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Cognitive effort investment and opportunity costs in strategic decision-making: An individual differences examination☆

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ABSTRACT

People are often more likely to persist with a strategy when more resources have been invested in this course of action, a phenomenon known as the 'sunk cost' effect. This effect has been difficult to demonstrate in the domain of real (non-hypothetical) effort investment, and this may be due in part to individual differences in the decision processes. We designed a decision-making task, where a cognitive effort investment is required to enact a strategy, to examine the extent to which individual differences in Need for Cognition (NFC), Lack of Premeditation, and subjective effort perception bear upon decisions to persist with a suboptimal strategy under varying levels of effort investment and opportunity cost—i.e. the difference in utility between persisting with versus switching strategies. We found that NFC and (Lack of) Premeditation predicted the extent to which strategy switch decisions were driven by opportunity costs. While we did not find an overall effect of past behavioral investment effect, self-reported effort (Temporal Demand) appeared to predict susceptibility to sunk cost. We also found a decrease in decision times with increasing sunk costs, but this effect did not appear to differ as a function of the individual differences examined.

1. Introduction

The 'sunk cost' fallacy describes a phenomenon whereby individuals are more likely to continue with a course of action—even to their detriment—after a irrecoverable investments of money, time, or effort has been made (Arkes & Ayton, 1999). As Rational Choice Theory prescribes that past investments or choices are irrelevant to present decisions, decisions based on sunk costs are thought to be an irrational (and pervasive) tendency. While the influence of sunk costs has been robustly demonstrated in choices relating to hypothetical monetary investments (Arkes & Ayton, 1999; Carnevale, Inbar, & Lerner, 2011), decision-makers also appear sensitive to past time investments (Navarro & Fantino, 2009; Sweis et al., 2018; but see Soman, 2001). It is less clear, however, whether previous expenditure of cognitive effort—that is, past investments of mental 'work'—directed towards the current course of action can also influence decisions to persist with versus abandon an individual's current course of action (Cunha Jr & Caldieraro, 2009; Emich & Pyone, 2018; but see Otto, 2010).

Part of the difficulty in demonstrating that choices are influenced by 'sunk effort' costs might stem from the considerable individual differences observed in the extent to which individuals are intrinsically motivated to exert versus withhold cognitive effort (Inzlicht, Shenhav, & Olivola, 2018; Sandra & Otto, 2018), in how much they find cognitively demanding behavior to be subjectively costly (Westbrook, Kester, & Braver, 2013) and in the level of short-sightedness or 'impulsivity' with which they make choices (Whiteside & Lynam, 2001). In the present study, we assess the extent to which these individual differences might bear upon how *real*, past behavioral investments or 'sunk effort' costs influence decisions to continue with or abandon a simple strategy. To do this, we designed a laboratory task in which a participant invests a variable amount of cognitive effort in one of two strategies, but in the course of carrying out the strategy, the conditions can change rapidly, possibly favoring a switch to the alternate strategy. In addition to examining how past effort investment engenders strategy persistence, which we take as evidence of a strategy choice informed by sunk costs, our task also affords examination of decision-makers' sensitivity to the opportunity cost of persisting with a suboptimal strategy—that is, the cost in terms of lost potential opportunities to earn more reward (Cunha Jr & Caldieraro, 2009; Otto & Daw, 2019).

The task, depicted in Fig. 1, consists of playing several 'rounds' of a

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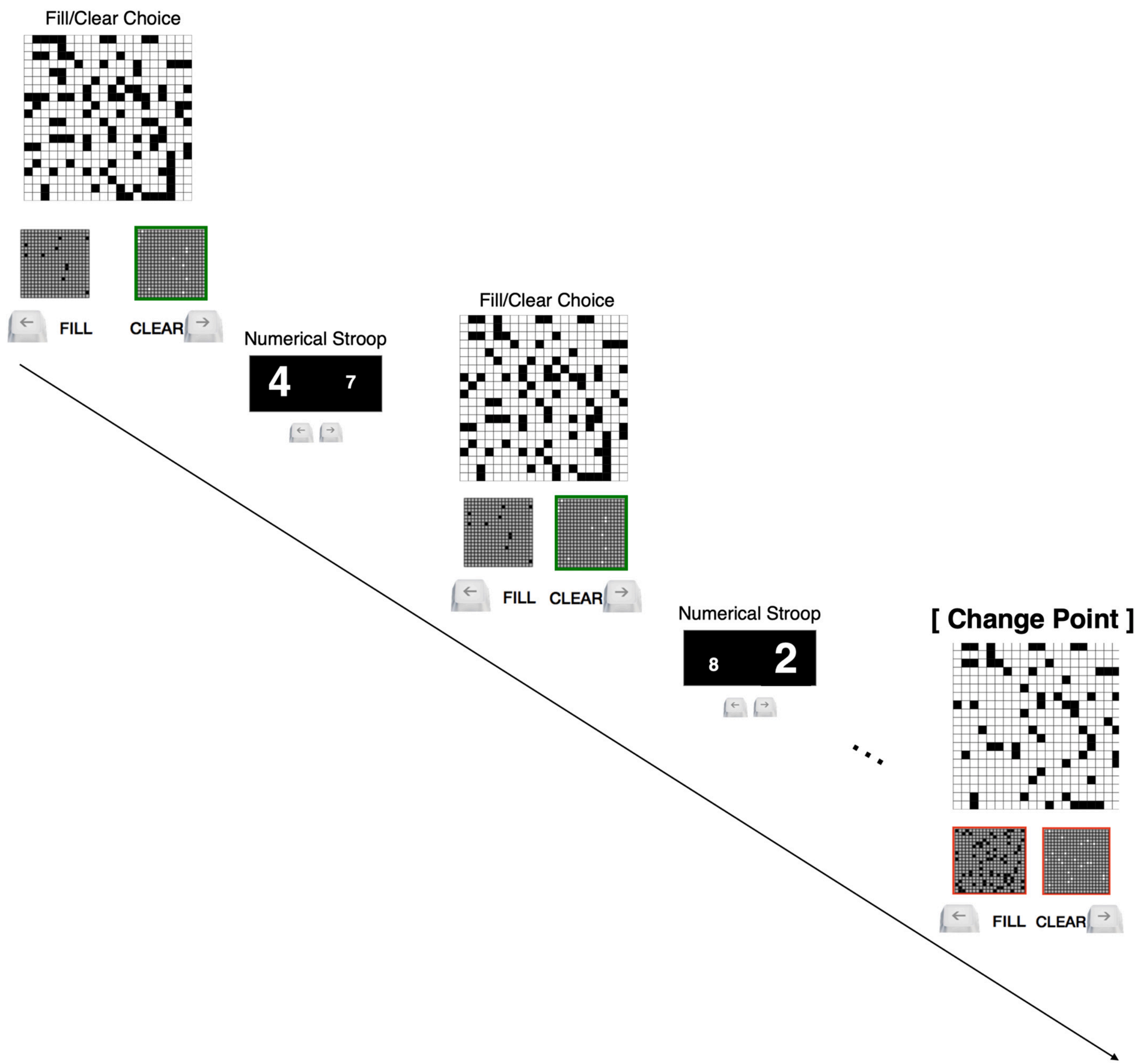

Fig. 1. The Fill/Clear board game. At the beginning of each game, a 20 by 20 board was presented with a random subset of squares filled in black. Participants filled or cleared squares, with the ultimate objective of either completely clearing or completely filling the board. In the current example, the participant presses the right key to choose clearing 10 squares at the beginning of the game (the two mini-boards above each action indicate the efficacy of filling and clearing respectively). The participant then had to correctly respond to three trials of the Numerical Stroop (feedback is given after response for each trial). Upon completing the effort task, 10 squares are cleared and the participant presses the right key to clear 10 subsequent squares. This sequence of events repeats for n times (i.e. Previous Steps Invested) until a Change Point occurs and the new efficacies are shown in the red-bordered mini-squares. Here the participant decides to persevere with the original strategy, electing to continue clearing the remaining squares on the board.

simple board-game-like task (for which participants are paid a monetary bonus) within a fixed amount of time. In each task round, participants had to achieve a simple goal, either completely 'filling' or 'clearing' the squares of a board by making consistent choices to the appropriate action ('fill' or 'clear') based on the efficacy of the two strategies. After several steps of filling or clearing the board, the relative efficacies of the two strategies can change (a Change Point), which can necessitate that the decision-maker switch strategies in order to complete the round with as few fill/clear actions as possible. In the example shown (Fig. 1), the 'clear' action is more efficacious at first insofar as completing the round in as few steps as possible (and is chosen for two steps) but after the Change Point, the 'fill' action becomes the more efficient strategy. After this point, persisting with the 'clear' action is a disadvantageous choice as the wasted steps spent applying this strategy (i.e., opportunity cost) are better spent completing more rounds of the game and increasing their total payment. Critically, in order to enact the chosen strategy at each step, participants were required to perform an unrelated, demanding Numerical Stroop Task (Jiang et al., 2016). Thus, each action a participant chose (clearing or filling the board) incurred a non-negligible investment of cognitive effort. Because Change Points occurs at different points in each game, this design allows us to independently manipulate the amount of effort invested in the current course of action before the Change Point (hereafter referred to as Effort Investment, or EI), and the

Opportunity Cost (OC) of perseverating with an ineffective strategy versus switching after a Change Point.

Notably, previous studies have found that individuals are differentially susceptive to the influence of sunk costs—in the context of hypothetical monetary scenarios— as a function of a number of trait variables including, cognitive flexibility, trait mindfulness and accounting expertise (Emich & Pyone, 2018; Hafenbrack, Kinias, & Barsade, 2014; Tan & Yates, 1995). This individual differences-based approach may yield further insight into the underlying cause of the sunk cost phenomenon in the domain of sunk effort costs. We hypothesize that Need for Cognition (NFC)— a trait measure of individual tendency to engage in and enjoy cognitively effortful endeavors, or alternatively, intrinsic motivation to exert cognitive effort (Cacioppo, Petty, Feinstein, & Jarvis, 1996)—could predict individuals' sensitivity to effort investment and possibly Opportunity Costs in deciding to persevere with versus change strategies in the task considered here. Indeed, previous work finds that high-NFC individuals show reduced susceptibility to sunk cost in decisions in hypothetical scenarios (Carnevale et al., 2011). We also reasoned that self-reported trait impulsivity—in particular, the (Lack of) Premeditation dimension of the UPPS scale (Whiteside & Lynam, 2001) reflecting an inability to consider the consequences of behavior—might also bear upon the choice to persist with versus abandon an ineffective strategy. Indeed, a body of previous work finds that self-reported trait impulsivity predicts strategic choice behavior (Otto, Markman, & Love, 2012; Zermatten, Van der Linden, d'Acremont, Jermann, & Bechara, 2005).

Moreover, as sensitivity to effort investment—here, the demanding Numerical Stroop task required at each step—might relate to well-documented individual differences in effort costs (Inzlicht et al., 2018; Westbrook et al., 2013), we included a measure of participants' subjective perception of how effortful they found the Numerical Stroop. If individuals who perceive the numerical Stroop task to be more subjectively effortful are more sensitive to effort invested, this measure should yield insight about the extent to which individuals treat previous effort investment as a cost, which may in turn exert predictive bearing upon strategy perseverance decisions as a function of previous cognitive effort investment.

Beyond choices themselves, we also endeavored to examine decision times (or response times; RTs). RTs have been used as an indirect measure of cognitive effort exertion, where longer RTs imply more effortful or deliberative choices, whereas faster RTs are taken as evidence for intuitive, heuristics-based, or 'emotional' responding (Evans, 2008; Otto, Gershman, Markman, & Daw, 2013). Accordingly, we examined how previous effort investment and opportunity costs jointly influence the speed with which choices are made at the Change Point, as an additional window into the cognitive processes underlying the choice between persevering at the invested course of action and switching to the more time-efficient alternative.

2. Method

2.1. Participants

We recruited 201 participants online through Amazon Mechanical Turk (Crump, McDonnell, & Gureckis, 2013). Consent was obtained in accordance with the university Ethics Board. Participants were compensated with a fixed amount ($3 USD) plus a bonus contingent on the number of games completed in the fixed 15-minute period. Prior to the introduction of the main task, we administered the Need for Cognition (NFC) scale, an 18-item questionnaire measuring the extent to which individuals engage with and enjoy cognitively demanding activities (Cacioppo et al., 1996), and the short version of UPPS-P Impulsive Behavior Scale (Cyders, Littlefield, Coffey, & Karyadi, 2014), a measure of five distinct aspects of impulsivity: Negative and Positive Urgency, Lack of Perseverance, Lack of Premeditation, and Sensation Seeking.

2.2. Board Fill/Clear task

The main task of the experiment is the Fill/Clear Board Game, inspired by Kool, McGuire, Rosen, and Botvinick (2010, Experiment 6). In this task, a round is completed by either 'filling' the 20 × 20 board such that all of the squares on the board become black, or 'clearing' the board such that all of the squares on the board become white (see Fig. 1). On each step, the efficacy of filling versus clearing is indicated graphically under the two options with a small grid depicting the number of squares that enacting the 'fill' and 'clear' actions would turn black or white, respectively. Thus, the current board state, alongside the depicted efficacy of each action permits a clear understanding of which action is superior, in terms of the strategy requiring the fewest steps to complete the board. Participants are given unlimited time to respond. To ensure that each choice required investment of cognitive effort, participants had to correctly complete 3 trials of a Numerical Stroop task (see below) in order to enact their choice and clear or fill the indicated number of squares.

Importantly, the efficacy of the fill and clear options, remained constant (10 squares per step) from the start of each round until, after a certain number of actions (pre-determined separately for each round of the game, ranging from 2 to 8 steps) whereby a 'Change Point' occurred which altered the relative efficacy of the actions (resulting in efficacy ranging from 3 to 180 squares per step). On roughly 50% of games, these Change Points necessitated a change in overall strategy (from filling to clearing or from clearing to filling) in order to minimize the number of steps required to complete the round, yielding games we termed *Switch-Optimal* in our analyses. To avoid fostering a general bias to change strategies, the remaining 50% of games required persevering with the pre-Change Point strategy in order to minimize steps to complete the game (*Persist-Optimal* games).

At each Change Point, we quantified the OC of persisting with the current strategy as the number of steps required to complete the round if the original strategy taken at the outset of the game is maintained (e.g. continue with the original 'fill' action) minus the number of steps required to complete the round if the participant were to change strategies (e.g. switch to 'clear'). Intuitively, a Change Point with a positive OC denotes that the alternative strategy requires few steps and a 'rational' participant should switch to the alternative strategy at the Change Point (a *Switch-Optimal* game described above). Conversely, OC is negative in *Persist-Optimal* games. We defined the amount of invested effort (EI) simply as the number of 'fill'/'clear' steps taken before the Change Point.

Following the questionnaires, participants were introduced to the "Fill/Clear" Board Game with several practice rounds. Participants were presented with various board scenarios and instructed explicitly about the strategy requiring less steps in each scenario, which aims at preparing them to discern the more efficient option both at the start of each game and at the Change Point of the game.

Participants subsequently practiced the Numerical Stroop, followed by an administration of the NASA Task Load Index (TLX, Hart and Staveland, 1988) questionnaire items to rate their subjective experience of effort with the Numerical Stroop tasks: for example, 'How hurried or rushed was the pace of the task?' (Temporal Demand). Following the Numerical Stroop training, participants completed as many rounds as they could for 15 min. Each round completed added a monetary bonus, creating a global sense of opportunity cost that compels a rational participant to choose the more efficient strategy whenever possible, maximizing the number of winnings.

2.3. Numerical Stroop task

As part of the Fill/Clear Board Game, participants performed consecutive trials of the Numerical Stroop (Jiang et al., 2016) after each fill/clear choice until 3 correct responses were made. In each trial of the Numerical Stroop, two numbers ranging from 2 to 9 were displayed in six sizes. When performing the 'value' subtask, participants had to ignore the physical sizes of the numbers and indicate whether the left- or right-side stimulus had a larger numerical value, whereas in the 'size' subtask, participants had to indicate which side of the display contained the larger-sized stimulus. One-third of trials were congruent insofar as the 'value' and 'size' subtasks require identical responses. Participants were told which subtask to play prior to each game round and were reminded of the to-be-performed subtask before each Numerical Stroop trial. Participants had a maximum of 2000ms to respond on each trial, after which, accuracy feedback was displayed. After three correct responses, the chosen fill or clear action in the main task was enacted, clearing or filling the indicated number of squares.

2.4. Data analysis

Our analysis of strategy perseveration focused primarily upon choices on Change Point trials with positive OC levels. Critically, we only analyzed Change Point choices on game rounds in which a participant made consistent strategy choices (e.g., all 'fill' or 'clear' actions) both before and after the Change Point, ensuring that participants were making Change Point choices on the basis of a coherent past strategy and that their post-Change Point behavior also reflected a coherent strategy (i.e. participants continued implementing the strategy chosen at the Change Point). We also excluded games with apparent inattentive behavior, with at least one fill/clear RT longer than 1 min and/or Numerical Stroop accuracy prior to the Change Point below 80%.

We examined Change Point choices using mixed–effects logistic regressions (Pinheiro & Bates, 2000) predicting strategy switches, categorizing the choice as a 'switch' if the post-Change Point action ('fill' or 'clear') was different from the pre-Change point strategy, as a function of OC and effort investment (EI). To account for potential practice effect as more game rounds were played, we also took the game round number as a predictor in this regression. Finally, between-subject individual difference variables were entered into the regression as z-scores. All of these predictor variables were taken as fixed effects, with random intercepts taken over participants. To analyze decision times, we estimated mixed-effects linear regressions taking log-transformed choice RTs at Change Points as the outcome variable with the same predictor variables.

3. Results

3.1. Overall choice behavior

Participants demonstrated a clear understanding of the goal of the game and the two possible strategies, as evidenced by their strategy choices in the initial step of each game (Fig. 2A): participants were more likely to choose filling over clearing with a larger proportion of filled squares (mixed-effects logistic regression, main effect of proportion filled: $\beta = 0.117$, $SE = 0.009$, $p < 0.0001$). On average, participants completed 9.03 ($SD = 3.53$) games. Examining overall choices made at Change Points, participants were more likely to change strategies in the games with a positive OC (such that abandoning the filling strategy in favor of clearing, or vice versa, becomes more time-efficient), compared to games with a negative OC (where persevering with the original strategy is advantageous; Fig. 2B) [main effect of OC: $\beta = 2.703, SE = 0.32, p < 0.0001$]. Across participants, we found that optimal Change Point choices—i.e., switch choices in *switch-optimal* games and stay choices in *persist-optimal* games—predicted a larger number of completed games ($r = 0.541$, $p < 0.0001$).

Thus, participants demonstrated a clear understanding that the benefit of a strategy in the face of a Change Point was based on the relative efficiency of persevering with versus switching strategies in terms of OC. Because the rational choice on *Persist-Optimal* (i.e., negative OC) games after the Change Points is persistence objectively, we reasoned that any pure influence of sunk costs (i.e., EI) upon Change Point choices would be most observable in the positive OC cases (which objectively favor strategy switching). Accordingly, the analyses that followed focused only on *Switch-Optimal* games with a positive OC (908 games).

We then examined, across all games with positive OC, whether past effort investment or EI—operationalized as the number of fill/clear steps completed prior to the change in strategy efficacy—exerted an overall effect on participants' propensity to continue with a strategy (Fig. 3A and B). However, we found no significant main effect of EI on strategy switch rates (Main effect of EI: $\beta = 0.156$, $SE = 0.210$, $p = 0.458$; Table 1). That is, overall, we did not observe a 'sunk cost' effect across participants, but we did, as expected, find that likelihood to switch strategies increased as the OC of persisting with the original strategy increases (Main effect of OC: $\beta = 1.184$, $SE = 0.248$, $p < 0.0001$). We also examined the extent to which sensitivity to OC in strategy switch/perseverance choices depended on the level of past effort investment. However, we found no significant interaction between OC and EI: ($\beta = -0.032$, $SE = 0.226$, $p = 0.889$), which suggests that participants' overall sensitivity to opportunity cost did not vary based on how much effort had been invested before the Change Point. Importantly, across all games, OC and EI were uncorrelated (Spearman's $\rho = 0.008$, $p = 0.723$).

3.2. Individual differences in strategy perseverance choices

While we did not observe susceptibility to past cognitive effort investment at the level of the entire sample—suggesting the possibility that either or both 1) a weak effect of sunk costs itself or 2) inter-subject heterogeneity rendered this effect undetectable—we then examined whether trait differences in Need for Cognition (NFC) and UPPS-P Lack of Premeditation might bear upon an individual decision-maker's sensitivity to past effort investment and/or Opportunity Costs in their decisions to switch strategies in the face of changes.

We observed that individuals higher in NFC, and lower in (lack of) premeditation both appeared overall more likely to switch strategies, and more sensitive to the opportunity cost of strategy perseverance (Fig. 4A and B). Statistically, we probed how each of these questionnaire-based measures—taken continuously—interacted with the OC of perseverating and past effort investment level in predicting strategy switch decisions. We found that higher NFC levels predicted greater

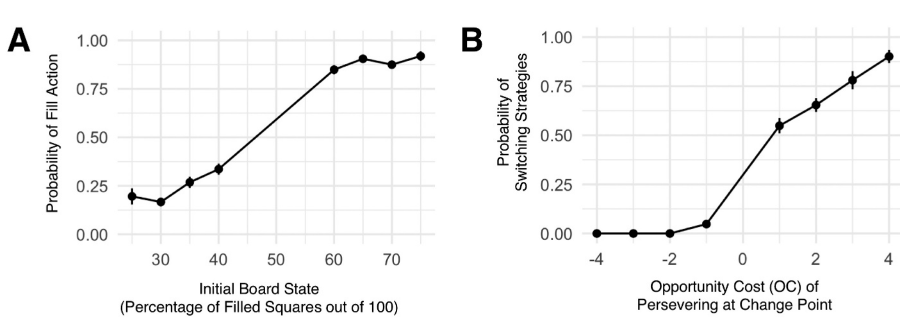

Fig. 2. Manipulation check for all games before exclusion. (A) Probability of Fill Action as function of the percentage of black squares in the board at game onset (Initial Board State). Participants were more likely to choose fill over clear as the percentage of black squares increase in the board. (B) Probability of switching to the alternative strategy after the Change Point as a function of the level of OC. Overall participants were more likely to switch in games with a positive OC compared to games with a negative OC.

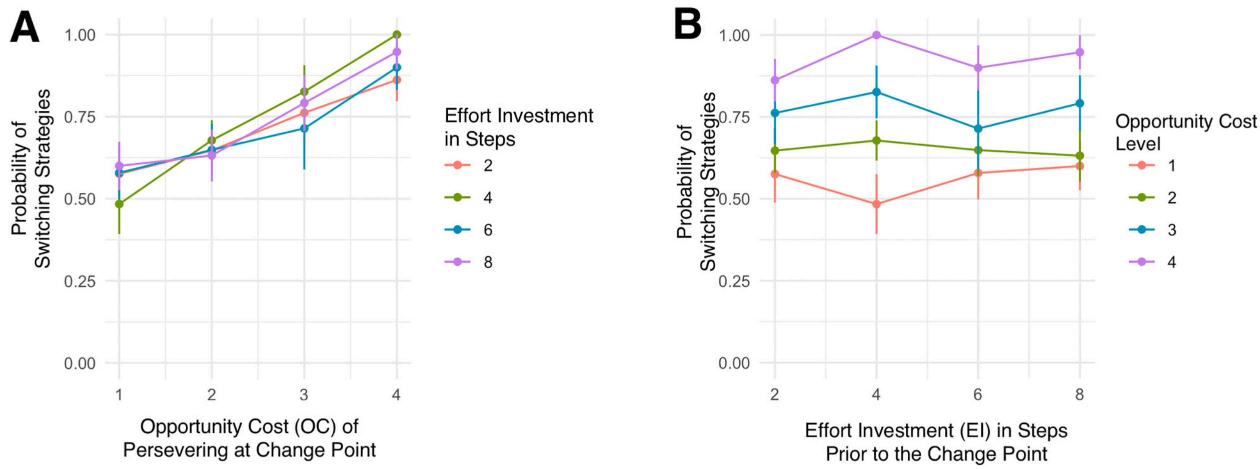

Fig. 3. The influence of Opportunity Cost and previous investment (number of previous steps invested in the current strategy at the Change Point) upon strategy choice. (A) Probability of Switching to the alternative strategy after the Change Point as a function of OC at varying levels of previous investment: the effect of Opportunity Cost on switching does not depend on the level of effort investment. (B) Probability of Switching as a function of past effort investment at varying levels of Opportunity Cost.

Table 1
Estimate, standard error and p-value for the mixed effects logistic regression model with main effects of Effort Investment and Opportunity Cost in *Switch-Optimal* games.

Coefficient	Estimate (SE)	p-Value
(Intercept)	1.722 (0.4716)	0.000261***
numGame	0.418 (0.2065)	0.042772*
Opportunity Cost	1.184 (0.2485)	< 0.0001***
Effort Investment	0.156 (0.2104)	0.458499
Opportunity Cost: Effort Investment	−0.032 (0.2261)	0.888644

'**' $p < 0.01$; '.' $p < 0.1$
* $p < 0.05$.
*** $p < 0.001$.

sensitivity to OC (OC × NFC interaction: $\beta = 0.574$, $SE = 0.243$, $p = 0.018$; Table 2), while a higher level of Lack of Premeditation score predicted less sensitivity to OC (OC × UPPS-P Lack of Premeditation interaction: $\beta = -0.572$, $SE = 0.234$, $p = 0.015$; Table 3). Neither of these trait variables significantly interacted with EI ($ps > 0.1$).

We also examined whether the subjective effort ratings of the Numerical Stroop task—measured by the TLX, before the main task—interacted with OC or EI. Because participants were required to accurately complete three Numerical Stroop trials for each fill/clear action prior to the Change Point, we reasoned that participants who found the Numerical Stroop more demanding should have heightened estimates of previous effort investment (i.e., Sunk Costs) and accordingly, might make strategy choices that are more sensitive to EI.

We found that Temporal Demand exerted a negative interaction with EI (TLX Temporal Demand × EI: $\beta = -0.461$, $SE = 0.218$, $p = 0.035$; Fig. 4C; Table 4). In other words, participants who found the task required to execute strategy steps more demanding appeared more susceptible to sunk cost effects in strategy decisions at Change Points, insofar as persisting more with an ineffective strategy as past effort investment increased. We did not observe that any of the other individual differences in subjectively-reported effort significantly interacted with sunk costs ($ps > 0.366$) or OC ($ps > 0.203$).

3.3. Choice response times (RTs) at Change Points

Finally, we examined RTs at Change Points in the same *Switch-Optimal* games analyzed above. Perhaps unsurprisingly, strategy switch choices took longer than repetition of choice strategies (Choice Type: $\beta = 0.541$, $SE = 0.083$, $p < 0.001$), mirroring past findings examining strategy switches in a similar task setting (Kool et al., 2010). While we did not observe overall behavioral investment effects on participants' choices, as described above, we reasoned that past effort investment might influence choice RTs in decisions to persist on *Switch-Optimal* games, where sunk costs are presumed to play a role.

Considering only choices where participants persisted with the pre-Change Point strategy, we observed that an increasing level of past effort investment engendered faster RTs (Fig. 5). Statistically, a mixed-effects linear regression revealed a significant main effect of EI taken upon RTs ($\beta = -0.245$, $SE = 0.072$, $p = 0.001$; Table 5), suggesting that perhaps choices made on the basis of sunk costs become less difficult as previous investment increases. Interestingly, these RTs did not vary significantly with the OC (main effect: $\beta = -0.104$, $SE = 0.0896$, $p = 0.245$), suggesting that RTs for strategy perseverance decisions were driven solely by previous effort investment. Finally, we tested whether the individual differences variables predict sensitivity to opportunity costs and sunk costs in choice influenced RTs on these choices, but found no significant interaction between NFC, UPPS-P Lack of Perseverance, or TLX Temporal Demand and OC ($ps > 0.1$) or EI ($ps > 0.1$), nor main effects of these trait variables ($ps > 0.1$).

4. Discussion

In this study, we examined the effect of past cognitive effort investment (i.e., behavioral sunk costs) upon decisions to persist with versus abandon ineffective strategies in a novel decision-making task. Importantly, the effective Opportunity Cost of persisting (OC) with a suboptimal strategy (in terms of lost potential rewards) also varied from round to round of the task, affording examination of the influence of sunk costs upon strategy persistence across a range of levels of OC. Overall, we found that when strategies participants employed were no longer ideal (favoring a change of strategy) participants responded appropriately, as they became more likely to switch strategies as the OC increased.

While we did not find that participants' decisions, overall, to persist with a suboptimal strategy increased with greater past investment of cognitive effort, we did observe that trait differences in both NFC and Lack of Premeditation predicted sensitivity to opportunity costs in the task: individuals with higher levels of NFC and lower levels of (Lack of) Premeditation appeared more sensitive to the OC. In other words, individuals with greater intrinsic motivation for cognitively demanding activities such as problem-solving (Cacioppo et al., 1996) and a greater tendency to engage in careful consideration of the consequences of

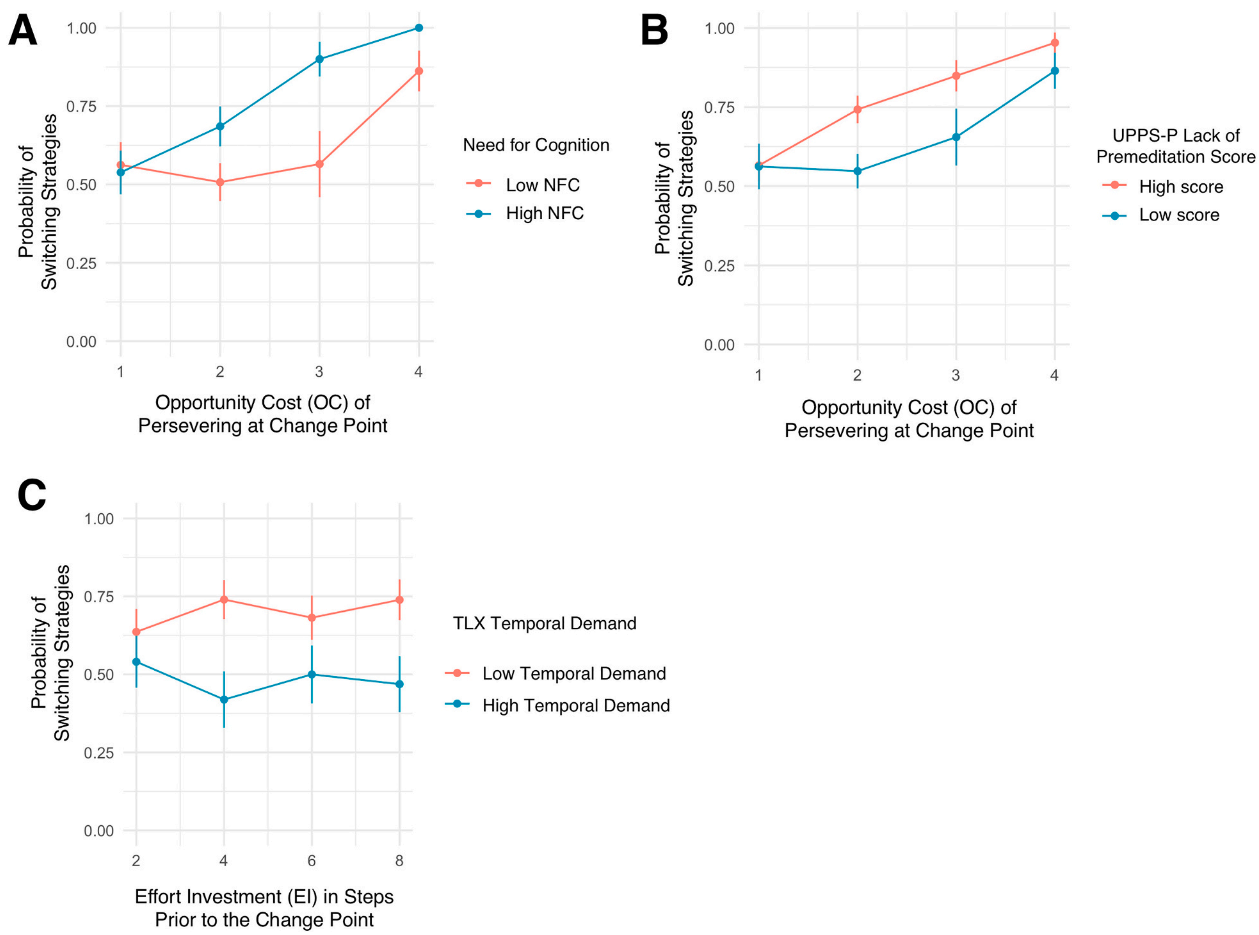

Fig. 4. (A) Probability of switching strategy after the Change Point as a function of OC for individuals low and high on NFC (tertile split). Individuals higher on NFC seem to be more sensitive to the increasing OC, and their possibility of switching increases more with a given increase in OC compared to their counterparts lower in NFC. (B) Probability of Switching as a function of OC for individuals high and low on Lack of Premeditation of the UPPS-P (tertile split). Lack of Premeditation seems to have an opposite effect from NFC in terms of sensitivity to OC. (C) Probability of Switching as a function of effort investment for individuals that reported high or low Temporal Demand of the NTLX for the effort task. Individuals who found the effort task demanding were more sensitive to the EI.

Table 2
Estimate, standard error and *p*-value for the model with interactions between NFC and Effort Investment, NFC and Opportunity Cost in *Switch-Optimal* games.

Coefficient	Estimate (*SE*)	*p*-Value
(Intercept)	1.821 (0.4863)	0.00018***
numGame	0.463 (0.2131)	0.02966*
Opportunity Cost	1.284 (0.2718)	< 0.0001***
Effort Investment	0.173 (0.2082)	0.40570
NFC	0.548 (0.4450)	0.21848
Opportunity Cost: NFC	0.574 (0.2432)	0.01835*
Effort Investment: NFC	0.301 (0.2189)	0.16868

‘**’ $p < 0.01$; ‘.’ $p < 0.1$.
* $p < 0.05$.
*** $p < 0.001$.

actions (Berg, Latzman, Bliwise, & Lilienfeld, 2015) appeared more inclined to change courses of action when faced with changes that rendered the current strategy ineffectual.

At the same time, we found that individuals who rated the Numerical Stroop task—for which repeated successful performance was required in order to enact out strategy choices— as subjectively more effortful appeared to make choices which were more influenced by past behavioral investments (i.e. sunk cost effects). Interestingly, we did not find that other self-reported TLX-based measures of cognitive effort predicted the influence on past strategy investment upon choice, except for Temporal Demand. Indeed, the temporal cost of effortful cognitive activity looms particularly large in the subjective perception of effort (Kurzban, Duckworth, Kable, & Myers, 2013), and dovetailing with our observation, recent work finds that *objective* time previously invested in a course of action yield sunk cost effects in a foraging task (Sweis et al., 2018).

The lack of an overall effect of previous strategy investment (i.e. sunk costs) in the general sample suggests that cognitive effort sunk cost effects might be generally weak, corroborating previous observations (Friedman, Pommerenke, Lukose, Milam, & Huberman, 2007; Otto, 2010). A possible reason for the lack of robust overall sunk cost effects observed here and previously is the provision of information concerning future returns expected by persisting with, versus abandoning the current course of action, which has been demonstrated to attenuate sunk effects in hypothetical situations (Tan & Yates, 1995). In the present study, the efficacy of candidate strategies is known at Change Points, potentially highlighting the opportunity cost of strategy persistence and mitigating effects of sunk effort costs.

Relatedly, the differential sensitivity to opportunity costs observed between high- and low-NFC participants could potentially explain previous results showing increased sunk-cost sensitivity (in hypothetical situations) among low-NFC decision-makers (Carnevale et al., 2011), if low-NFC individuals do not fully take into account the opportunity costs of persistence with the ineffective action in the hypothetical decision scenarios examined there. Along the same lines, in a previous study examining information-gathering behavior in a cognitive task, low-NFC individuals expended less effort into gathering

Table 3
Estimate, standard error and *p*-value for the model with interactions between Lack of Premeditation and Effort Investment, Lack of Premeditation and Opportunity Cost in *Switch-Optimal* games.

Coefficient	Estimate (*SE*)	*p*-Value
(Intercept)	1.930 (0.4922)	< 0.0001***
numGame	0.471 (0.2132)	0.0271*
Opportunity Cost	1.368 (0.2813)	< 0.0001***
Effort Investment	0.170 (0.2073)	0.4113
UPPSP_NO_Premedi	−0.980 (0.4473)	0.0285*
Opportunity Cost: UPPSP_NO_Premedi	−0.572 (0.2342)	0.0146*
Effort Investment: UPPSP_NO_Premedi	−0.097 (0.2107)	0.6459

'**' $p < 0.01$; '.' $p < 0.1$.
* $p < 0.05$.
*** $p < 0.001$.

Table 4
Estimate, standard error and *p*-value for the model with interactions between Temporal Demand and Effort Investment, Temporal Demand and Opportunity Cost in *Switch-Optimal* games.

Coefficient	Estimate (*SE*)	*p*-Value
(Intercept)	1.810 (0.4982)	0.00028***
numGame	0.383 (0.2139)	0.07376
Opportunity Cost	1.231 (0.2632)	< 0.0001***
Effort Investment	0.170 (0.2115)	0.42079
TLXtemp	−0.684 (0.4431)	0.12259
Opportunity Cost: TLXtemp	−0.506 (0.2593)	0.05103
Effort Investment: TLXtemp	−0.461 (0.2184)	0.03493*

'**' $p < 0.01$; '.' $p < 0.1$.
* $p < 0.05$.
*** $p < 0.001$.

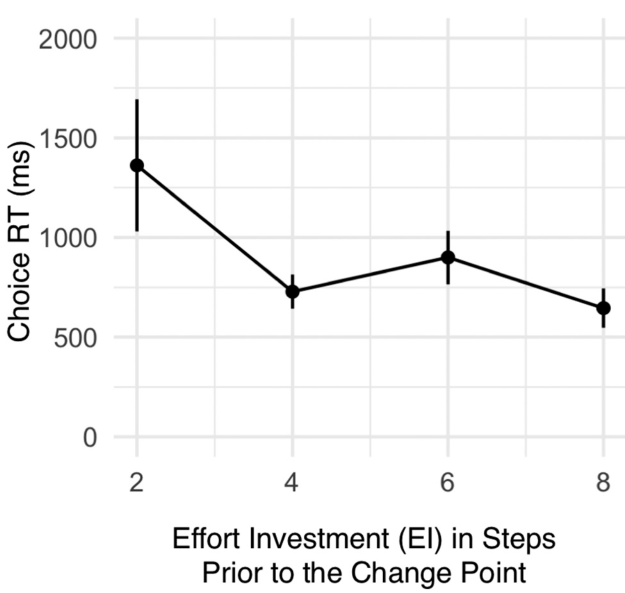

Fig. 5. RT for persist choices as a function of EI in the *Switch-Optimal* games: in the games where people persisted despite of the alternative strategy being more time-efficient, their decision to persist seems to take less time as their effort investment increases. These RTs are plotted collapsing over OC levels; note that we observed no significant effect of OC.

information presumably used to guide decisions (Verplanken, Hazenberg, & Palenéwen, 1992).

Finally, we observed that RTs for strategy repetition choices—in *Switch-Optimal* rounds that objectively favored a change of strategy—-were faster as participants' level of past strategy investment increased. As our present analysis only concerned suboptimal choices presumably

Table 5
Estimate, standard error and *p*-value for the linear mixed model of log-transformed decision times (RTs) at Change Point in 'switch-optimal-but-persisted' games.

Coefficient	Estimate (*SE*)	*p*-Value
(Intercept)	6.360 (0.1006)	< 0.0001***
numGame	−0.223 (0.0844)	0.008291**
Effort Investment	−0.235 (0.0716)	0.001031**
Opportunity Cost	−0.104 (0.0896)	0.244498

'*' $p < 0.05$; '.' $p < 0.1$.
** $p < 0.01$.
*** $p < 0.001$.

made on the basis of past effort investment, this pattern of choice might suggest that strategy decisions made on the basis of sunk costs become less difficult with larger effort investments. With the assumption that intuitive choices are faster than deliberative choices (Evans, 2008; Otto, Gershman, Markman, & Daw, 2013), the pattern of RTs here could be interpreted as reflecting an increasing reliance upon intuitive—and possibly irrational—decision-making. It is worth noting that this sunk cost-based speeding effect occurred irrespective of the opportunity cost of persisting with the suboptimal strategy, suggesting that the apparent ease of these suboptimal, sunk-cost based strategy decisions was driven primarily by the level of previous effort investment.

CRediT authorship contribution statement

Xu Yan: Conceptualization, Methodology, Software, Investigation, Formal analysis, Writing - original draft. **A. Ross Otto:** Conceptualization, Methodology, Formal analysis, Writing - review & editing, Supervision, Funding acquisition.

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