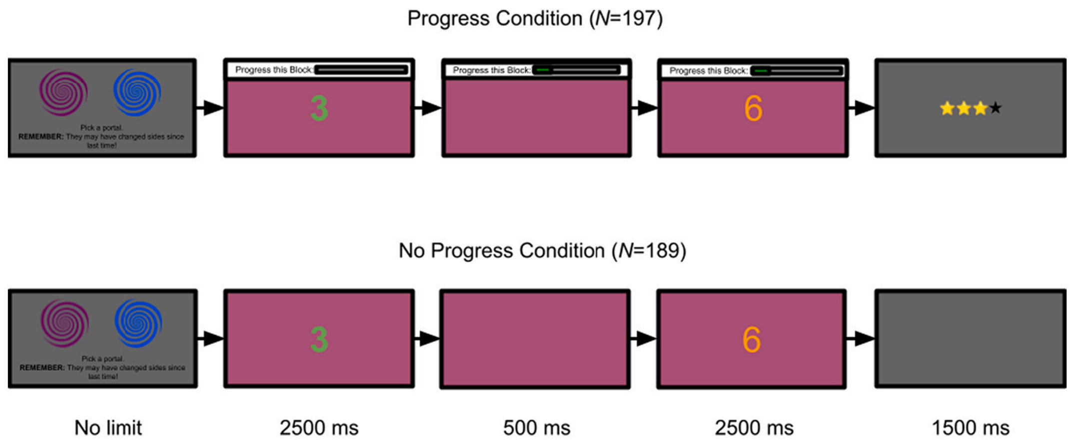

Fig. 1. Task diagram for Experiment 1. The top path shows screenshots of the task from in the Progress condition, whereas the bottom path shows screenshots from in the No Progress condition. Note the progress bar increase is not to scale and just for visualization purposes.

indicate whether the digit was an even or odd number. Once a response was made, a blank inter-stimulus interval appeared for 500 ms prior to the next digit appearing. If no response was made, the trial timed out and the task continued. Participants first practiced 10 trials of each subtask, followed by 20 trials of interleaved practice.

In the main choice task, before completing each block of task-switching, participants chose one of two "portals" (one blue and one purple; see Fig. 1). Participants were told that these portals led to different "worlds", in which the switch tasks differed slightly from each other, but were not explicitly told that the demand levels differed between worlds. Rather, participants learned this portal-to-demand-level mapping on the basis of 2 practice blocks, each containing 10 task-switching trials (which were not analyzed here). After each choice, participants completed either a low-demand (10% task switch rate) or a high-demand (90% task switch rate) version of the task-switching paradigm described above. The associations between the color of the world and the demand level of the task-switching paradigm was randomized between participants (Table 1).

To manipulate progress information, participants in the Progress condition received feedback both within and between task-switching blocks, following Katzir et al. (2020). Specifically, within each block, participants were presented with a green bar at the top of the screen that indicated how much progress they had made during that block (i.e., the bar was 50% full when a participant completed half of the trials that block; see Fig. 1). Between blocks, participants were shown a screen indicating how much progress they had made through the entire task. This screen consisted of 4 stars, one being filled in for each block the participant had completed thus far, presented for 1500 ms. In the No-Progress condition, the main task was the same, but participants did not receive any indication of progress either within or between task-switching blocks.

2.1.3. Self-report measures

After the main task, we collected data on how subjectively demanding participants found both demand levels of task-switching paradigm using a subset of questions from the NASA-Task Load Index (TLX; Hart, 2006), a 6-item questionnaire that assesses the degree to which individuals found a task to be (1) mentally demanding, (2) physically demanding, (3) temporally demanding, (4) effortful, (5) frustrating, and (6) difficult to perform (we omitted the 'physical demand' question from the original TLX). Specifically, participants rated the blue and purple worlds (e.g., high- and low-demand switch tasks) on each of the TLX subscales using a 9-point Likert scale, where higher values indicated increased demand or difficulty.[2] Finally, participants completed a short debriefing questionnaire in which they described their subjective experience of the task, provided demographic information, and provided optional text responses to the following questions: "When choosing between the portals, did you develop a preference for choosing one over the other?", "Did you notice a difference between the tasks in each portals? If so, what was it?", and "Did you find the task more difficult in one portal than the other?"

Table 1
The demand level (task switch rate) and progress information conferred for each deck (lettered A-F) in Experiments 2 and 3.

Task switch rate	No progress	Progress
10%	A	D
50%	B	E
90%	C	F

2.1.4. Data analysis

Inferential statistics for task-switching RTs and accuracy were computed using mixed-effects linear regression, and mixed-effects logistic regression respectively using the lme4 package (Bates, Mächler, Bolker, & Walker, 2014) for R (version 3.6.3). These models predicted participants' correct RTs, and accuracy as a function of trial type (switch or repeat) and progress condition (progress or no progress) on a trial-by-trial basis, with random effects taken over participants. To examine effects of demand level on task-switching performance, we expanded these accuracy and RT models to include demand level. To examine subjective effort ratings, we conducted a series of linear multilevel models, predicting each subscale of the NASA-TLX from condition (Progress versus No Progress) and demand level (high demand versus low demand) and adjusted *p*-values for multiple comparisons across TLX subscales using a Bonferroni correction. Finally, to test for differences in effort avoidance between the Progress and No Progress condition, we used a logistic multilevel model predicting demand-avoidant choice as a function of progress condition, with random effects taken over participants.

2.2. Results

2.2.1. Task-switching performance

As depicted in Fig. 2, participants were both slower ($M_{repeat} = 811.42$, $M_{switch} = 1037.81$) and less accurate ($M_{repeat} = 0.84$, $M_{switch} = 0.77$) on switch compared to repeat trials, suggesting that, as predicted, switching between magnitude and parity judgements was more

[2] While we used a 9-point scale here instead of the original 21-point scale, all questions were the same as the original TLX (Hart, 2006).

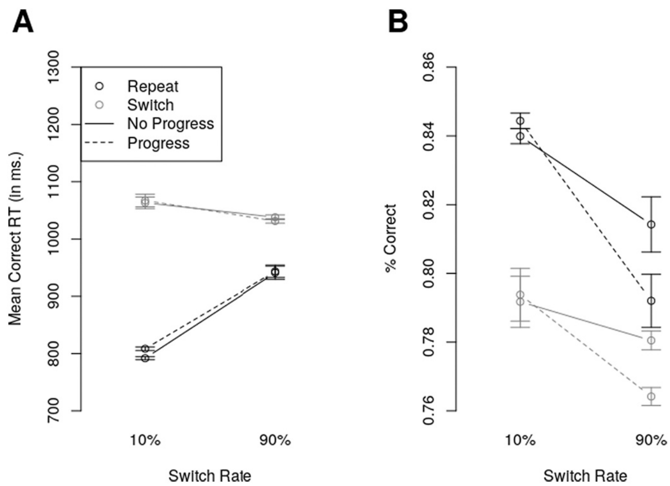

Fig. 2. Task-switching performance in Experiment 1, expressed in RTs (panel A) and accuracy rates (Panel B). Participants were, slower and less accurate in high-demand blocks than low-demand blocks, and participants were slower and less accurate in task switch trials compared to task repeat trials. Errors bars represent standard errors of the mean.

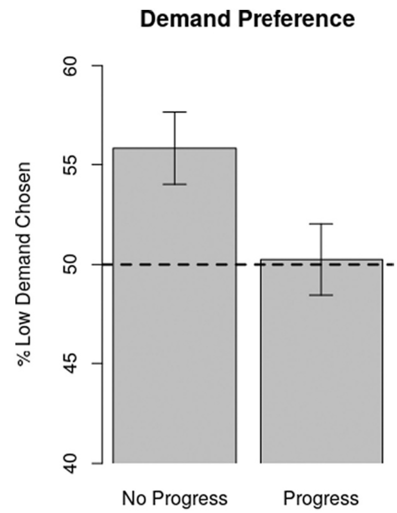

Fig. 3. Demand preference in Experiment 1. Participants were significantly less demand-avoidant in the Progress compared to the No-Progress condition. The dashed line shows chance-level responding (50%; i.e., was indifference to demand level).

demanding, following typically observed task-switching performance (Monsell, 2003). Statistically, mixed-effects regressions revealed a significant main effect of trial type (switch versus repeat) on correct RTs (b = 224.56, CI = [219.78, 229.34], $p < .0001$) and accuracy rates (OR = 0.70, CI = [0.68, 0.73], $p < .0001$).

Examining the effect of progress information on task performance, we found no significant main effect of progress on RT (b = 0.18, CI = [−73.28, 73.63], $p = .9960$) or accuracy (OR = 0.87, CI = [0.68, 1.12], $p = .2820$), but did find a small, but, significant interaction between progress and demand on accuracy, such that the difference in accuracy between low-demand ($M_{\text{No Progress}} = 0.85$; $M_{\text{Progress}} = 0.84$) and high-demand ($M_{\text{No Progress}} = 0.78$; $M_{\text{Progress}} = 0.77$) blocks was slightly smaller in the No Progress condition than the Progress condition (OR = 0.89, CI = [0.83, 0.96], $p = .003$). Results at the trial level closely mirrored those above, however, the interaction between progress condition and trial type (switch versus repeat) did not reach statistical significance (OR = 0.93, CI = [0.87, 1.00], $p = .055$).

2.2.2. *Demand avoidance*

As depicted in Fig. 3, we observed that participants in the No-Progress condition made more demand-avoidant choices (*P*(Low Demand Choice) = 0.56) than participants in the Progress condition (*P* (Low Demand Choice = 0.50). Put another way, choices of participants in the No-Progress condition echoed the demand avoidance rates seen in past work employing the canonical DST (Bogdanov et al., 2021; Kool et al., 2010), while participants in the Progress condition were seemingly indifferent to cognitive demand level. Statistically, a mixed-effects logistic regression, revealed a significant main effect of condition on demand avoidance (OR = 0.11, CI = [1.01, 1.24], $p = .030$).

Participants in the No-Progress condition generally avoided high-demand blocks (OR = 0.87, 95% CI = [0.80, 0.98], $p = .0211$, Pr(Low Demand Choice) = 0.56), whereas those in the Progress condition were seemingly indifferent to demand altogether, choosing one option as often as the other (OR = 0.98, CI = [0.86, 1.14], $p = .8878$, Pr(Low Demand) = 0.50). Put simply, when participants had information about progress during blocks of task-switching, they did not exhibit demand-avoidant choices, but without information about progress participants exhibited typical demand-avoidant choices.

2.2.3. *Subjective demand ratings*

Finally, we examined how post-task subjective effort ratings (measured using the TLX) of each "world" (i.e. demand level) varied as a function of objective task switch rate, and progress condition. Numerically, for all items, higher objective demand led to an increased self-reported effort (Low-demand mean ratings: Effort = 6.65, Frustration = 5.42, Mental demand = 6.69. Performance = 6.61, Temporal demand = 6.20; High-demand mean ratings: Effort = 7.00, Frustration = 5.48, Mental demand = 6.91. Performance = 6.41, Temporal demand = 6.42). Statistically, we found a significant effect of objective demand level on all items [effort (b = 0.35, SE = 0.09, $p_{\text{Bonferroni}} = 0.0002$, CI = [0.18, 0.52], $d = -0.20$), mental demand (b = 0.23, SE = 0.08, $p_{\text{Bonferroni}} = 0.0132$, 95% CI = [0.08, 0.37], $d = -0.13$), difficulty to perform (b = −0.19, SE = 0.07, $p_{\text{Bonferroni}} = 0.032$, 95% CI = [−0.33, −0.05], $d = 0.11$), temporal demand (b = 0.22, SE = 0.08, $p = .0252$, 95% CI = [0.07, 0.37], d = −0.11)] except Frustration (b = 0.06, SE = 0.09, $p_{\text{Bonferroni}} = 1.00$, CI = [−0.11, 0.24], $d = -0.03$): In all cases, higher demand led to an increased subjective sense of cognitive demand and difficulty to perform. We did not observe any significant effects of condition (Progress versus No-Progress; all $ps > 0.50$) or interactions between condition and demand level (all $ps > 0.45$) upon any subscale. Overall, these patterns of ratings suggest that higher switch rates were experienced by participants as more demanding, irrespective of information about task progress.

2.3. *Discussion*

In Experiment 1, we sought to provide an initial demonstration of whether information about feedback modulates demand-avoidant preferences in a variant of a well-established demand selection paradigm (Kool et al., 2010). We find compelling support for this hypothesis: participants who received trial- and block-wise progress feedback during blocks of task-switching were less likely to avoid the more demanding, high-switch-rate, version of the task. Interestingly, the effect of progress information on demand-avoidant choice occurred in the absence of subjective demand decreases between conditions, suggesting that information conferring progress may have acted purely upon preferences, but not necessarily upon the perceived demand levels of the two options.

It is worth noting a number of features of the design of Experiment 1—and the ensuing results—warrant caution in interpreting the effect of progress information. Whereas in the original DST, participants made a demand decision on each trial rather than once per each block (Kool et al., 2010), in the current experiment participants completed a block of trials following each choice. We chose this design to emphasize progress salience, as we reasoned that trial-to-trial increments in the progress bar across the entire 300 trials would not be readily perceptible by participants who were focused on the task-switching paradigm. At the same time, this design choice engendered important limitations. First, the magnitude of the effect of progress on demand avoidance was subtle, which held the consequence that progress information merely engendered *indifference* between the demand levels, while participants who saw no progress information exhibited demand avoidance typically seen in variants of the DST (Kool et al., 2010; Sayalı & Badre, 2019). This subtle observed effect on demand-avoidant choice could stem both from the between-subjects nature of the progress manipulation, and the small number of effective choice trials. Similarly, the between-subjects design implemented in Experiment 1 was likely insensitive to differences in subjective effort ratings between progress levels, possibly because the TLX might best be used as a measure of *relative* difference in subjective effort (Noyes & Bruneau, 2007), rather than to compare experiences of participants who have only been exposed to one condition in absolute terms (as in the present Experiment).

While Experiment 1 provides an initial demonstration that perceived progress can modulate individuals' effort preferences, the between-subjects design of this study is inherently limited in capturing the possible interplay between progress information and demand avoidance at the level of the individual—that is, will an individual be less likely to avoid a given demand level if it confers progress information? The subsequent experiments employ a within-subjects design to more directly probe how progress information modulates demand-avoidant choice across varying levels of cognitive demand, and furthermore, whether individuals will choose a higher-demand course of action in order to receive information about progress—that is if they will explicitly trade demand avoidance for progress information.

3. Experiment 2A and 2B

In Experiments 2A and B, we utilized a within-subject variant of the DST, following the paradigm used by Sayalı and Badre (2019) to investigate how progress information affects demand avoidance. Critically, this task design allowed us to independently examine participants' demand preference, progress preferences, and their possible interaction. In Experiment 2A, participants chose between pairs of 6 "decks", each of which was associated with a specific demand level (i.e., switch rate; 10%, 50%, 90% probability of a task switch) and a progress condition (No-Progress versus Progress) which they learned about previously in a learning phase. In Experiment 2A, each selection of a deck resulted in a variable-length block of task-switching defined by the chosen demand level (e.g., 10% switch rate) and progress condition. In Experiment 2B, we repeated the same experiment with a fixed block length to rule out the possibility that progress information simply acted to reduce uncertainty about the length of each task-switching block.

In both experiments, we pre-registered our predictions with the Open Science Foundation (https://osf.io/2vcbk). We predicted that demand avoidance would depend jointly upon the demand and progress information associated with each option in a pair of decks, such that (1) lower-demand tasks would be selected more often when progress was held constant (i.e., No-progress versus No-progress options), (2) options conferring progress information would be selected more often when demand was held constant (e.g., 10% switch rate versus 10% switch rate), and (3) when both progress and demand options varied (e.g., A No-progress with a 10% switch rate versus a Progress deck with a 90% switch rate), higher-demand options would be more likely to be chosen if they were associated with progress and avoided if they were not.

Echoing the results of Experiment 1, and following past work (Sayalı & Badre, 2019), we expected that task-switching performance would vary monotonically according to switch rate, such that higher switch rate blocks would incur slower overall RTs and decreased accuracy. We expected the magnitude of these switch rate effects to be similar across progress conditions. Finally, we predicted that the magnitude of RT effects would depend on the block-wise switch rate, such that task repetition RTs would increase as the overall switch rate increased and switch reaction times would decrease.

3.1. Method

3.1.1. Participants

In Experiment 2A, we recruited 107 participants from AMT (M_{age} = 36.98, s_{age} = 9.67, 61% men). An a priori power analysis (see preregistration; https://osf.io/2vcbk) revealed that 105 participants were sufficient to detect effect sizes of minimal interest with more than 90% power in this within-subjects design. Per our analysis plan, participants with average RTs below 200 ms and/or average accuracy below 60% were excluded. Applying these criteria, 60 participants remained in final analysis (age range = [21–69], M_{age} = 38.58, s_{age} = 11.21, 65% male). In Experiment 2B, 105 participants were recruited from AMT (M_{age} = 38.93, s_{age} = 10.45, 67% men). Applying the same criteria discussed above, 53 participants were included in the final sample (age range = [25–70], M_{age} = 41.25, s_{age} = 11.87, 62% male). In both experiments, the exclusion of the above participants does not affect the patterns of significance of our key results.

3.1.2. Within-subjects progress DST

As in Experiment 1, Experiment 2 had two phases: a learning and choice phase. In the Learning Phase, participants completed the same task-switching paradigm as in Experiment 1: they judged digits based on their parity or magnitude depending on the digit's font color (green = magnitude, orange = parity). Participants first completed 40 practice trials of the task-switching paradigm in isolation: 10 magnitude judgements, 10 parity judgements, and 20 trials where the rules switched. To manipulate demand and progress in the current experiment, participants were shown "decks" of cards that represented the 3 demand levels and 2 progress levels. The demand level dictated the overall switch rate in a subsequent block of task-switching. The three possible switch rates were 10%, 50%, and 90%. The progress level dictated whether progress information was shown or not during the subsequent task-switching block. Following the presentation of a Progress Deck, participants received within-block progress feedback on the subsequent switch task. Progress feedback in this case refers to a green bar at the top of the screen that filled up from left to right following each magnitude/parity judgment (see Fig. 4). No such feedback was shown following a No Progress deck. The factorial combination of demand levels (10%, 50%, and 90% switch rates) and progress levels (Progress versus No-progress) yielded six total decks (see Fig. 4). Following the practice trials, the participants completed three blocks of task-switching under each demand/progress condition (i.e., as if they had chosen each deck). In order to associate demand/progress conditions to decks, a deck was presented at the beginning of each Learning Phase block and their symbol was shown in the background during task-switching. Task-switching performance in the Learning Phase was not analyzed.

In the Choice Phase, participants made a series of choices between the 15 unique possible pairings of decks, each presented 4 times, resulting in 60 explicit decisions per participant. Each trial, participants were presented with two of the six decks described above (up to 3000 ms). Participants selected one of these decks using their keyboard keys (E or I). After choosing a deck, participants completed a block of task-switching. Critically, the deck that participants chose determined both the demand level (10%, 50%, 90% switch rate) and progress level (Progress versus No Progress) of the subsequent task-switching block. For instance, if a participant selected the deck with a diamond symbol (see Fig. 4), the rules in the following block of task-switching would switch 10% of the time and the progress bar would not be shown. In Experiment 2A, each block of task-switching resulting from a choice varied in length according to a normal distribution with a mean of 13 trials (truncated between 8 and 21 trials). Participants were told during the task instructions that some blocks would be longer than others.

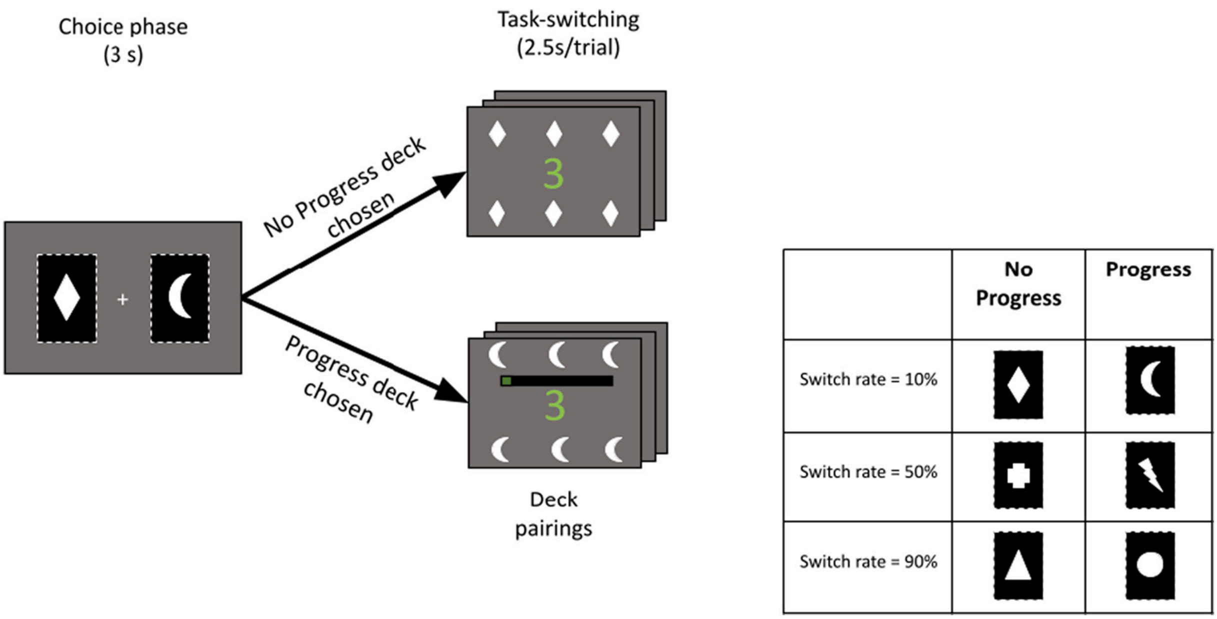

Fig. 4. Task design for Experiments 2A and 2B. The top path and bottom paths depict the task-switching trial if participants chose a No-Progress versus a Progress deck, respectively. The table depicts the six different deck stimuli in the Demand Selection Task, their associated task switch rate, and whether or not progress information was present during if they were selected.

Experiment 2B employed a fixed number of trials per task-switching block (16 trials), and participants were informed during the task instructions that every block would have the same length.

3.1.3. Subjective demand ratings

Finally, we collected data from the 'demand' subscale of the NASA-TLX (Hart, 2006). After completing the main experiment, participants were asked to answer the following question for each of the decks using a 7-point scale: "How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?"

3.1.4. Data analyses

In general, our approach to modeling task-switching performance mirrored that of Experiment 1, with the exception that block-wise demand level had three levels (10% switch rate, 50%, 90%) and that random effects were taken over participant and block. To model the post-task subjective effort ratings of each deck, measured by the TLX demand subscale, we estimated a linear mixed-effects model predicting participants' ratings from demand level and progress condition, with random effects taken over participant.

To examine deck choices, we estimated two mixed-effects logistic regression models. The first model predicted participants' choice of the high-demand deck, in pairings with unequal demand levels, as a function of demand pairing (e.g., 10% switch rate deck vs. 90% switch rate deck) and progress pairing (Progress versus No Progress), with random effects taken over participant. The second model predicted participants' choice of a Progress versus No-Progress deck based on each possible demand pairing. Of the 15 possible deck pairings, 12 pairs tested participants' demand preferences (when a given deck pair had different demand levels, i.e., participants could choose a high or low demand option) and 3 of which tested participants' progress preferences (when a given deck pair had the same demand level, i.e., participants could only choose a Progress or No-progress option as demand was fixed). All nested models were tested with a likelihood ratio test (χ^2 test) to determine whether the inclusion of each predictor significantly improved the likelihood that the model explained participants' choices.

3.2. Results

3.2.1. Task-switching performance

Across Experiments 2A and 2B, participants were slower (Experiment 2A: $M_{\text{repeat}} = 747.47$, $M_{\text{switch}} = 944.03$, Experiment 2B: $M_{repeat} = 821.65$, $M_{\text{switch}} = 963.12$) and less accurate (Experiment 2A: $M_{\text{repeat}} = 0.94$, $M_{\text{switch}} = 0.90$; Experiment 2B: $M_{\text{repeat}} = 0.94$, $M_{\text{switch}} = 0.91$) on task switches compared to task repetition trials (see Fig. 5). This was confirmed, statistically, by the mixed-effects models which revealed a significant effect of trial type on both RT (Experiment 2A: b = 194.90, CI = [189.29–200.50], $p < .0001$; Experiment 2B: (b = 143.87, CI = [138.02–149.72], $p < .0001$) and accuracy (Experiment 2A: OR = 0.61, CI = [0.57–0.66], $p < .0001$; Experiment 2B: OR = 0.69, CI = [0.64–0.74], $p < .0001$).

In Experiment 2A, we also found a small but statistically significant effect of progress information on accuracy, such that participants were more accurate on Progress versus No-progress blocks (OR = 1.09, CI = [1.01–1.17], $p = .0240$), but this effect was not replicated in Experiment 2B (OR = 1.06, CI = [0.99, 1.14], $p = .1050$). In both experiments, RT switch costs varied according to block-level switch rates (2A: $\chi^2(4) = 353.72$, $p < .0001$; 2B: $\chi^2(4) = 107.24$, $p < .0001$) such that repeat trial RTs increased as block-level with increasing switch rate whereas switch trial RTs decreased (see Table 2). In both experiments, RT did not decrease within task-switching blocks as a function of trial (Experiment 2A: b = 0.78, CI = [−0.63, 2.18], $p = .2780$, 2B: b = −0.36, CI = [−1.82, 1.10], $p = .6314$), nor did this effect interact with progress information (Experiment 2A: interaction b = −0.57, CI = [−2.37, 1.23], $p = .534$; 2B: b = 1.08, CI = [−0.85, 3.00], $p = .2719$).

3.2.2. Preference for demand avoidance

To ascertain whether participants had effectively learned the demand levels associated with each deck in the Learning phase, we first examined deck preferences across pairings within the same progress condition (e.g., Progress or No-Progress) but different demand levels (e.g., 10% versus 50%). These deck preferences are depicted in Fig. 6A and D. In Experiment 2A, we observed that participants, overall, exhibited demand-avoidant choices (see Fig. 6A), as they chose the higher-demand deck significantly less frequently than chance (P(Choose Low Demand) = 59%, OR = 0.69, CI = [0.61–0.78], $p < .0001$), echoing the

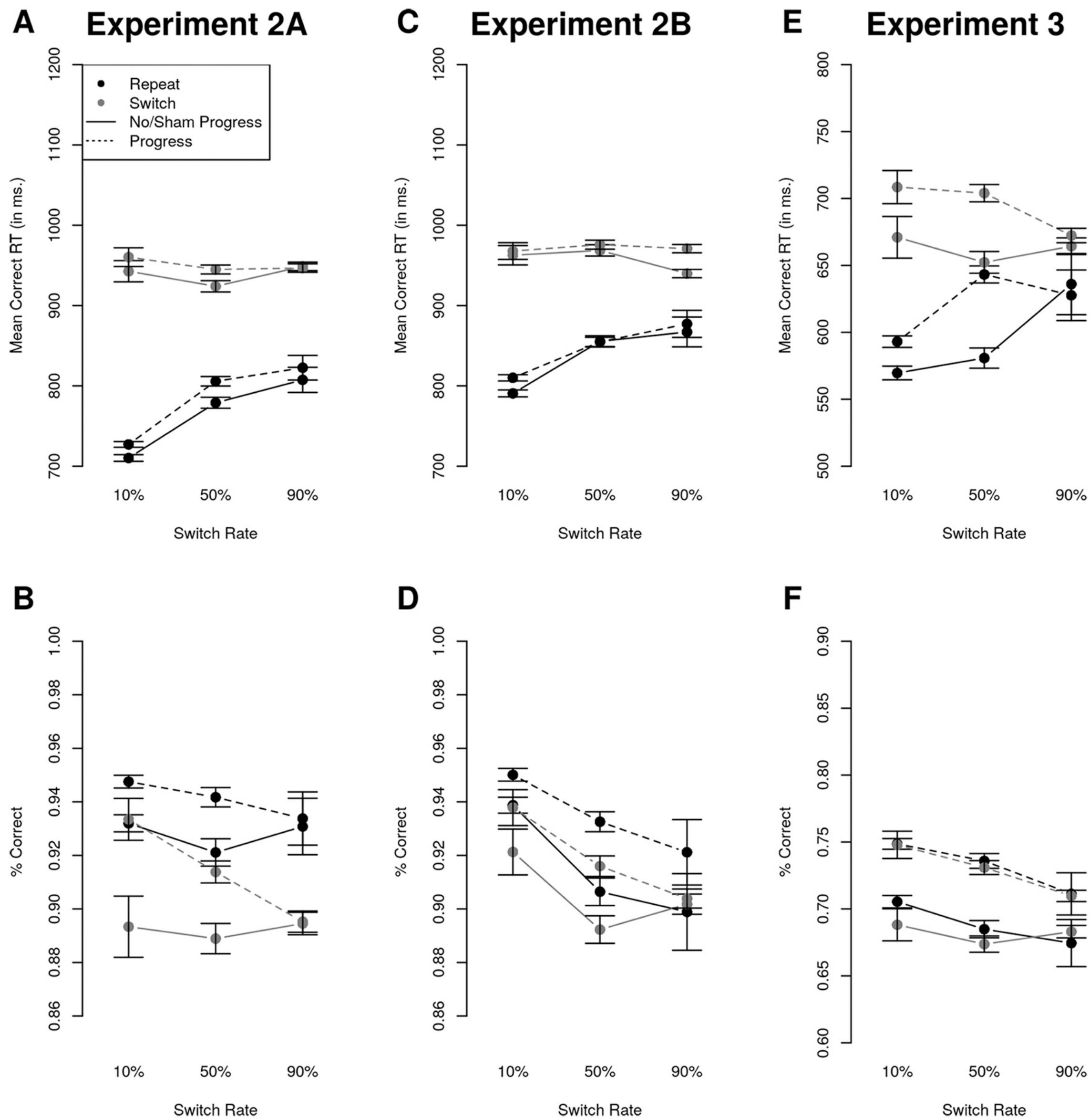

Fig. 5. Task-Switching Performance in Experiment 2A, 2B, and 3. Participants in all experiments were both slower (Panels A, C, and E) and less accurate (Panels B, D, and F) on task switches compared to task repetitions. As the proportion of switch trials in a block increased, RT increased and accuracy decreased monotonically. Results Experiment 3 closely mirrored these findings. Solid lines and dashed lines depict performance for task blocks where progress information was present, and dashed lines the same for tasks where no progress information was presented (or Sham Progress information in Experiment 3). Error bars represent standard error of the mean.

preferences observed by Sayalı and Badre (2019). We did not observe that demand avoidance varied significantly as a function of demand level pairing—e.g., demand avoidance did not differ between 10% versus 50% deck pairings and 50% versus 90% deck pairings ($\chi^2(2) = 2.51$, $p = .2852$). In both No Progress (P(Choose Low Demand) = 56%, OR = 0.78, CI = [0.65, 0.93], $p = .0066$), and Progress (P(Choose Low Demand) = 63%, OR = 0.57, CI = [0.47, 0.68], $p < .0001$) only pairings, participants chose higher-demand decks significantly less than chance.

The results of Experiment 2B mirrored those of 2A, revealing that participants were demand-averse, selecting the lower-demand deck significantly less than chance overall (P(Choose Low Demand) = 57%, OR = 0.80, CI = [0.71–0.89], $p < .0001$; Fig. 6D), in pairings where neither deck yielded progress (P(Choose Low Demand) = 54%), OR = 0.83, CI = [0.70, 1.00], $p = .0441$, and in pairings where both decks yielded progress (P(Choose Low Demand) = 58%, OR = 0.70, CI = [0.59, 0.84], $p = .0001$). In contrast to Experiment 2A, we found that demand avoidance did vary according to demand pairing, such that participants significantly avoided demand more often in higher demand pairings (50% versus 90% and 10% versus 90%) than in low demand pairings (10% versus 50%) ($\chi^2(2) = 8.45$, $p = .0146$); see Table 3 for statistics on each resultant deck pairing.

3.2.3. Preference for progress information

We next examined participants' preference for progress decks across deck pairings in which demand was the same (e.g., 10% switch rate versus 10% switch rate), but where progress condition differed (i.e., No-Progress versus Progress). Overall, in Experiment 2A, participants preferred decks that yielded information about their progress in the task-switching block to those that did not (P(Choose Progress) = 0.62, OR = 1.65, CI = [1.35–2.02], $p < .0001$, see Fig. 6B). Furthermore, these effects were moderated by demand level, such that participants most preferred progress information in the context of lower-demand tasks (10% and 50% switch rate decks; $\chi^2(2) = 8.33$, $p = .0155$; see Table 3).

We observed a similar pattern of choices in Experiment 2B, where

Table 2
RTs by demand level and trial type in Experiments 2A and 2B.

Experiment 2A			
Block Switch Rate (Trial Type)	*b*	*95% CI*	*p*
10% (Repeat) [Intercept]	721.51	668.75–774.27	<.001
50% (Repeat)	66.65	58.24–75.05	<.001
90% (Repeat)	102.20	84.96–119.43	<.001
10% (Switch)	233.53	218.89–248.16	<.001
50% (Switch)	−92.76	−110.23 to −75.29	<.001
90% (Switch)	−107.42	−130.18 to −84.66	<.001
Experiment 2B			
10% (Repeat) [Intercept]	802.56	746.72–858.41	<.001
50% (Repeat)	39.86	30.92–48.80	<.001
90% (Repeat)	72.78	51.32–94.24	<.001
10% (Switch)	165.34	151.22–179.45	<.001
50% (Switch)	−46.76	−64.00 to −29.52	<.001
90% (Switch)	−78.14	−103.89 to −52.40	<.001

participants exhibited a robust preference for Progress Decks over No-progress decks (*P*(Choose Progress) = 0.63, OR = 1.68, CI = [1.32–2.12], p < .0001; see Fig. 6E), which was most pronounced in pairings of low (10% versus 10%)- and medium (50%–50%)-demand decks ($\chi^2(2) = 15.95$, $p = .0009$; see Table 3). In short, these observed preferences for progress information were similar across experiments Experiment 2A and Experiment 2B.

3.2.4. Modulation of demand avoidance by progress information

Finally, we examined choices in deck pairs where both demand level and progress information varied (Fig. 6C and F). Examining choices in Experiment 2A, in deck pairs where progress information was associated with the lower-demand task (depicted by gray bars), participants overwhelmingly avoided the high-demand deck (*P*(Choose Low Demand) = 0.70), OR = 0.42, CI = [0.34–0.51], $p < .0001$). Conversely, when progress information was associated with a higher-demand deck—in other words, when progress information could be obtained by choosing a higher level of demand (depicted by black bars)—participants exhibited no significant preference for demand avoidance. In fact, we observed a (non-significant) trend towards a preference for higher-demand options (*P*(Choose Low Demand) = 0.46, OR = 1.17, CI = [0.98–1.41], $p = .0840$), which appeared most pronounced in low demand deck pairs—that is, the 10% versus 50% switch rate pairings (see Table 3).

In Experiment 2B, participants again demonstrated marked demand aversion when progress information was associated with lower demand tasks (*P*(Choose Low Demand) = 0.64, OR = 0.55, CI = [0.46–0.66], $p < .0001$; see Fig. 6F). However, when progress information could only be obtained by completing a higher demand task, participants significantly preferred high demand tasks to low demand tasks (*P*(Choose Low Demand) = 0.45, OR = 1.21, CI = [1.02–1.45], $p = .0322$). This effect was again most pronounced in low demand context (10%–50% pairings; see Table 3).

3.2.5. Subjective demand ratings

In both experiments, subjective mental demand increased monotonically with objective demand, such that decks with higher switch rates were generally experienced as more mentally demanding (see Fig. 7 and Table 4). Interestingly, we also observed a main effect of progress information on subjective demand, such that participants reported that decks associated with progress information were rated as less demanding than decks not associated with progress information (Experiment 2A: b = −0.76, CI = [−1.16 to −0.36], $p = .0002$; 2B: -0.61, CI = [−0.94 to −0.28], $p = .0003$). We did not, however, observe a significant interaction between switch rates and progress information (Experiment 2A: $\chi^2(2) = 1.64$, $p = .4369$; 2B: $\chi^2(2) = 5.97$, $p = .0505$).

3.3. Discussion

Experiments 2A and 2B employed a within-subjects design based on Sayalı and Badre (2019) to examine how demand levels and progress information, which varied jointly across decks. Conceptually replicating Sayalı and Badre's (2019) results, we observed in both experiments that participants, overall, were effort-averse, opting to choose the less demanding option of each pair with which they were presented. Further, when we examined choices between options of equal demand level, we found that participants exhibited a marked preference for information about progress, echoing the results obtained in Experiment 1. In line with the findings of Katzir et al. (2020)—who observed that information about trial-wise progress in a task of long, but indeterminate, length improved asymptotic performance in a demanding cognitive control task—we found a small, but significant, effect of progress information on accuracy, such that task-switching accuracy improved in blocks where progress information was available. Notably, we only observed this accuracy effect in Experiment 2A, where—as in Katzir et al. (2020)—block lengths were uncertain, but not in Experiment 2B, where block lengths were fixed, suggesting that the performance benefits of progress information may be contingent upon its ability to reduce uncertainty about the length of a task block.

Interestingly, when greater effort exertion was required to acquire progress information—participants' demand-avoidant preferences were attenuated, resulting in a tendency towards choosing the higher demand option, and this was most pronounced at lower demand levels. Put another way, we found evidence that, to some extent, participants were willing to trade off effort avoidance against progress information. However, it is worth noting that this pattern of choice —i.e., a preference for higher levels of cognitive demand—might not unequivocally indicate demand-seeking preferences per se, but could instead reflect a strong preference for progress information that simply overrides 'default' cognitive effort avoidance.

Conversely, when progress information coincided with low demand, participants were exceptionally effort averse. Furthermore, progress information reduced participants' reported levels of task demand associated with each deck, as measured by the NASA-TLX, over and above the deck's objective demand level. These findings suggest the possibility that progress information might act to decrease the perceived costs—rather than increase the perceived benefits—of effort exertion. We return to this issue in the General Discussion.

Importantly, in Experiment 2B, where the length of task-switching blocks was held constant, deck preferences and subjective demand ratings were nearly identical to those in Experiment 2A, where task-switching blocks were of variable length. These similar patterns of results suggest against the possibility that information about progress acted upon demand preferences because it reduced uncertainty about the length of task-switching blocks. That is, if participants' observed preferences for progress information in Experiment 2A merely reflect a desire to reduce uncertainty about the length of the to-be-completed task-switching block, we would expect to see no effect of progress information in Experiment 2B (where block lengths were fixed), in which case progress information played no role in reducing uncertainty about the duration of task-switching blocks. Finally, we observed, in both experiments, that participants' apparent demand avoidance was stronger when making choices between decks that both conferred progress than between decks which did not confer progress, though participants significantly avoided higher-demand decks in both cases, an effect we did not explicitly make a prediction about.

Together, the results of Experiments 2A and 2B build on the results of Experiment 1, further suggesting that the typically-observed demand-avoidant preferences observed in the literature can be tempered, and even reversed by the prospect of information about task progress. However, an open question concerns whether participants' observed preference for Progress information in Experiments 2A, and 2B could be explained by a preference for the presence of changing visual stimuli

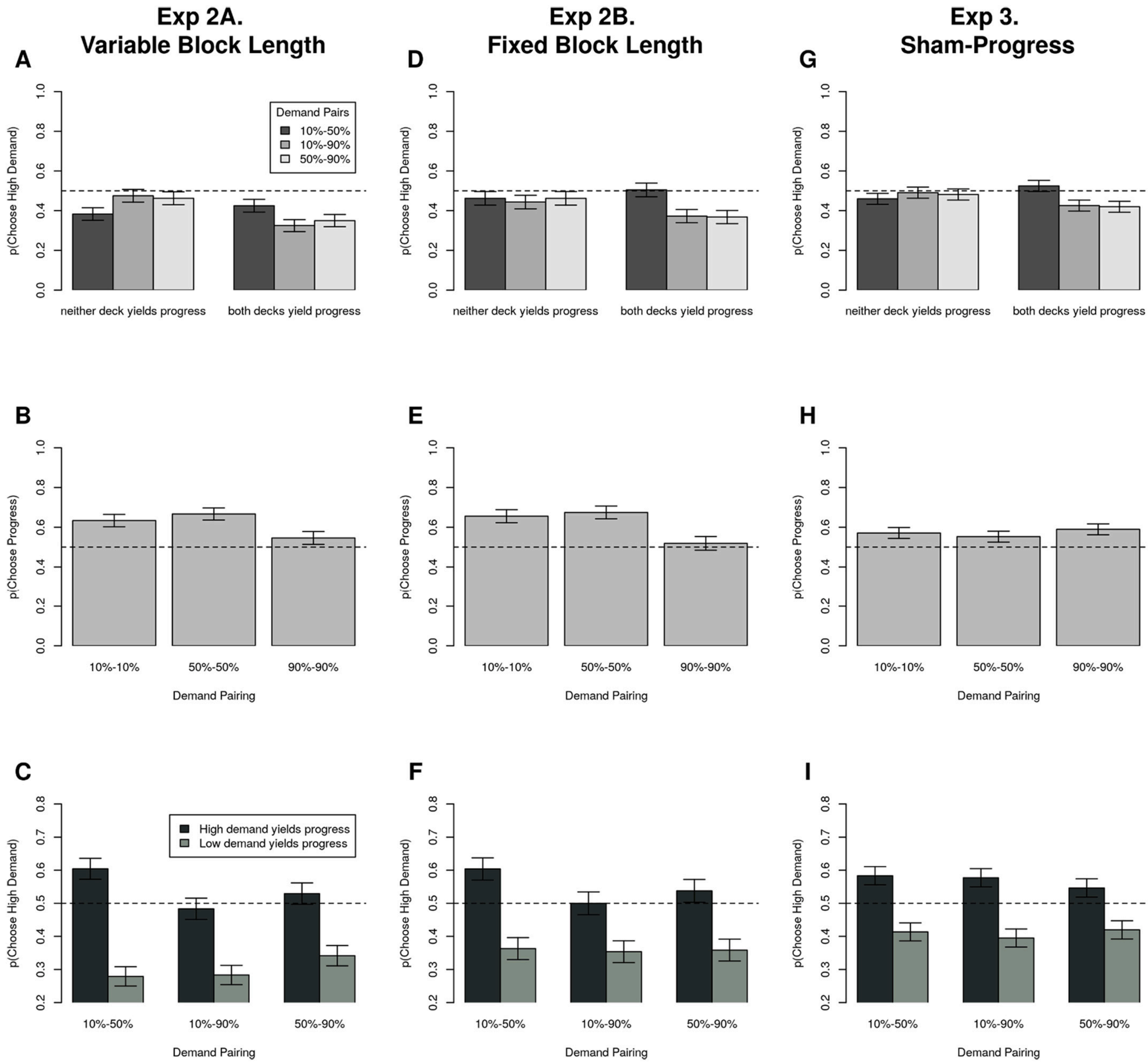

Fig. 6. Demand and progress preferences in Experiment 2A, 2B, and 3 When progress was held constant (Panels A, D, and G), participants were averse to cognitive demand. When demand was held constant (Panels B, E, and H), participants preferred progress decks to non-progress decks. When both demand and progress levels varied (Panels (C, F, and I), participants preferred or were indifferent to high demand when higher demand level yielded progress information, but avoided demand altogether when it did not. Bars represent standard error.

more broadly[3]—in this case, the progress indicator depicted in Fig. 4. That is, to the extent that completing blocks of task-switching engender boredom, owing to its repetitive (and possibly under-stimulating) nature (Tam, van Tilburg, Chan, Igou, & Lau, 2021), we might expect that participants would seek out circumstances that provide additional perceptual stimulation (Berlyne, 1958, see also Wu, Ferguson, & Inzlicht, 2021), which would manifest in general preference for Progress decks regardless of its informational value. The subsequent experiment evaluates this alternative explanation.

4. Experiment 3

To rule out the possibility that the progress preferences observed in the previous experiments simply stem from a desire for changing perceptual information—the progress bar—we carried out a third experiment that was nearly identical to that of Experiment 2B, in which No-Progress decks were replaced with "Sham-Progress" decks, which associated with a perceptually identical progress bar but importantly, did not convey meaningful information about block progress. In these Sham-Progress decks, the movement of the progress bar was random and did not relate to the participant's progress within the task-switching block, but the Progress decks—as in Experiments 2A and B—carried genuine progress information. Thus, if participants exhibited a marked preference for 'true' progress information, this preference could be

[3] We thank Jack Dolgin and Wouter Kool for pointing this out to us.

Table 3
Deck preferences in Experiment 2 and 3.

Pairings	Experiment 2A % (OR)	95% CI	p	Experiment 2B % (OR)	95% CI	p	Experiment 3 % (OR)	95% CI	p
A vs. B	38 (0.61)	0.46–0.81	.001	46 (0.85)	0.64–1.14	.292	46 (0.85)	0.68–1.06	.154
A vs. C	47 (0.90)	0.68–1.19	.458	44 (0.79)	0.59–1.06	.115	49 (0.96)	0.77–1.20	.74
A vs. D	*64 (1.79)*	*1.32–2.42*	*<.001*	*67 (2.02)*	*1.44–2.85*	*<.001*	*57 (1.35)*	*1.06–1.71*	*.015*
A vs. E	61 (1.54)	1.17–2.03	.002	60 (1.52)	1.16–2.01	.003	58 (1.40)	1.12–1.76	.003
A vs. F	48 (0.93)	0.71–1.22	.617	50 (1.00)	0.76–1.31	1.000	59 (1.37)	1.09–1.71	.006
B vs. C	46 (0.85)	0.64–1.13	.268	46 (0.85)	0.64–1.14	.292	48 (0.93)	0.74–1.16	.509
B vs. D	26 (0.38)	0.28–0.51	<.001	36 (0.57)	0.43–0.75	<.001	41 (0.70)	0.56–0.88	.002
B vs. E	*68 (2.09)*	*1.54–2.85*	*<.001*	*69 (2.22)*	*1.57–3.14*	*<.001*	*55 (1.24)*	*0.98–1.58*	*.071*
B vs. F	53 (1.13)	0.86–1.48	.386	54 (1.16)	0.89–1.53	.273	55 (1.21)	0.96–1.51	.101
C vs. D	28 (0.39)	0.29–0.52	<.001	36 (0.55)	0.41–0.73	<.001	39 (0.65)	0.52–0.82	<.001
C vs. E	34 (0.51)	0.38–0.68	<.001	36 (0.55)	0.42–0.74	<.001	42 (0.72)	0.58–0.90	.004
C vs. F	*55 (1.22)*	*0.91–1.63*	*.187*	*52 (1.09)*	*0.78–1.51*	*.615*	*59 (1.46)*	*1.14–1.85*	*.002*
D vs. E	42 (0.73)	0.55–0.97	.028	50 (1.02)	0.76–1.36	.899	52 (1.10)	0.88–1.38	.381
D vs. F	32 (0.47)	0.35–0.63	<.001	0.58 (37)	0.43–0.79	<.001	43 (0.74)	0.59–0.93	.009
E vs. F	34 (0.52)	0.39–0.70	<.001	36 (0.57)	0.42–0.77	<.001	42 (0.72)	0.58–0.90	.004

Note. Plain text refers to choices about demand, italic text refers to deck pairs which only varied with respect to progress information conferered. Percentages and Odds Ratios (OR) > 1 reflect decisions in favour of high-demand tasks when choices are about demand or in favour of Progress decks when choices are solely about progress. CI are in Odds Ratio scale. Refer to Table 1 for deck descriptions.

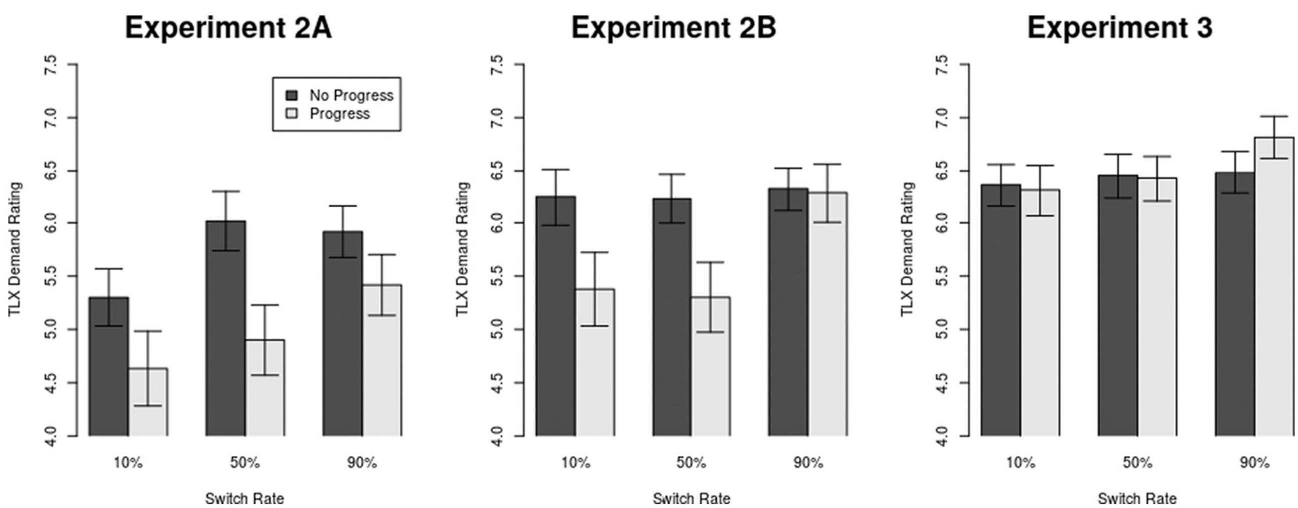

Fig. 7. Subjective Effort Ratings, in Experiment 2A, 2B, and 3, measured using the TLX Demand subscale (i.e., "How mentally demanding was the task?"). In all experiments, as the objective task demand (or task switch rate; horizontal axis) increased associated with a deck increased, participants rated the deck as more subjectively demanding (vertical axis). Notably, in Experiments 2A and 2B, participants rated decks that yielded progress information (light gray) as less demanding than those that did not yield progress information (dark gray).

Table 4
TLX Demand subscale ratings in Experiment 2A and 2B across demand levels and progress conditions.

Predictors	Experiment 2A b	CI	p	Experiment 2B b	CI	p
10% Switch Rate	5.35	4.84–5.85	<.001	6.12	5.62–6.61	<.001
50% Switch Rate	0.49	0.00–0.98	.050	−0.05	−0.45–0.36	.818
90% Switch Rate	0.70	0.21–1.19	.005	0.49	0.09–0.89	.017
Progress Condition	−0.76	−1.16 to −0.36	<.001	−0.61	−0.94 to −0.28	<.001

attributed to genuine progress information and not simply a preference for the presence (versus absence) of visual stimuli that change from trial to trial. Accordingly, we expected to see the same pattern of preferences for progress information—even if it incurs additional cognitive demand—as observed in Experiments 2A and 2B.

4.1. Method

4.1.1. Participants

We collected data from 107 participants on AMT (M_{age} = 38.22, s_{age} = 9.96, 76% men). Applying the same criteria as in Experiment 2A and 2B, we noticed a substantial loss of data (N = 41; 62% data lost). To mitigate this unexpectedly high exclusion rate and increase power, we relaxed our exclusion criteria, such that participants with an average reaction time below 100 ms and/or average accuracy below 50% were excluded. These criteria yielded a more acceptable proportion of excluded data (N = 81, age-range = [25, 66], M_{age} = 38.04, s_{age} = 9.28, 77% male) and were used for analysis. Importantly, the patterns of statistical significance reported below remain the same regardless of which exclusion criteria we applied and for the full sample.

4.1.2. Sham progress versus true progress DST

The design employed in Experiment 3 was identical to that used in Experiment 2B, with the exception of a "sham progress bar" that was present in task-switching blocks after a Sham-Progress deck was selected. Importantly, this bar was visually identical to that in Progress deck condition, whose appearance varied randomly from trial to trial. Specifically, on each trial, the bars' filled portion was computed as a randomly selected integer portion of its total length (i.e., 1 to 16 out of 16 total trials per block), such that, in principle, perceptual states could repeat. In contrast, when a Progress deck was selected, a "true" progress bar was presented, which behaved in the same way as it did in Experiment 2A and 2B, increasing linearly in size each trial. In other words, while being visually identical to the Progress decks' progress bar, the false progress in the No Progress decks bar conveyed no useful progress information.

4.2. Results

4.2.1. Task-switching performance

As in Experiment 2A and 2B, participants responded more slowly ($M_{repeat} = 595.90$, $M_{switch} = 675.41$) and less accurately ($M_{repeat} = 0.72$, $M_{switch} = 0.70$) on switch trials than repeat trials (see Fig. 5E and F). This was supported statistically by mixed-effects models, which revealed a significant effect of trial type (switch versus repeat) on RTs (b = 91.66, CI = [86.18–97.14], $p < .0001$) and accuracy (OR = 0.94, CI = [0.91–0.97], $p = .0007$). Additionally, we found that the magnitude of the relationship between RTs and trial type varied significantly according to the block-level switch rate ($\chi^2(4)$ =65.84, $p < .0001$), such that repeat RTs increased with the block-level switch rate (10% (intercept): b = 490.69, CI = [415.26–566.13], $p < .0001$; 50%: b = 38.81, CI = [30.32–47.30], $p < .0001$; 90%: b = 70.37, CI = [50.75–90.00], $p < .0001$), whereas switch RTs decreased (10%: b = 603.77, CI = [527.44–680.11], $p < .0001$; 50%: b = −45.47,CI = [−61.98 to −28.95], $p < .0001$; 90%: b = −75.64, CI = [−99.51 to −51.77], $p < .0001$). Examining the effect of progress information on task performance, we found that participants were significantly more accurate on blocks following choices to Progress decks (in which true progress feedback was presented) compared to blocks following choices to Sham-Progress decks (OR = 1.07, CI = [1.03–1.11], $p = .0003$). We found no significant interaction between demand and progress level on RT ($\chi^2(2)$ = 0.93, $p = .6264$) or accuracy ($\chi^2(2)$ =1.92, $p = .3823$). As in Experiment 2, RTs were did not vary as a function of trial within blocks (b = −0.13, CI = [−1.51, 1.24], $p = .8481$) nor this trial effect vary according to whether true progress information was present or not (b = 0.46, CI = [−1.36, 2.29], $p = .6199$).

4.2.2. Preference for demand avoidance

As in Experiment 2, we began by examining participants' preferences across deck pairings in which demand level varied, but progress condition was the same (Progress versus Progress or Sham-Progress versus Sham-Progress). In line with the results from Experiment 2, we found that participants made demand-avoidant choices overall, preferring low-demand tasks significantly more than chance (*P*(Choose Low Demand) = 0.53, OR = 0.92, CI = [0.85–0.99], $p = .0202$; see Fig. 6G). Such demand avoidance was also present statistically significantly in choices where both decks yielded progress information (*P*(Choose Low Demand) = 54%, OR = 0.84, CI = [0.73, 0.96], $p = .0100$, and numerically in choices where neither deck did (*P*(Choose Low Demand) = 53%, OR = 0.91, CI = [0.80, 1.04], $p = .1766$). Demand avoidance did not significantly vary according to demand level ($\chi^2(8)$ = 11.27, $p = .1867$; see Table 3). Consistent with our findings in Experiment 2, these results suggest that participants by and large exhibited generally demand-averse preferences when the two decks conferred the same information about block progress.

4.2.3. Preference for progress information

We next examined participants' preference for progress decks across deck pairings in which demand levels were identical, but where decks conveyed different information about progress (i.e., Sham-Progress versus Progress). Here, we observed a marked preference for Progress decks compared to Sham-Progress decks (*P*(Choose Progress) = 0.57, OR = 1.35, CI = [1.15–1.57], $p = .0002$; see Fig. 4H), and this preference occurred irrespective of demand level ($\chi^2(2)$ =0.94, $p = .6253$). In other words, despite the presence of a visually identical "progress" bar in Sham-Progress decks, participants overall exhibited a preference for veridical progress information.

4.2.4. Modulation of demand avoidance by progress information

Finally, following Experiments 2A and 2B, we examined choices in deck pairs where options varied both in different progress and demand level associations, we found that participants were markedly demand-averse when true progress information could be acquired by choosing the low-demand deck (*P*(Choose Low Demand) = 0.59, OR = 0.69, CI = [0.60–0.79], $p < .0001$; gray bars in Fig. 6I). By contrast, in pairings in which decks conferring true progress information were more demanding, participants consistently chose the higher demand deck (*P* (Choose Low Demand) = 0.43; OR = 1.32, CI = [1.16–1.51], $p < .0001$; black bars in Fig. 6I). These preferences did not differ, significantly, as a function of demand level ($\chi^2(8)$ = 11.27, $p = .1867$). In other words, participants still elected to undertake a more demanding cognitive task in order to receive true progress information, even if they could work less hard to receive the same visual stimuli (the sham-progress bar).

4.2.5. Subjective demand ratings

As in Experiment 2, we also found that higher switch rate decks were generally experienced as more subjectively demanding, as measured by the NASA-TLX questions (10% (Intercept): b = 6.29, CI = [5.91–6.67], $p < .0001$, 50%: b = 0.10, CI = [−0.21, 0.41], $p = .5320$; 90%: b = 0.31, CI = [0.01, 0.62], $p = .0464$; see Fig. 7). However, in contrast to Experiments 2A and B, we found no significant effect of progress information on subjective demand ratings (b = 0.09, CI = [−0.17, 0.34], $p = .5030$), nor a significant interaction between demand and progress ($\chi^2(2)$ = 1.85, $p = .3955$).

4.3. Discussion

Experiment 3 sought to rule out the possibility that participants' preference for progress information observed in the previous experiments merely stemmed from a desire for additional visual information. Controlling for the amount of perceptual information available across Progress and Sham-Progress decks, we observed that participants' preferences—both with respect to demand avoidance and progress information—mirrored those of Experiments 2A and 2B. In contrast to Experiments 2A and 2B however, progress did not modulate subject demand ratings. One explanation for this disparity may stem from the false-feedback delivered by the sham-progress bar, which may have reduced participants' beliefs about the efficacy of their actions (Frömer, Lin, Wolf, Inzlicht, & Shenhav, 2021; Otto, Braem, Silvetti, & Vassena, 2021), reducing the expected value of effort expenditure, and in turn inflating the perceived demands imposed by the sham-progress blocks.

Nevertheless, the results of Experiment 3 conceptually replicate the patterns of demand preference observed in Experiments 2A and 2B, suggest that individuals prefer to avoid cognitively demanding tasks, prefer veridical progress information over meaningless, but visually identical trial-to-trial information, and moreover, were willing to complete more demanding cognitive tasks to obtain this progress information. Again, as task-switching blocks following deck selections were fixed in length, and the trial-to-trial amounts of visual information were equated across all decks, it is difficult to explain these patterns of choice as reflecting a preference for 1) reduction of uncertainty about task block lengths or, 2) additional visual stimulation during blocks of task-switching.

5. General discussion

While a large and growing body of work suggests that people, by and large, avoid cognitively effortful activities (Kool & Botvinick, 2018), here we consider the possibility that these preferences for effort avoidance might be tempered by the prospect of information about task progress. Accordingly, the present series of experiments examined whether progress information could modulate well-documented aversion to cognitive effort expenditure, by examining individuals' effort preferences in variants of a demand selection task (DST) wherein participants made choices between courses of action that varied with respect to the level of imposed cognitive demand and—in Experiments 2 and 3—the availability of information about trial-wise progress through a block.

In short, across these experiments, we found support for our three key hypotheses. First, we found that, all else being equal, participants overall avoided the more cognitively demanding course of action, corroborating a body of previous results employing variants of the DST (Bogdanov, Nitschke, LoParco, Bartz, & Otto, 2021; Bogdanov, Renault, Loparco, Weinberg, & Otto, 2022; Kool et al., 2010; Patzelt et al., 2019; Sayalı & Badre, 2019). Second, when choosing between courses of action with equal cognitive demands, we observed that individuals preferred to receive information about their temporal progress over no information. Third, and perhaps most interestingly, we found that the prospect of progress information modulated participants' 'default' demand-avoidant preferences, which manifested as a choice to engage in harder mental work if it was accompanied by information about progress. Importantly, this apparent modulation of demand-avoidant preferences was still observed even when participants had the option of a less demanding course of action. Why might information about an individual's temporal progress through a task modulate effort investment? Taking the influential cost-benefit view of cognitive effort valuation (Shenhav et al., 2017), we consider two plausible but not necessarily mutually exclusive possibilities.

On the one hand, progress may moderate demand aversion by reducing perceived effort costs, rendering higher-demand courses of action less undesirable—or, put another way, making lower-demand options less favorable compared to the opposing higher-demand option faced in the decision. In line with this interpretation, we observed in Experiments 2A and 2B that progress information reduced participants' reported task demand, over and above the objective task demand level associated with each deck/cue. With the assumption that these TLX scores directly index participants' subjective effort costs (Hart, 2006), these results lend support to the notion that progress information acts directly to reduce subjective effort costs of a particular course of action. It is important to note, however, that it is unclear whether TLX scores function as a pure measure of effort costs, or instead, if they reflect a composite of the costs, benefits—and possibly other factors—ascribed to a particular course of action. To this point, future psychometric work is needed to determine the purity with which TLX scores reflect direct effort costs in cognitive tasks.

Taking the effort cost reduction view, one plausible mechanism by which progress information reduces perceived effort costs is by reducing uncertainty with respect to task progress. A body of work suggests that resolving task state uncertainty requires the mobilization of subjectively costly cognitive control processes to resolve (Mushtaq, Bland, & Schaefer, 2011; Osman, 2010). In this context, uncertainty refers to the number of trials in a block of task-switching. In Experiment 2A, the number of trials per block varied, such that if a No-Progress deck is chosen, participants had continual uncertainty about how many trials remained in a block. Insofar as the participant's goal is to finish the task as quickly and accurately as possible, temporal progress information could allow participants to accurately estimate remaining time-on-task and allocate cognitive resources to the primary task (Katzir et al., 2020). In Experiment 2B, we fixed the number of trials per block and thus, controlled for one source of uncertainty across Progress and No-Progress decks. However, fully resolving uncertainty in Experiment 2B would require tracking the number of completed (with respect to to-be completed) trials in each block, while at the same time accurately judging each digit in accordance with the trial's task rule—a feat that is possible, but that comes at substantial cognitive costs (e.g., increased load on working memory). By providing a low-effort means of tracking the amount of time spent on-task, progress information can be thought of as a form of cognitive offloading, allowing one to outsource the effort costs associated with resolving temporal uncertainty (i.e., tracking one's time-on-task) thus reducing perceived costs and rendering higher-demand options less unfavourable (Gilbert et al., 2020; Risko & Dunn, 2015).

Moreover, a more accurate estimate of one's accumulated time spent on a task reifies one's goals—transforming the abstract desire to eventually finish the task into a concrete one: to finish the task in 5 more trials, for instance—further motivating effort exertion (Borovoi, Schmidtke, & Vlaev, 2020). Importantly, in the current study, we found that progress motivated effortful action even when we reduced temporal uncertainty in the environment (Experiment 2B and Experiment 3). Moreover, progress did not reliably improve actual performance on the cognitive tasks, nor did these improvements significantly affect effort-based decision-making (see Supplemental Materials). This suggests that while temporal progress information may have reduced uncertainty and offset cognitive costs at "local" level (within blocks of determined length), another explanation may be warranted to explain how temporal progress information motivates effort exertion.

On the other hand, rather than reducing perceived effort costs, information about progress could instead add intrinsic value to a potential course of action, indirectly offsetting the costs of effort—in other words, leaving the effort costs associated with higher-demand options unaffected, but adding additional value to a choice that justifies higher-demand selection (Inzlict et al., 20,018). This view is supported by past work demonstrating that progress indicators can offset effort costs by increasing an individual's motivation to achieve their goal (Cheema & Bagchi, 2011; Kivetz et al., 2006). Notably, Kivetz et al. (2006) found increased motivation to achieve a goal even when progress was illusory, suggesting that the sense of progress itself was inherently valuable in informing people's decisions, above and beyond its instrumental use. Similarly, Cheema and Bagchi (2011) showed that the motivating effects of progress information depended in part on its salience, such that difficult-to-visualize progress information (a stopwatch) motivated effort less than easy-to-visualize progress information (a progress bar), despite the fact that in both forms of progress ostensibly resolve task-related uncertainty.

These results dovetail with previous literature in educational and workplace settings, which suggests that information about an individual's progress can improve performance—and, more importantly, willingness to undertake effortful tasks. For example, in higher education, the introduction of 'progress files'—documents managed by the student that contains information about their achievements and performance since beginning university—are thought to improve students' learning outcomes and eventual employability (Clegg, 2004; East, 2005). In the workplace, progress indicators are thought to confer meaning to employees' work and have been demonstrated to increase worker productivity (Amabile & Kramer, 2011). While these findings highlight the tangible benefits that progress-induced effort investment can have on society, the present experiments might help clarify the nature of these phenomena: progress information might carry intrinsic value that, when weighed against the inherent costs of effort, tilts the cost-benefit analysis in favour of effort investment. Further lending support to the view that progress information enhances perceived benefits, we observed that participants strongly preferred for decks that conveyed progress to those that did not, when the objective level of cognitive demand was held constant. This was true not only when progress reduced uncertainty about task block length (Experiment 2A), but also when block lengths were fixed and predictable (in Experiments 2B and 3).

While both the effort cost reduction and value-adding views of progress information are plausible, the current data remain inconclusive with respect to which mechanism (or to what degree each mechanism) is at play and future work is needed to resolve this cost-benefit question. Rather, the present results represent an important step in understanding the factors that influence effort-based decision-making and the role that temporal progress information plays in motivating increased effort exertion. Of note in this respect, we find limited evidence for the effect of progress information on task-switching performance in the current set of experiments: accuracy was only slightly improved when progress information was present—and this only in Experiment 2A—and never had an effect on participants' performance across task-switching trials. As such, our results attest to the modulatory role that temporal progress information plays on effort preferences rather than performance per se, supplementing past work that has focused exclusively on the latter (Katzir et al., 2020).

Whether the prospect of progress information acts upon demand preferences by reducing effort costs and/or adding value, the current results have important implications for our understanding of effort-based decision-making in situations where effort appears to modulate the net value of effort expenditure. In such circumstances (mountain-climbing, building furniture, Sudoku, video games; Inzlicht et al., 2018), our results raise the possibility that the net value of effort (benefits less costs) could be modulated by other valuable or salient stimuli in the environment. While the current study suggests that temporal progress information is one such piece of information, the literature suggests that people are willing to incur monetary costs to acquire information, whether this information is instrumental to the task at hand or not (Bennett, Bode, Brydevall, Warren, & Murawski, 2016; Golman & Loewenstein, 2018). In both cases, these features can shift preferences in such a way that may, at first blush, appear puzzling—i.e., people incurring costs for 'no reason'—but that ultimately can be explained without substantial alteration to the traditional cost-benefit framework. Importantly, effort may still genuinely add value in some contexts, as Inzlicht et al. (2018) suggest, but we propose that certain features of a task such as the presence of progress information may be able to account for seemingly paradoxical behavior, while maintaining the general framework of effort as cost.

Finally, it is important to remark on limitations of the present results and future directions that they may suggest. First, we only collected basic demographic data on participants, which limited our ability to explore individual differences (e.g., education level, SES, etc.) that may contribute to differential sensitivity to progress and/or effort. This represents an interesting avenue for future research which, to our knowledge, currently remains unexplored. We probed this demographic question in the Supplemental Materials by examining aging effects on effort and progress sensitivity. Second, in this series of experiments, we sought to provide an initial demonstration that progress information could, under certain circumstances, modulate preferences for demand avoidance. Here we examined only the effects of information about temporal progress—rather than, say, progress with respect to some criterion performance (i.e. accuracy) level. It is worth noting, however, a number of studies have investigated the role of performance-related progress on goal pursuit—that is, progress that is contingent on one's performance (Earley, Northcraft, Lee, & Lituchy, 1990; Fishbach & Dhar, 2005; Amir & Ariely, 2008). Indeed, outside of the lab, progress is often inextricably linked to one's performance—the mountaineer must work to scale the mountain. The current results should therefore be interpreted with this caveat in mind, with an eye towards future work that aims to examine the role of performance-contingent progress in cognitive effort-related decisions.

Finally, in the present studies, temporal progress was always linear in nature, increasing gradually from trial-to-trial. In reality however, variability in the schedule of progress feedback has been shown to have an influence on peoples' perception of progress and their preferences (Soman & Shi, 2003). In other words, progress information that is conveyed in fits and starts may have unique effects on demand preference, even when it yields the same content as continuous progress feedback (e.g., an estimation of remaining time on task). For instance, when running a marathon, the rate at which one experiences progress towards a goal changes over the course of the run (cf. Kivetz et al., 2006). Soman and Shi (2003) demonstrated that such differences in progress continuity had a strong effect on consumer behavior, but little is known about its effects on demand preferences. Similar results have been found in the design of online surveys, where participants' expectations about progress schedules and the continuity of progress itself greatly impacted participant compliance (Yan, Conrad, Tourangeau, & Couper, 2011). As in the previous point then, interpretation of the current results should be limited to continuous progress and future research should work to determine whether differences in progress continuity affect cognitive effort investments.

Author contributions

S.D. conceived of the initial research question, designed and programmed all experiments, collected and analyzed data, and co-authored the manuscript. A.R.O. assisted in the conception and design of the experiments, secured funding, and co-authored the manuscript.

Data and materials availability

All task code, raw data, and analysis scripts are available at https://github.com/seandamiandevine/EffortProgress.

Preregistration

The designs, hypotheses, and analyses for Experiment 1 and 2A were preregistered at https://osf.io/48b9g/registrations.

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Competing interests

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2022.105107.

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