Why Do People Increase Effort Near a Deadline? An Opportunity-Cost Model of Goal Gradients

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Abstract

People tend to gradually reduce effort when performing lengthy tasks, experiencing physical or mental fatigue. Yet, they often increase their effort near deadlines. How can both phenomena co-occur? If fatigue causes the level of effort to decline, why does effort rise again near a deadline? The present paper proposes a model to explain this pattern of behavior and tests three predictions that follow from it. Four lab experiments (two preregistered, N_{total}=311) show that effort, indexed by the rate of keypresses in a computer game, increases more steeply (1) toward a deadline than toward a performance criterion, (2) when a concurrent task is present (vs. absent), and (3) with more (vs. less) effective actions. We suggest that changes in opportunity-cost, which is the cost of missing out on alternatives when engaging in a focal action, can explain these effects. Specifically, we suggest that as the deadline approaches, (1) the value of performing competing, alternative activities decreases because they can be postponed past the deadline with lower cost and (2) engaging in competing alternatives become increasingly more costly, because compensating for the lost time becomes more difficult. Both processes contribute to diminishing the net value of alternative activities and thus reduce the opportunity cost associated with engaging in the focal activity. We discuss the practical implications of this model for diverse fields such as economic behavior, sports, and education.

Keywords: motivation, effort, goal-gradient, end spurt, opportunity cost.

People find it hard to exert intense effort over long periods of time (Bennie et al., 2018; Lu et al., 2021), tending to gradually decrease effort, experiencing either psychological (Baumeister et al., 1998; Inzlicht et al., 2014; Kool & Botvinick, 2014; Kurzban et al., 2013; Shenhav et al., 2017) or physiological (Gandevia, 2001; Sahlin, 1992) fatigue. And yet, occasionally effort increases over time, as one gets close to goal completion (Bonezzi et al., 2011; Cryder et al., 2013; Forster et al., n.d.; Heath et al., 1999; Heilizer, 1977; Hull, 1932; Katzir et al., 2020; Kivetz et al., 2006; Koo & Fishbach, 2012; Losco & Epstein, 1977; Miller & Murray, 1952). For example, swimmers accelerate as they get closer to the end of an event (McGibbon et al., 2018), and experimental participants work harder (e.g., take shorter breaks) as they approach the end of the experiment (Katzir et al., 2020). The tendency to increase effort (i.e., mobilize more resources to carry out instrumental behavior; Sander & Scherer, 2009) closer to goal completion has been termed *goal-gradient* (Hull, 1932). Goal-gradients are often preceded by an initial decline in effort, giving rise to a U-shaped pattern of effort allocation, referred to as the stuck-in-the-middle (STIM) effect. The STIM effect was documented in a variety of domains, including sports (Garland, 2005; Martin et al., 2019; Muehlbauer et al., 2010; Tucker et al., 2006), manual work (Halperin et al., 2014) and cognitive performance (Bonezzi et al., 2011). For example, 1600-m race athletes would typically start at a high velocity, slow down during the second and third lap, and then accelerate in the final lap (Tucker et al., 2006). As another example, students tend to study harder at the beginning and end of the academic year than in its middle (Brahm et al., 2017).

A possible explanation for the goal-gradient and STIM effects is that effort level is determined by comparing the cost of investing effort (e.g., how unpleasant it is) against its benefit (e.g., how rewarding it is; Botvinick & Braver, 2015; Körding et al., 2004; Kurniawan et al., 2013; Kurzban et al., 2013; Mobbs et al., 2018; Morel et al., 2017; Pessiglione et al., 2018; Rangel et al., 2008; Shenhav et al., 2017). For example, according to the expected value of control model (Shenhav et al., 2013, 2017), people strive to increase their actions' reward per unit of time, while weighing it against the actions' inherent costs from investing cognitive resources. The higher the "net value" of investing effort, the more effort would be invested. To account for the STIM effect within that model, one needs to assume high net value of effort close to the starting and ending points of a task. Consistent with this notion, researchers have theorized that closer to a reference point, each unit of effort (e.g., a specific action) is perceived as more impactful and hence more valuable. For example, when 10 steps remain to finish a task, the next step would reduce 10% of the discrepancy from the current position to the task's end, whereas when two steps remain to the end, the next step would reduce 50% of the discrepancy. As a result, when the end is used as a reference for monitoring progress, effort would seem more impactful and thereby also more valuable as one progresses toward task-completion (Cryder et al., 2013; Emanuel, 2019; Forster et al., 1997; Heath et al., 1999; Koo & Fishbach, 2012; Wallace & Etkin, 2017). Similarly, if the starting point is used as a reference for monitoring progress, then the second step increases distance from the starting point by 50% and is therefore more impactful and more valuable than the 21st step, which increases this distance by only 5% (Bonezzi et al., 2011; Fishbach et al., 2009, 2011; Koo & Fishbach, 2012). Moreover, people tend to initially use the starting point as a reference, but switch to using the end point as they approach it (Bonezzi et al., 2011; Koo & Fishbach, 2012). This tendency gives rise to the STIM effect, whereby action value, and therefore level of effort, peak in the beginning and toward the end of a task.

Deadline-Bound Tasks

Oftentimes, people perform a task toward a deadline (e.g., “read as many pages as possible in 10 minutes”) rather than toward a performance criterion (e.g., “read 10 pages”). Effort tends to intensify close to deadlines, giving rise to a goal-gradient or STIM patterns (Howell et al., 2006; Touré-Tillery & Fishbach, 2012, 2015). Extant theories, however, do not explain goal-gradients in deadline-bound tasks. This is because the impact of one’s actions on task progress, and consequently the value of these actions, do not necessarily increase closer to a deadline. For example, completing the 28th minute of a 30-minutes exercise indeed closes a larger time gap to the end (33%) compared to the 21st minute (10%). Yet, it is not one’s actions that cause time to pass, and therefore the action (e.g., another pushup) should not be perceived as particularly efficient and valuable. Why, then, does effort increase as the deadline approaches? What determines the steepness of these goal-gradients? We attempt to answer those questions within a novel, opportunity-cost model of STIM.

We suggest that the STIM pattern with deadlines can be understood if we consider how opportunity cost changes in the course of a task (Kurzban et al., 2013; Seli et al., 2016). In what follows, we first explain what opportunity cost is, and how it changes in the course of deadline-bound as well as target-bound tasks. We then derive from this model the prediction that the STIM pattern would not only emerge with deadlines but that its second part, namely the goal-gradient, might actually be steeper with deadlines than with performance criteria. The model we propose also predicts that the goal-gradient would be steeper when a concurrent, competing task is introduced on top of the focal, deadline-bound task, as well as when the action one performs toward the focal, deadline-bound task is relatively more efficient. Our experiments test these predictions. We proceed here with a verbal description of the model, and offer a more formal description in Appendix A. Of note, Touré-Tillery and Fishbach (2012, 2015) also suggested a model in which effort increases closer to deadlines due to the diagnosticity of actions near salient end points. We suggest an opportunity cost model that is consistent with this account, yet may extend to additional contexts (see General Discussion).

Opportunity Cost

Opportunity cost of performing a focal task, A, refers to the cost of foregoing action toward an alternative task, B, when engaging in task A (Kurzban et al., 2013; Le Heron et al., 2020). In this view, the value of acting toward a focal task is compared to the value of the next best alternative. The more valuable is the next-best alternative relative to the focal action (the more valuable is doing B instead of A), the higher the opportunity cost of the focal action, A. For example, the opportunity cost of writing a grant proposal is higher to the extent that the next best alternative (e.g., checking email) is more attractive. Of note, alternatives to the focal task might include not only major tasks such as shopping, partying, and watching a series but also minor activities such as adjusting one’s chair, scratching one’s head, and even mind-wandering and idling (Kurzban et al., 2013).

How does opportunity cost change over time? Prominent models of opportunity cost maintained, based on the principle of diminishing marginal utility (Charnov, 1976; Gossen, 1854; Mobbs et al., 2013, 2018), that in the course of performing a task the value of further acting on it tends to decline (Charnov, 1976). For example, resources get depleted with continuous foraging, making any existing alternatives relatively more attractive, and causing one to invest less effort in continued foraging. Importantly, this logic also applies beyond the context of foraging (Kurzban et al., 2013). For example, a few hours into writing a grant proposal, the added value from continued writing decreases, and the relative value of checking email increases, and we can expect the writer to invest more effort in checking their mail, and less in writing. Importantly, in these models (see especially Kurzban et al., 2013), the effort a person invests in a focal task at any point in time is proportional to the difference (at that point in time) between the value of the focal task and the value of alternatives (and thus the effort invested in the focal task is inversely related to opportunity cost, which is typically defined as the value of the alternative minus the value of the focal option). We adopt this general approach[1].

Opportunity Cost Closer to a Deadline

We would like to propose two additional (non-mutually exclusive) processes that might underlie the temporal dynamics of opportunity cost. Both processes operate on the value of alternatives. The first process is that closer to the end of the focal task,

[1]Kurzban and colleagues (2013) also considered a ratio model, in which the effort invested in the focal task is defined as the ratio between its value and the combined value of the focal task and the alternatives. We adopt a difference model because it is consistent with other conceptualizations of net value of action as action benefit minus action cost (e.g., Shenhav et al., 2017).

alternative tasks can be postponed past the end of the focal task with lower cost, simply because it would entail a shorter delay. In other words, before the focal task is over, as its end approaches, alternatives gradually come to pose lower opportunity cost because the cost of postponing them diminishes and hence the benefit of engaging in them diminishes as well. As a result, opportunity cost of engaging in a focal task diminishes closer to its end. The cost of postponing alternatives is obviously proportional to the value of the alternatives. For example, the cost of postponing shopping until after the exam depends on the value of shopping and not only on how soon the exam is. It is less costly to postpone shopping when shopping is less attractive and when you postpone it for shorter time (see Section 2 and Equation 4 in the appendix). Although this process might be particularly prominent with deadline-bound tasks, in which the actor tends to be aware of the time left for the task, it can also apply to target-bound tasks. The second process, in contrast, is unique to deadline-bound tasks.

The second process is that closer to a deadline, the cost of engaging in alternatives increases, because it becomes harder to compensate for neglecting the focal task. For example, the cost of shopping instead of writing a grant depends on how near the deadline is. A week before the grant's deadline, shopping instead of writing the grant might be compensated for by working harder on the grant the next day, but one day before the deadline, such compensation is practically impossible, so the cost of shopping becomes very high. Reflecting this logic, we postulate a steep increase in the cost of engaging in alternatives near a deadline. As noted above, this process applies to deadline-bound tasks but not to target-bound tasks. For example, when one's goal is to finish reading five pages with no particular time-limit, then going shopping after four pages is no more difficult to compensate for than after one page. Note also that the cost of engaging in alternative activities depends on the value of the focal task and not only on how close its deadline is. For example, the cost of shopping instead of writing a grant is proportional to the importance of the grant (see Section 3 and Equation 5 in the appendix).

In sum, extending opportunity cost models to the special case of tasks with deadlines, we propose that in addition to the initial decrease in effort, as the deadline approaches opportunity cost of allocating effort to the focal task diminishes because (a) the cost of postponing alternatives past the deadline diminishes (i.e.,, the benefit of engaging in alternatives diminishes), and (b) the cost of allocating effort to alternatives increases (i.e., the cost of engaging in alternatives increases). These propositions lead to the prediction that when working on a task that has a deadline, effort would first decrease and then increase, giving rise to a STIM pattern (see Figure A1 in the appendix). In addition, our model makes specific predictions regarding the goal-gradient component of the predicted STIM pattern. Specifically, we predict a steeper goal-gradient (1) when people work toward a deadline compared to when they work toward a performance criterion; (2) when there is an alternative task that can be performed concurrently with the focal task but can also be postponed past the focal tasks' deadline (Figure 3A in the appendix); (3) with a higher value of the focal action (Figure 4A in the appendix). We explain below how these predictions follow from our model.

A Steeper Goal-gradient with a Deadline than with a Performance Criterion

Above, we hypothesized that actors would increase effort near a deadline due to two processes: First, the benefit of engaging in alternatives decreases because the cost of postponing them past the deadline decreases; second, the cost of engaging in alternatives increases because opportunities to compensate for not acting on the focal task become scarcer. We also noted that whereas the first process applies to both deadline-bound and target-bound tasks, the second process applies only to deadline-bound tasks.

We also described a process that might create a goal gradient only in target-bound tasks. Specifically, if actors use the target as a reference and perceive an action's effectiveness in terms of how much a unit of effort reduces the remaining discrepancy to that reference, then they might perceive their actions to be more effective closer to the target and increase effort accordingly. It is important to note, however, that there are other ways to perceive action effectiveness that would not cause one to increase effort closer to reaching a target – for example, if one evaluates action effectiveness in terms of the portion of the total required quantity each action adds, or in terms of how much it adds to what has been accomplished already. Indeed, Bonezzi and colleagues (2011) have shown that effort did not increase closer to the end of the task when people did not use the end as a reference point.

This analysis suggests that a target is one optional reference for evaluating performance and would contribute to a goal-gradient only to the extent that this option is realized. In contrast, a deadline imposes an objective constraint on the ability to compensate for the time lost when one engages in alternatives and is therefore a more potent cause for goal-gradient than a target. Accordingly, we predict a STIM pattern with a steeper goal-gradient when people work toward a deadline than toward a target. This prediction is explicated in Section 5.1 and Figures A1 and A2 in the appendix.

A Steeper Goal-gradient in the Presence of a Concurrent Task

Adding an alternative activity to a focal deadline-bound task would obviously increase opportunity cost of performing the focal task and reduce the level of effort allocated to it. For example, all else being equal, a person who is renovating a house would invest less in writing a grant than a person who is not engaged in such a concurrent project. As explained earlier, however, if the additional task can be pursued after the deadline (e.g., if renovations could resume after the grant's deadline), then as one gets closer to the grant submission deadline, the opportunity cost imposed by the alternative is lifted, and effort allocated to the focal task would increase. Consistent with this notion, Seli et al. (2018) found that mind wandering, an ever-present alternative to almost any task, decreased as the deadline of the experimental task approached. We predict that introducing a concurrent task would not only decrease effort allocated to the focal task but would also make the goal-gradient steeper (i.e., produce a steeper increase in effort toward the deadline). This prediction is explicated in Section 5.2 and in Figure A3 in the appendix.

A Steeper Goal-gradient when Action is more Efficient

As explained earlier, near a deadline (but not near a target) the cost of engaging in alternatives increases because opportunities to compensate for not acting on the focal task become scarcer. We also maintained that the cost associated with engaging in alternatives is proportional to the value of the focal task. For example, the cost associated with drinking coffee with friends instead of writing a grant proposal is proportional to the value of writing the grant. It follows that the increase near a deadline in the cost of alternatives would also be proportional to the value of the focal task. We therefore predict a STIM pattern with a steeper goal-gradient when one's actions carry more value, for example, because they are more effective. This prediction is explicated in Figure 5.3 and Figure A4 in the appendix.

The Present Research

We used a task that has been found to reliably elicit the STIM effect (Emanuel et al., 2021), namely, a computer game in which participants control a spaceship and shoot asteroids by pressing the spacebar, and the frequency of pressing the spacebar serves as a measure of effort. Experiment 1 examined whether a STIM pattern with a steeper goal-gradient would emerge when playing under a deadline than when playing for a target score. Experiment 2 examined whether adding a concurrent task that can be continued after the deadline will give rise to a STIM pattern with a steeper goal-gradient. Experiments 3 and 4 examined whether a STIM pattern with a steeper goal-gradient would emerge when action value is higher, that is, with more efficient actions.

Experiment 1

This experiment employed a within-participant, counterbalanced design in which we compared a task performed toward a target-score, with a task performed toward a deadline, operationalized as a time limit for gaining points. We predicted a STIM pattern with a steeper goal-gradient in the former, deadline-bound task.

Method

Participants

In all experiments we determined sample size as the maximum number of participants we could recruit until the end of the semester (Experiment 1), until we used up available course credits (Experiment 2), or monetary resources (Experiments 3 and 4). In the present experiment, two participants met the exclusion criteria, which we describe in detail in the Results section and which we used also in Experiments 2-4 (and preregistered in Experiments 2 and 4). This left us with 58 paid participants (33 women, 25 men; M_{age} = 26.31, *SD* = 5.50).

Materials and Procedure

All materials and procedures for all experiments were approved by the Tel-Aviv University institutional review board. Participants were told that they take part in a motor learning study and seated in front of a 21.5" computer screen. We introduced them to the game instructions (fully available in the supplemental online materials (SOM) at https://cutt.ly/WvT9NtT; Emanuel et al., 2021). We told them that they can control the spaceship with the arrow keys, and fire projectiles by pressing the spacebar. If they hit an asteroid with a projectile, they earn 10 points. They can fire an unlimited number of projectiles. Each participant performed two conditions: timer and target-score, in counterbalanced order. In the timer condition, we explained that “Your task is to gain as many points as you can. The session will end when the countdown timer at the top of the screen reaches zero.” In the target-score condition the last sentence was replaced with “The session will end when the counter on the top of the screen reaches the target number of points.”

There was a maximum of 13 asteroids on the screen. After an accurate shot, the asteroid that was hit disappeared, and another one appeared in a random place on the screen after 500 milliseconds. Although this type of games was probably familiar to many of our participants, the specific setup (the keys, how sensitive they are, the velocities, the number of asteroids, the length of the sessions, the scoring schema) was new, and required some practice to master. Figure 1 presents a sample screen from the game. The exact time of each spacebar press was recorded, and the number of spacebar presses served as the dependent variable. Overall scores for each condition were also recorded.

For participants that performed the target-score condition first, we set a target score of 7000 points, and recorded the time it took them to reach that score. We then used this time as a deadline in their second, timer condition. For participants that performed the timer condition first, we set a deadline of 15 minutes. The score they achieved in the timer condition served as their target score in the second block. In both conditions, we told participants that for each block, the upper third of performers (the fastest third in the target-score condition, the highest-scoring third in the timer condition) would get a bonus of five NIS (approximately $1.5). Performance was estimated relative to a pre-existing baseline, and the bonus was paid to participants at the end of the session. Before starting the experiment, participants completed a five-minute practice session in which no bonuses were awarded. Additional details about the instructions, and experimenters' training, are available in the SOM at https://cutt.ly/WvT9NtT.

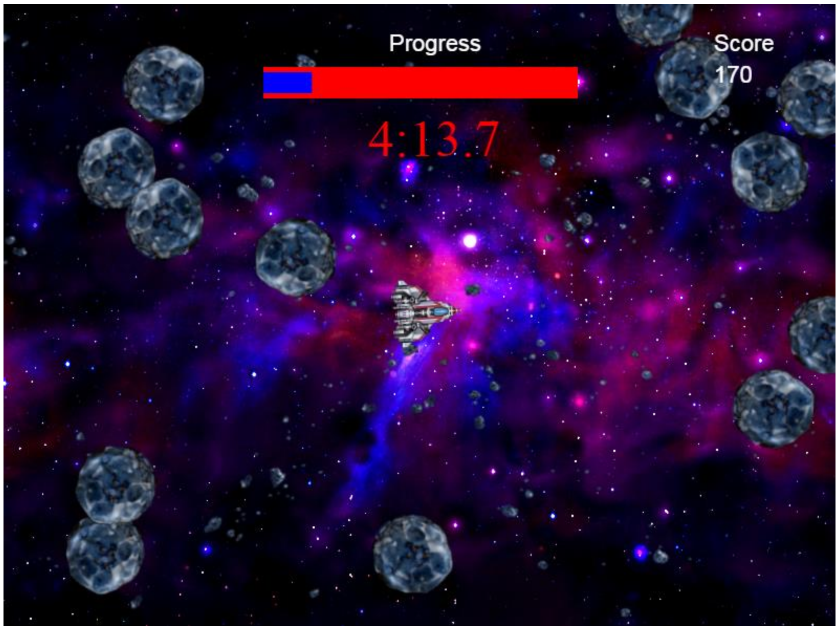

Figure 1. A sample screen from the timer condition in Experiment 1. The red line represents the block's overall time, and the blue line represents time since the beginning of the block. The timer (red numbers) counts the time left for the block in the timer condition, or the progress toward a target score, in the target-score condition.

Results

We used R (version 4.0.2; R Core Team, Vienna, Austria and the ggplot2, cowplot, lme4, lmeTest, dplyr, and tidyr packages (Bates et al., 2015, p. 4; Claus, 2020; Kuznetsova et al., 2017; Wickham, 2016, 2020; Wickham et al., 2020) in all subsequent analyses and figure making. Syntax and datasets for all analyses are available at https://cutt.ly/WvT9NtT.

Validation of Spacebar Presses as a Measure of Effort

Because participants' explicit goal was to achieve the highest possible score, we first sought to establish that spacebar presses correlated substantially with that score. Number of spacebar presses correlated highly with the overall score in the timer condition of the present experiment, $r(56) = .67$, $p < .001$, as well as in all subsequent experiments: In the aliens and no-aliens condition in Experiment 2, $r(55) = .89$, $p < .001$; $r(55) = .85$, $p < .001$, respectively; the half-score and double-score conditions in Experiment 3, $r(95) = .74$, $p < .001$; $r(95) = .85$, $p < .001$, respectively; and the short-range and long-range conditions in Experiment 4, $r(96) = .71$, $p < .001$; $r(96) = .93$, $p < .001$, respectively. Although these correlations are high, they also show that pressing the spacebar and scoring points are somewhat distinct. Because pressing the spacebar reflects attempting to score rather than actual scoring, it reflects effort better than the score, which obviously also depends on skill.

Stuck-in-the-Middle and Goal-gradient

We used the same analyses in all experiments (Emanuel et al., 2021). For each participant, we divided each block (i.e., in Experiment 1, the timer and target-score blocks) into seven equal time-segments and standardized the number of spacebar presses in each segment: We subtracted the number of spacebar presses in each time-segment from each participant's block mean, and divided the result by their standard deviation of that block. This resulted in a z-score for each segment within each block, for each participant. The following exclusion criterion served us in this and all subsequent experiments (preregistered for Experiments 2 and 4): For each participant and each block, we calculated the standard deviation of spacebar presses between the segments. We excluded participants that showed exceptionally high standard deviations (three standard-deviations above the mean standard deviation for that condition). An analysis in which we exclude participants based on the aggregation of both blocks yielded similar results, and is reported in the SOM.

To detect a STIM effect (a U-shape pattern of effort over time) the vertex should be determined, along with two linear trends: A decreasing trend from the starting point to the vertex, and an increasing trend from the vertex to the end, the latter reflecting a goal-gradient (Simonsohn, 2018). To avoid overfitting, we opted to use the same vertex for all four experiments, and determined it at the middle point, Segment 4, as was also preregistered (Experiment 2). In the SOM we also report the main analyses with the vertex at Time Segment 3, which has been used in previous work (Emanuel et al., 2021) and is consistent with an empirical estimation of the vertex in some of our experiments. The SOM also reports the analyses in which the vertex was fitted separately for each condition. These analyses yield findings similar to what we report here. We tested for a U-shape pattern (within participants) by fitting an interrupted mixed regression model (Marsh & Cormier, 2001). This model tested for two linear trends: (1) a downward trend from the starting point to the vertex (i.e., from the 1st time segment to the 4th time segment), and (2) an upward trend from the vertex to the end (i.e., from the 4th time segment to the 7th time segment). A significant negative slope for the downward trend and a significant positive slope for the upward trend would indicate a U-shaped trend of spacebar presses over time, akin to the STIM pattern. Also, the magnitude of the positive slope of the upward trend reflects the steepness of the goal-gradient. The analysis was done by coding three dummy variables (Marsh & Cormier, 2001; Muggeo, 2003; Simonsohn, 2018) based on the time variable (coded form 1 to 7, the vertex at Time 4): A dummy variable indicating the downward trend, $time_{\text{downward}} = time - vertex$ if $time < vertex$ and 0 otherwise (i.e., resulting in the values -3,-2,-1,0,0,0,0 from time segment 1 to time segment 7); a dummy variable indicating the upward trend, $time_{\text{upward}}$ = *time* – *vertex* if *time* ≥ *vertex* and 0 otherwise (i.e., 0,0,0,0,1,2,3); and a dummy variable, *upward*, which controlled for the intercept at the vertex, *upward* = 1 if *time* ≥ *vertex* and 0 otherwise (i.e., 0,0,0,1,1,1,1). We coded a dummy variable representing condition (target-score condition coded as -1, timer condition coded as 1) and two interaction terms (see equation below) – one tested for difference between conditions in the downward trend, and the other tested for difference between conditions in the upward trend (i.e., the goal-gradient). In this and all subsequent multi-level analyses, we followed Bliese and Ployhart's (Bliese & Ployhart, 2002) recommendations for adding random effects based on the deviance index for goodness of fit. Based on this criterion, we included in our model by-participants random intercept, and random slopes for the downward and upward trends. The models' fixed effects specifications were of the following form:

$$Y_{time(j)} = b_0 + b_1{*}Time_{downward(j)} + b_2{*}Time_{upward(j)} + b_3{*}Upward_j + b_4{*}Condition + b_5{*}Condition{*}\ Time_{downward(j)} + b_6{*}\ Condition{*}\ Time_{upward(j)}$$

$Y_{time(j)}$ is the number of spacebar presses in time segment j, b_0 is the intercept, b_1 and b_2 are the coefficients of the linear downward and upward trends over time, respectively. b_3 controls for the intercept of the upward trend (adding this coefficient for statistical analyses of U-shapes is recommended by Simonsohn (2018). This coefficient makes the model an interrupted rather than a segmented regression model (Muggeo, 2003)). b_4 is the coefficient of the difference between the two conditions at the point of the vertex. Importantly, b_5 and b_6 are the coefficients of the difference between conditions in the downward and upward trends over time, respectively.

There was an overall STIM effect, as indicated by significant downward, $b_1 = -.592$, $SE = .058$, $t(210.99) = -10.18$, $p < .001$, 95% CI_{b1} [-.712, -.483], and upward trends, $b_2 = .083$, $SE = .036$, $t(72.61) = 2.29$, $p = .025$, 95% CI_{b2} [.013, .155]. The timer and target-score conditions did not differ in the downward trend, $b_5 = .04$, $SE = .059$, $t(690.99) = .75$, $p = .451$, 95% CI_{b5} [-.057, .165], but did differ in the upward trend, $b_6 = .142$, $SE = .059$, $t(690.99) = 2.40$, $p = .016$, 95% CI_{b6} [.019, .251].

In all the studies we also redid the analysis with fitting a vertex separately per condition rather than fixing it at the same time-point across all conditions in all experiments. These analyses yielded significant differences between the conditions in the predicted direction $t(57) = 18.09$, $p < .001$, $d = 2.37$, 95% $CI_{difference}$ = [.32, .40]. The SOM presents more detail on these analyses for all the experiments (Table S2), along with an explanation regarding why they yield particularly large effects.

We also made sure that the increase in keypresses does not come at the expense of accuracy, and does not represent shifting strategy to faster, less accurate shooting. We examined accuracy (number of hits divided by number of presses) as a function of time segment in Experiments 1, 2, and 4 (in Experiments 3 it was impossible to retrieve this data). This measure was standardized within participants in the same manner as keypresses, and the figures are presented in the SOM (Figure S1). We found that accuracy initially increased and then reached an asymptote, thus showing a typical learning curve. Importantly, this pattern means that the increase in effort toward the end of the task in our studies (goal-gradient) cannot be explained by shifting to a strategy of faster, less accurate shooting, as a downward shift in accuracy toward the end has not been observed in our studies.

In sum, consistent with our prediction, a steeper goal-gradient emerged in the timer condition, in which participants performed the task toward a deadline, compared to the target-score condition, in which they worked toward a performance criterion (Figure 2).

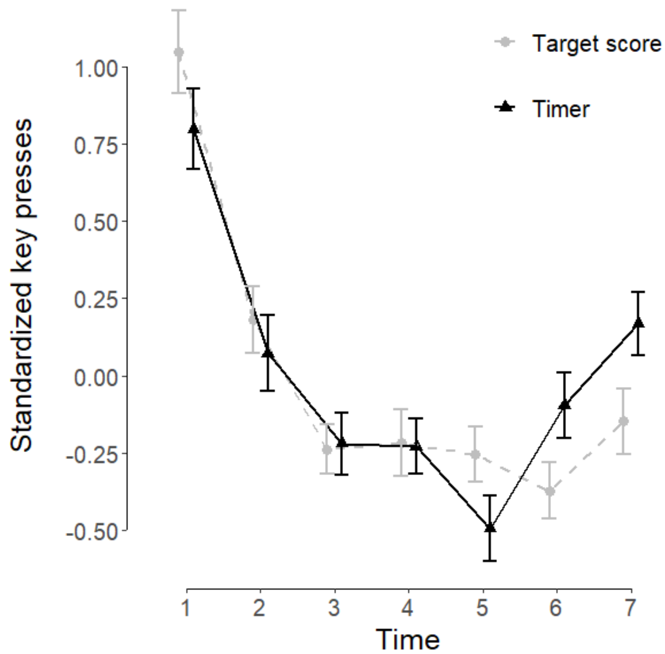

Figure 2. Results of Experiment 1: Mean standardized spacebar presses per time-segment by condition. A STIM pattern of effort allocation with a steeper goal-gradient (i.e., a steeper increase in effort toward the end of the task) was found in the timer condition than in the target-score condition, $p = .016$. Error bars represent standard errors of the mean.

Experiment 2

In Experiment 2 we introduced a task that could be performed concurrently with shooting asteroids but could also be completed after the deadline for shooting asteroids has passed. We examined whether introducing the concurrent task (which obviously increases opportunity cost of acting on the focal task) would lower the level of effort allocated to the focal task, and whether this effect would gradually lift off as the deadline drew nearer. Our main prediction was that introducing the concurrent task would give rise to a STIM pattern with a steeper goal-gradient. This experiment was preregistered at https://aspredicted.org/blind.php?x=y9ka5c.

Method

Participants

After excluding two participants, we were left with 57 participants who took part in the experiment in exchange for course credits (42 women, 17 men; M_{age} = 22.64, *SD* = 1.56).

Materials and Procedure

After a five-minute practice session, each participant completed two 15-minute blocks, order counterbalanced between participants. The no-aliens condition was identical to the timer condition of Experiment 1, except that a banner at the bottom of the screen said “Shoot asteroids.” In the aliens condition, in addition to shooting asteroids, participants had to collect aliens. Specifically, alien-spaceships appeared one at a time every 20-30 seconds at a random vertical position and flew from left to right across the screen. Participants could collect them by simply touching them with their own spaceship. After the deadline, the asteroids disappeared, and participants could not gain any additional points. The block, however, did not end until participants completed collecting the specified number of aliens, which was 36. Moreover, after the deadline, alien spaceships became more frequent such that a new alien-spaceship appeared randomly every 7-16 seconds. A counter indicated the number of collected aliens below the score indicator, and a banner at the bottom of the screen said “Shoot asteroids + collect aliens” (see Figure 3). We told participants that they can choose to collect any number of alien-spaceships before the asteroid game is over and continue collecting them afterwards. We also told them that the frequency of alien-spaceships will increase after the deadline. In both conditions, we told participants that for each block, the highest-scoring third of participants would get a bonus credit. Performance was estimated relative to a pre-existing baseline, and the bonus credit was delivered to participants at the end of the experimental session. Prior to the two experimental sessions, participants completed a practice block of five minutes, which was identical to the aliens condition, in which they had to collect only 12 aliens by the end of the practice block, and in which no bonus for performance was granted. The order of the experimental conditions was counterbalanced between participants.

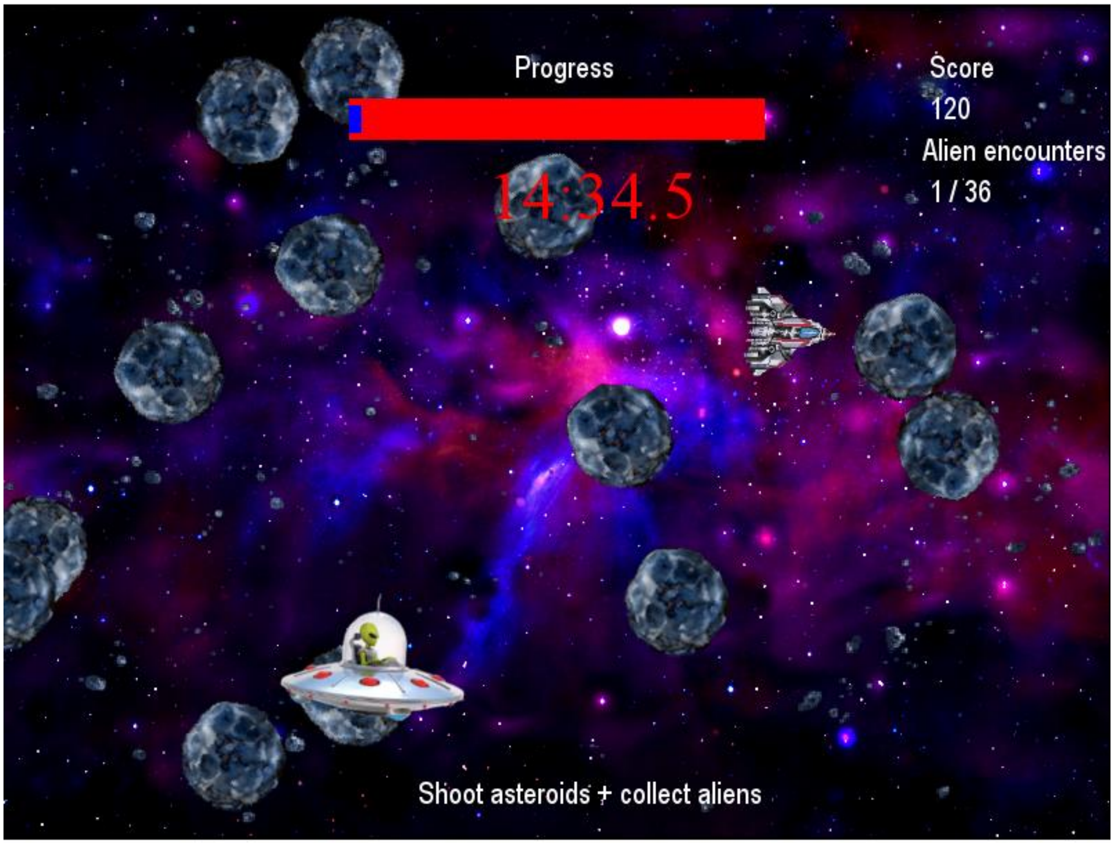

Figure 3. A sample screen from the aliens condition. A counter for collected aliens was presented below the score counter, and a banner stating "Shoot asteroids + collect aliens" was presented at the bottom of the screen.

Results

Overall Effort and Opportunity Cost over Time

The overall number of spacebar presses was higher in the no-aliens condition (*M* = 3362.75, *SD* = 799.77) compared to the aliens condition (*M* = 3140.14, *SD* = 812.90), $t(56) = 3.37$, $p = .001$, $d = .44$, 95% $CI_{difference}$ [90.29, 354.94]. Effect sizes for this and all other Cohen's d statistics were calculated as the mean of the differences divided by the standard deviation of the differences, dz. This result is consistent with the notion that the concurrent task of collecting aliens increased opportunity cost of the primary task of shooting asteroids, and thereby reduced the effort allocated to it.

To examine the time-course of the effect of adding the concurrent task, we subtracted for each participant and for each time-segment the raw number of keypresses in the aliens condition from the corresponding number in the no-aliens condition. This difference represents the cost that the concurrent task imposed on the main task (i.e., how much less of the main task participants did when the concurrent task of collecting aliens was introduced). A significant linear slope for time, $b_1 = -4.06$, $SE = 1.53$, $t(55.09) = -2.64$, $p = .010$, 95% CI_{b1} [-6.92, -.91], indicated that the difference between the two conditions gradually decreased (Figure 4A). This result is consistent with the notion that, as the deadline for shooting asteroids approached, opportunity cost of attempting to shoot asteroids (i.e., the cost imposed by the concurrent task) decreased.

Stuck-in-the-Middle and Goal-Gradient

An overall STIM effect emerged, as indicated by a significant downward, $b_1 = -.394$, $SE = .067$, $t(32.51) = -5.88$, $p < .001$, 95% CI_{b1} [-.532, -.269], and upward trends, $b_2 = .169$, $SE = .039$, $t(39.23) = 4.26$, $p < .001$, 95% CI_{b2} [.095, .246]. The downward trend did not differ between conditions, $b_5 = -.048$, $SE = .060$, $t(678.99) = .800$, $p = .423$, 95% CI_{b5} [-.073, .173], but the upward trend did, $b_6 = .139$, $SE = .060$, $t(678.99) = 2.29$, $p = .022$, 95% CI_{b6} [.024, .251], indicating a steeper goal-gradient in the aliens condition compared to the no-aliens condition (Figure 4B). An analysis with a vertex fitted separately for each condition was consistent with this finding, $t(56) = 4.25$, $p < .001$, $d = .56$, 95% $CI_{difference}$ [.07, .21] (see SOM). Thus, as predicted, a concurrent task not only introduced opportunity cost for the focal task but also made its goal-gradient steeper.

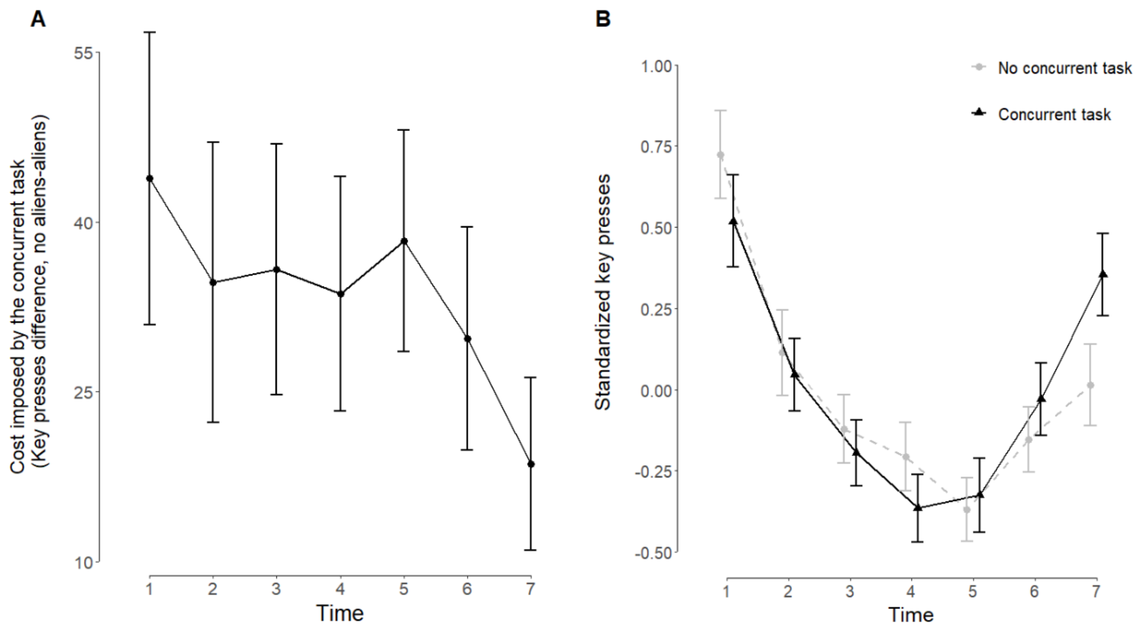

Figure 4. Results of Experiment 2: ***A.*** Mean difference in keypresses between the no-aliens (no concurrent task) and the aliens (concurrent task) condition, by time segment. The numbers are overall positive, suggesting that introducing a concurrent task reduced effort allocated to the focal, deadline-bound task, p =.001. The gradual decrease over time, p = .010, is consistent with the possibility that the opportunity cost that is due to the concurrent task is reduced as the deadline for the focal task draws nearer. ***B.*** Mean standardized spacebar presses per time-segment by condition. A STIM pattern of effort allocation with a steeper goal-gradient emerged when a concurrent task was introduced, in the aliens condition, p = .022.

Experiment 3

Experiments 3 and 4 tested the prediction that a more pronounced STIM effect would emerge with actions that are inherently more impactful, or in other words, hold higher action value. In Experiment 3 we manipulated the points-return for accurate asteroid shots. Specifically, all participants first played a practice block in which each accurate shot awarded 10 points. Then, they moved to a situation in which the same action had more value or less value, depending on the condition. Specifically, in the high action value (double score) block participants were informed that each accurate shot would now award 20 points, whereas in the low action value (half score) block they were informed that each accurate shot would now award 5 points. We predicted a STIM pattern with a steeper goal-gradient in the double-score condition compared to the half-score condition.

Method

Participants

After excluding three participants, we had 97 paid participants (53 women, 45 men; M_{age} = 25.51, *SD* = 3.36).

Materials and Procedure

All materials and procedures were identical to the timer condition of Experiment 1, except that no progress-bar was presented, and participants were not awarded a bonus payment for good performance. After a one-minute practice session, each participant completed two seven-minute blocks, order counterbalanced between participants. In the practice block, an accurate shot awarded ten points whereas in the experimental blocks it awarded either five points (half-score condition) or twenty points (double-score condition).

Results

Overall Effort

A paired-sample t-test did not find a difference in the overall number of spacebar presses between the double score condition (*M* = 1295.94, *SD* = 504.58) and the half score condition (*M* = 1315.88, *SD* = 497.94), $t(96) = 1.42$, $p = .156$, $d = -.14$, 95% $\text{CI}_{\text{difference}}$ [-

7.8, 47.6]. Our model, and in fact any model that views effort as determined by action cost and action benefit would predict that effort would increase when points are doubled and decrease when they are halved. It is possible that such cost-benefit based, “reasoned” motivation is not the only type of human motivation. In many situations, making something more difficult makes people increase effort toward achieving it (e.g., Brehm & Self, 1989) for reasons other than “net action value”. For example, motivation can increase if a task is perceived as a challenge. A further analysis of overall presses showed that participants who first performed the double score condition and then moved to the half-score condition greatly increased effort (from M = 1221.98 in the double score condition to M = 1300.62 in the half score condition, $t(49) = -4.26$, $p < .001$, $d = .60$), a pattern that is perhaps consistent with this possibility. Those who started with the half-score condition only slightly increased effort when they moved to a double score condition (from M = 1332.12 to M = 1374.63, $t(49) = -2.50$, $p = .016$, $d = .-36$), giving rise to a significant interaction of order and condition, $F(1, 95) = 23.15$, $p < .001$, $\eta_p^2 = .19$. It is possible, however, that these order effects emerged due to a between block-learning stemming from the relatively short practice and experimental blocks. These issues were addressed in a subsequent preregistered conceptual replication (see Experiment 4).

Stuck-in-the-Middle and Goal-Gradient

An overall STIM effect emerged, as indicated by a significant downward, $b_1 = -.255$, $SE = .059$, $t(99.46) = -4.32$, $p < .001$, 95% CI_{b1} [-.374, -.145], and upward trends, $b_2 = .069$, $SE = .033$, $t(106.13) = 2.08$, $p = .039$, 95% CI_{b2} [.004, .134]. A difference was found between conditions in both the downward trend, b_5 = -.118, *SE* = .048, *t*(1159.02) = -2.47, *p* = .013, 95% CI$_{b5}$ [-.299, -.053], and the upward trend, b_6 = .166, *SE* = .048, *t*(1159.02) = 3.46, *p* <.001, 95% CI$_{b6}$ [.060, .328] (Figure 5). The latter indicated, as predicted, a steeper goal-gradient in the double-score condition, in which participants' actions were more effective. An analysis with separately fitted vertex for each condition was consistent with this finding, *t*(96) = 4.25, *p* < .001, *d* = .71, 95% CI$_{difference}$ [.10, .18] (see SOM).

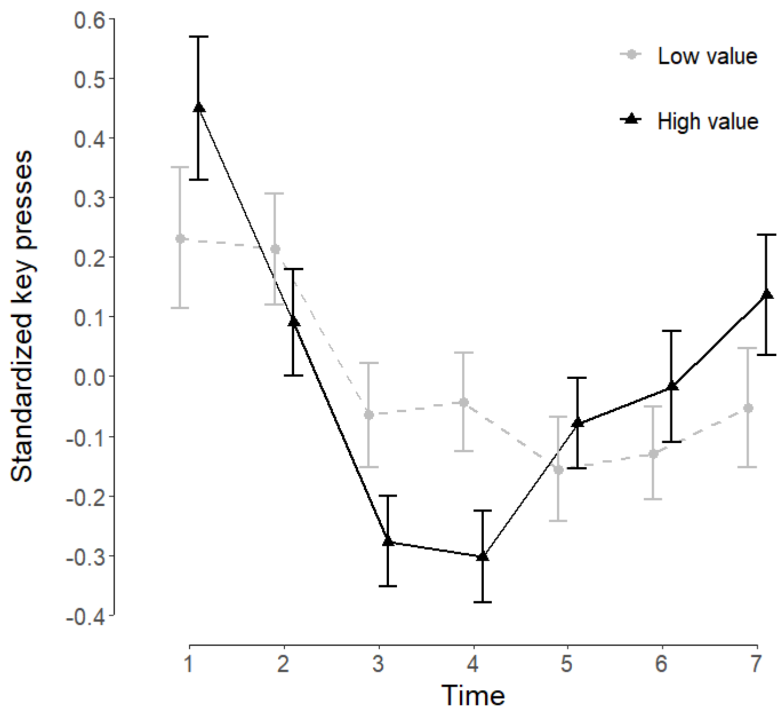

Figure 5. Mean standardized spacebar presses per time-segment by condition in Experiment 3. Error bars represent standard errors of the mean. A STIM pattern with a steeper goal-gradient was found in the double-score (high action value) condition, in which action was more effective, than in the half-score (low action value) condition, in which it was less effective, *p* < .001.

Experiment 4

In the present experiment we attempted to replicate Experiment 3 with a different manipulation of action value. Specifically, we manipulated how far the shots reached in each condition: In the condition with a high action value the shots reached farther than in the condition with a low action value. We predicted a STIM pattern with a steeper goal-gradient in the long-range condition compared with the short-range condition. This experiment was preregistered at http://aspredicted.org/blind.php?x=84ax6p.

Method

Participants

After excluding two participants, we had paid 98 participants (61 women, 39 men; M_{age} = 24.23, *SD* = 3.55).

Materials and Procedure

All materials and procedures were identical to the timer condition in Experiment 1, except that the range of shots differed between conditions. After a five-minute practice session, each participant completed two 15-minute blocks, order counterbalanced between participants. Specifically, in the short-range condition, the shots traveled a short distance before they disappeared (~ 4 cm). Additionally, a banner on the bottom of the screen said: “Shots reach closer”. In the long-range condition, the shots traveled a longer distance before they disappeared (~ 10 cm). A banner on the bottom of the screen said: “Shots reach farther”. Participants completed both conditions, order counterbalanced between participants. Participants initially performed a five-minute practice block in which the shots traveled ~7 cm before they disappeared.

Results

Overall Effort

A paired-samples t-test indicated that participants pressed the spacebar more in the long-range condition (*M* = 3577.94, *SD* = 861.10) than in the short-range condition (*M* = 3044.84, *SD* = 842.95), $t(97) = -11.91$, $p < .001$, $d = 1.20$, 95% $CI_{difference}$[-622, -444].

Stuck-in-the-Middle and Goal-Gradient

An overall STIM effect emerged, as indicated by a significant downward, $b_1 = -.516$, *SE* = .056, $t(96.99) = -9.17$, $p < .001$, 95% CI_{b1}[-.627, -.408], and upward trends, $b_2 = .071$, *SE* = .031, $t(97.00) = 2.29$, $p = .024$, 95% CI_{b2}[.009, .133]. Conditions did not differ in the downward trend, $b_5 = .028$, *SE* = .042, $t(107.4) = .638$, $p = .523$, 95% CI_{b5}[-.062, .121], but did differ in the upward trend, $b_6 = .140$, *SE* = .042, $t(107.4) = 3.16$, $p = .001$, 95% CI_{b6}[.046, .235], indicating, as predicted, steeper goal-gradient in the long-range condition, in which action was more effective, compared to the short-range condition (Figure 6). An analysis with a vertex fitted separately for each condition was consistent with this finding, $t(97) = 5.34$, $p < .001$, $d = .53$, 95% $CI_{difference}$ [.08, .19] (see SOM).

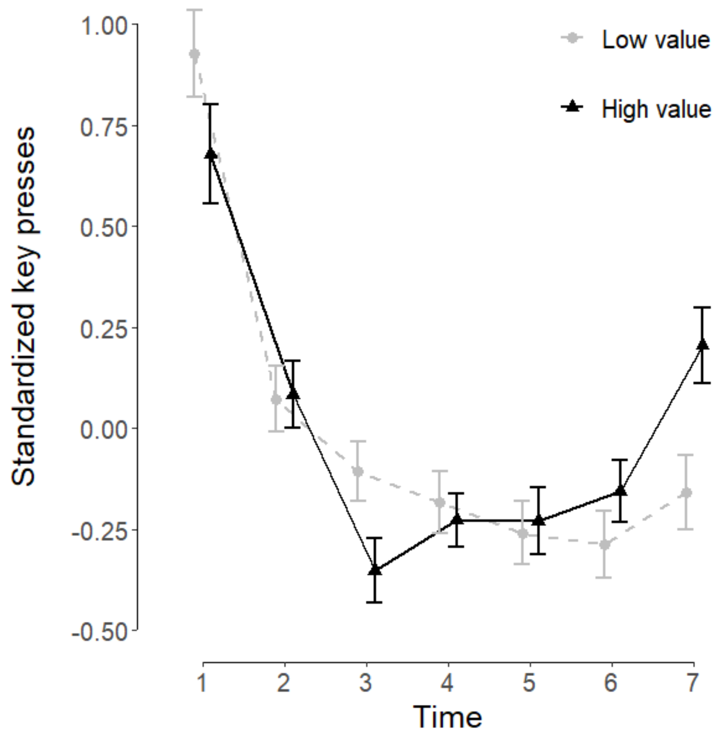

Figure 6. Mean standardized spacebar presses per time-segment by condition in Experiment 4. Error bars represent standard errors of the mean. A STIM pattern with a steeper goal-gradient was found in the long-range (high action value) condition, in which action was more effective, than in the short-range (low action value) condition, in which it was less effective, $p = .001$.

General Discussion

We proposed an opportunity cost model to explain why people increase effort as they get closer to a deadline. Specifically, we suggested that as the deadline approaches the value of alternatives decreases and they come to pose less opportunity cost. This is because closer to a deadline (1) the cost of postponing alternative activities past the deadline decreases; (2) the cost of engaging with alternatives increases as it becomes difficult to compensate for not doing the focal task. We used a computer game task to test predictions that follow from this logic in four experiments. Experiment 1 showed that participants increased effort toward a deadline more than toward a target score. Experiment 2 showed that effort increased more steeply toward the deadline in the presence of a concurrent task that could be completed after the deadline. Experiments 3 and 4 showed that effort increased more steeply toward the deadline when actions had higher value because they granted more points (Experiment 3) or because they were more effective (Experiment 4). The proposed opportunity cost model of goal-gradients has important real-world implications as well as interesting connections to extant theories of motivation and related findings. In most of our experiments, participants were promised and actually received a bonus for performing at the top third of participants. This type of incentive did not allow them to know whether they are going to receive the bonus, neither in the course of the game nor at completion. This feature of ambiguity of the experimental task was designed to keep participants motivated through the game regardless of how well they felt that they played. If one feel good (bad) about their score and the way they played, it is possible that other participants played even better (worse). Such social comparisons, if occurred, likely added noise to our experiments and lead to an under estimation of the reported effects.

Steeper Goal-Gradients with Deadlines than with Performance Criteria

Our finding that people increase effort more steeply toward a deadline than toward a performance criterion suggests that setting deadlines might be a particularly potent way to elicit high levels of effort. For example, in physical training, assigning a deadline (e.g., “do as many squats as you can in 1.5 minutes”), more than assigning a target amount (e.g., “do 60 squats”), could motivate people to “push themselves to the limit” as the end approaches. Whether that is desirable (because it drives one to higher achievements) or not (because it increases the likelihood of injuries) depends, of course, on the situation. For example, most injuries in young soccer players were found to occur in the last 15 minutes of each half (Hawkins & Fuller, 1999). This could be an effect of cumulating fatigue but could also be the outcome of increasing effort toward the deadline, as our model would suggest. On a related note, it would be interesting to compare whether sports injuries are more likely in time-bound physical tests such as the Cooper test (e.g., "run as far as you can in 12 minutes") than in score-bound ones (e.g., the first to reach 5 km wins).

Prominent theories of motivation suggest that task-related negative feelings during performance (i.e., fatigue, boredom, dejection) reflects opportunity cost (Kurzban et al., 2013; Rom et al., 2019). These models maintain that opportunity cost increases over time, and therefore fatigue and boredom increase as well (Kurzban et al., 2013). Our model predicts instead that such negative feelings would follow a reversed STIM pattern, first increasing and then decreasing toward the deadline. It also suggests that setting deadlines may counteract fatigue and boredom at the end of tasks.

Consistent with this possibility and with the notion that opportunity cost decreases when the end of a task draws near, Katzir et al. (2020) found that fatigue and boredom during a long and difficult cognitive task were mitigated when a clear end point was introduced compared to a condition in which the end was not clear to participants.

Our model could also explain why and under which conditions deadlines mitigate procrastination. Specifically, it explains why engaging in alternative activities reduces as one gets closer to a deadline and suggests that the effect of adding a deadline would be particularly dramatic when the alternatives are more attractive as well as when the focal task is more valuable. For example, we might predict that students will procrastinate doing their coursework as long as it does not have a clear deadline, and that this effect would be more dramatic for more important courses and when procrastination is caused by more attractive activities.

Steeper Goal-Gradients with More Concurrent Tasks

We found that adding a concurrent task to a deadline-bound focal task reduced people's overall investment of effort in the focal task but led to steeper increase of effort toward the task's deadline. We suggested that this was the case because the burden of opportunity cost, which the concurrent task introduces, is gradually lifted as one gets closer to the deadline. Based on these findings, we would predict that excessive life-tasks (e.g., taking care of young children or elderly parents) would cause people to invest less effort in work, and that this effect would decline near a deadline of work-related tasks. We would also predict that removing a task's deadline would be particularly detrimental for task performance among people who are more preoccupied with demanding personal tasks. An interesting test case is the NSF's elimination of deadlines for grant submissions in certain areas of science, which resulted, according to recent data, in a 59% reduction in submissions (Hand, 2016). It would be interesting to examine whether submissions decreased more steeply among people with busier personal lives, as our findings would suggest.

Our results are consistent with the "urgency effect," whereby people prioritize tasks near their deadline, even if doing so is detrimental to overall profit. For example, Zhu et al.(2018) found that when choosing between two tasks of writing product reviews, students preferred the higher-paying task when both tasks had similar and relatively long completion times. However, introducing a short completion time to the low-payoff task increased the rate at which it was chosen over the high-payoff task. Returning to our work-family conflict example, introducing deadlines to work-related tasks could benefit work, but could at the same time be detrimental to a person's role as a family member, and even to their overall well-being.

Steeper Goal-Gradients when Action is More Effective

According to classic theories of motivation, people tend to exert more effort when they perceive it to be more effective (Bandura, 1977; Brehm & Self, 1989; Karsh et al., 2016; Kruglanski et al., 2012). Our model predicts, and our findings actually show that this effect is particularly pronounced near a deadline. The reason, according to our model, is that as a deadline draws nearer, effort gradually comes to reflects more the value of the focal task and reflect less the value of alternative tasks.

An interesting implication is that close to a deadline (compared to points in time that are farther away from the deadline), effort would better reflect (i.e., would be more diagnostic of) the perceived effectiveness of the action. For example, how hard a student studies for an exam would be indicative of their academic self-efficacy when the exam is near, but not when it is far in the future, in which case the effort invested in studying might reflect the availability, the attractiveness and the efficiency of performing alternative activities.

The STIM effect with deadlines was previously suggested to stem from a somewhat different mechanism than the one we proposed. Specifically, Touré-Tillery and Fishbach (2012, 2015) suggested that performance at the beginning and end of tasks feeds into judgments of self-value as well as into social judgment (i.e., is particularly diagnostic of the actor’s ability in their own eyes as well as in the eyes of others), because these are salient moments. As a result, actors increase effort in such moments. Our model suggests an additional reason, beyond salience, for why actions are more diagnostic of motivation to perform a focal, deadline-bound task near the deadline: It is because this is the time when the actor is more likely to concentrate on the focal task rather than on alternatives.

Conclusion

In four experiments, we demonstrated the stuck-in-the-middle effect when participants worked toward a deadline and found that its second component, the goal-gradient (i.e., the increase in effort toward the deadline) was steeper when working toward a deadline (compared to a target criterion), when a concurrent task was present, and when one’s actions were more effective. We proposed to explain these effects in terms of the opportunity cost of the focal task, which decreases near a deadline because the value of engaging in alternative activities decreases whereas the cost of doing so increases.

Context of the research

The idea for this research emerged from the realization that extant models of goal gradients apply to target-bound tasks, but they cannot explain why they emerge with deadlines. Each of the authors was interested in the effect of deadlines for somewhat different reasons. The first author is interested in patterns and mechanisms of effort allocation over time in both physical and mental activities (Emanuel, 2019; Emanuel et al., 2019, 2020, 2021). The second author comes at the same question from the perspective of research on self-regulation and self-control (Katzir et al., 2020, 2021; Katzir & Liberman, 2021; Rom et al., 2019). The last author, on the other hand, is interested in how psychological distance affects motivation by ways other than the effects of distance on construal (Liberman & Trope, 2008, 2014) and on the anticipated value of the focal task (Liberman & Trope, 2003; Trope et al., 2007). We plan to continue exploring our model of effort in deadline-bound tasks by looking at tasks that involve physical effort as well as by exploring more extended tasks in the real life (e.g., students studying for an exam). We hope that our model will help us design interventions that would help people achieve their goals and improve their well-being.

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Appendix A

A model of how effort changes in the course of a task

The following model describes how observed effort, namely the effort people exert on a task, changes in the course of that task. In deadline-bound tasks, we divide the task into T equal time-segments that range from $\mathrm{t} = 1$ to $\mathrm{t} = \mathrm{T}$. In target-bound tasks, we divide the task into T equal segments of the target quantity (e.g., in a score-bound computer task, divide the target number of points into T equal parts). We assume, like other models of effort (e.g., Kurzban et al., 2013; Shenhav et al., 2013, 2017), that at each point, t, observed effort is a monotonous increasing function of the net value of action, that is, action benefit minus action cost. In our model, the cost of the focal action is the value of alternative actions, which is in turn comprised of the benefit of the alternatives minus their cost.

$$(1)\ \mathrm{ObservedEffort_t} = f\left(\mathrm{Vfocal_t} - (\mathrm{alternatives.benefit_t} - \mathrm{alternatives.cost_t})\right)$$

Where:

Vfocal = value of the focal action (e.g., how important and enjoyable is doing homework).

$\mathrm{alternatives.benefit_t}$ = how attractive it is to engage in alternatives (e.g., when doing homework, how important and enjoyable are the available distractors), at a given point, t.

$\mathrm{alternatives.cost_t}$ = how costly it is to engage in alternatives (e.g., when doing homework, how detrimental is checking email for the completion of one’s homework), at a given point, t.

f is a monotonous increasing function of the net value of action, that transforms the net value of action into effort.

Each of the value component changes over the course of the task, and we now turn to examine this change, that is, describe each component as a function of t (segment from the starting point) and T (overall number of segments). Some of these relations were described in the literature, whereas others are, to the best of our knowledge, proposed here for the first time.

1. How value of the focal action changes over time ($Vfocal_t$)

1.1) According to Bonezzi and colleagues (2011), if the starting point is used as a reference for monitoring goal progress, then perceived action efficiency might decline over time. For example, the 2nd step increases distance by 50%, the 11th step by 10% (see also Förster et al., 1998). The logic behind this decline is captured by hyperbolic functions (these functions are also widely used in models that describe temporal discounting of value, e.g., Laibson, 1997). We let $0 \leq \alpha$ be the parameter that controls the rate of diminishing perceived action efficiency. The higher is α, the steeper the decline.

1.2) According to Bonezzi and colleagues (2011), in target-bound tasks, if the end-point is used as a reference for monitoring goal progress, then perceived action efficiency might increase closer to the target (for example, when only two steps are left to the target, the next step closes 50% of the remaining distance to the target, but at an earlier stage, when 10 steps are left to the target, the next step would close only 10% of the remaining distance to the target). Following Bonezzi et al. (2012), we let the increase toward the end be controlled by the same parameter, $0 \leq \alpha$, that controls the initial decrease in perceived action efficiency. Of course, this should not need to be necessarily the case. The higher is α, the steeper the increase closer to the target. Importantly, we argued on theoretical grounds (pp. 3-4) that this component is absent in deadline-bound tasks.

We further posit, along with Bonezzi and colleagues (2011) and other theories, most notably "the small area" hypothesis by Koo and Fishbach (2012), that people orient toward only one reference point, and tend to use the point closer to them. Thus, they initially use the starting point as a reference, and shift to using the end point as a reference in the middle of the task.

1.3) According to Kurzban (2013) and others (Charnov, 1976b; Gossen, 1854b; Mobbs et al., 2013b, 2018b), marginal utility from any activity gradually decreases. It is possible that this can happen regardless of any reference point that the actor might use. For example, people initially find a video game exciting but their excitement gradually fades. Models of diminishing marginal utility are often captured by exponential functions (e.g., Charnov, 1976; Kurzban et al., 2013). We let $0 \leq \beta \leq 1$ be the parameter that controls the rate with which the utility of the focal activity diminishes over time. The lower is β, the steeper is the decline over time in the value of the focal activity.

Summarizing points 1-3, we can now describe Vfocal_t in deadline-bound and in target-bound tasks.

In deadline-bound tasks:

(2) $\mathrm{Vfocal}_t = \frac{1}{1+\alpha(t-1)} \beta^{(t-1)} \cdot \mathrm{Vfocal}$

In target-bound tasks:

(3) $\mathrm{Vfocal}_t = \frac{1}{1+\alpha(\min((t-1),(T-t))} \beta^{(t-1)} \cdot \mathrm{Vfocal}$

2. How the benefit of engaging in alternatives changes over time ($alternatives.benefit_t$)

We propose that as the end of the task draws near, the benefit of engaging in alternatives decreases, because it becomes gradually less costly to postpone them. (We think that “cost to postpone” and “benefit to engage” are directly related.) For example, when doing homework is the focal activity, checking email becomes less attractive when less homework remains to be done (less time until submission deadline or less questions to answer). To the best of our knowledge, this component is modeled here for the first time. We assume a linear decrease over time in the benefit in engaging in alternatives and let $0 \leq \gamma \leq 1$ be the parameter that controls the steepness of this decrease.

We also assume that *the benefit of engaging in alternatives* is proportional to the value of alternative actions, which we denote as $\mathrm{Valterantive}$. For example, *the benefit of engaging in alternatives* should be higher when an alternative concurrent task is introduced (vs. when it is absent), and to the extent that the alternative is more attractive. For simplicity, we assume this component to be similar across target-bound and deadline-bound tasks.

(4) $\mathrm{alternatives.benefit}_t = \gamma \cdot \frac{T+1-t}{T} \cdot \mathrm{Valterantive}$

3. How the cost of engaging in alternatives changes over time ($alternatives.cost_t$)

We propose that the cost of engaging in alternatives to the focal task ($\mathrm{alternatives.cost}_t$) increases close to a deadline because opportunities to compensate for failing to act on the focal task get scarcer. For example, losing one day of studying (e.g., and going shopping instead) is costlier the day before an exam than ten days before the exam because ten days before an exam one can compensate for the lost studying time by studying harder on another day. But the day before the exam such compensation becomes impossible. Importantly, we explained that this logic applies to deadline-bound tasks, but not to target-bound tasks (pp. 7-8).

We think that the pressure that deadlines exert steeply increases as the deadline approaches, and therefore chose to express this relation in a hyperbolic function. We let $0 \leq \delta$ be a parameter that controls the extent of increase in $\mathrm{alternatives.cost}_t$ toward a deadline. The higher δ, the steeper the increase. We also explained that the effect of a deadline would be typically more prominent than the effect of a target score as a reference (pp. 8-9), which is captured in our model by the parameter α in Equation 3. For that reason, we assume $\delta > \alpha$.

$\mathrm{Alternatives.cost}_t$ should be proportional to the value of the focal task because it is costlier to forego a more valuable task. For example, $\mathrm{alternatives.cost}_t$ would be higher if one is engaging in alternatives when studying for a more important exam. We let $\mathrm{C} \cdot \mathrm{Vfocal}$ (a proportion of Vfocal), where $\mathrm{C} > 0$, be the maximum amount of effort that a deadline can add to one's performance.

(5) $\text{alternatives.cost}_t = \frac{1}{1+\delta(T-t)} \cdot C \cdot \text{Vfocal}$

4. Observed effort

We can now rewrite observed effort (Equation 1) in deadline-bound tasks as

(6) $\text{ObservedEffort}_t = f\left(\text{Vfocal}_t - (\text{alternatives.benefit}_t - \text{alternatives.cost}_t)\right)$

$$= f\left(\frac{1}{1+\alpha(t-1)}\beta^{(t-1)} \cdot \text{Vfocal} - \gamma \cdot \frac{T+1-t}{T} \cdot \text{Valternative} + \frac{1}{1+\delta(T-t)} \cdot C \cdot \text{Vfocal}\right)$$

And in target-bound tasks as

(7) $\text{ObservedEffort}_t = f\left(\text{Vfocal}_t - (\text{alternatives.benefit}_t)\right)$

$$= f\left(\frac{1}{1+\alpha(\min((t-1),(T-t))}\beta^{(t-1)} \cdot \text{Vfocal} - \gamma \cdot \frac{T+1-t}{T} \cdot \text{Valterantive}\right)$$

5. Predictions of the model

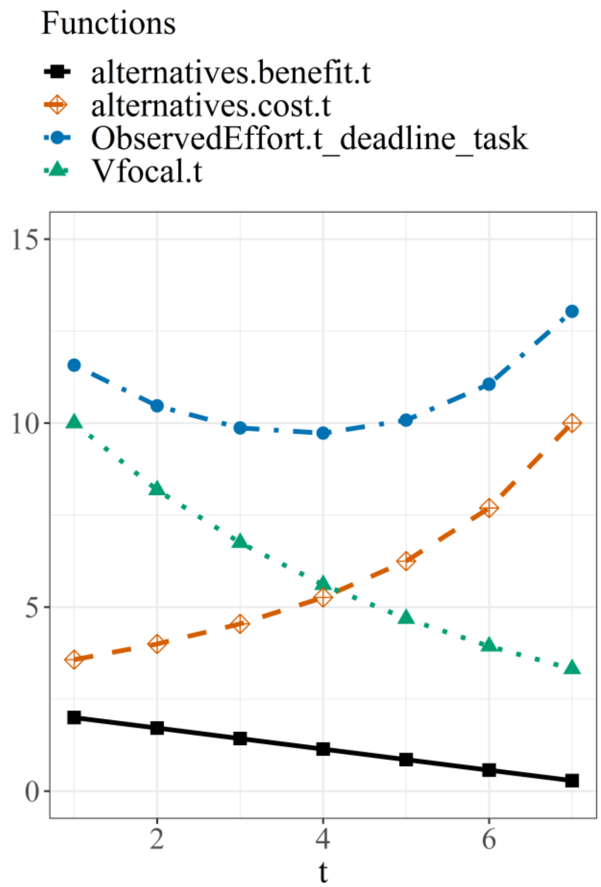
The following figures show the predictions of our model for the situations examined in our studies, specifically, for deadline-bound versus target bound tasks, when a concurrent task is introduced versus not, and when the value of the focal action is low versus high.

5.1 Deadline-bound versus target-bound tasks

Figures A1 and A2 depict the model's predictions of observed effort and its components, in deadline-bound tasks and in target-bound tasks, respectively. For these and subsequent figures, we let f to be an identity function, $f(x) = x$, and set the parameters as follows:

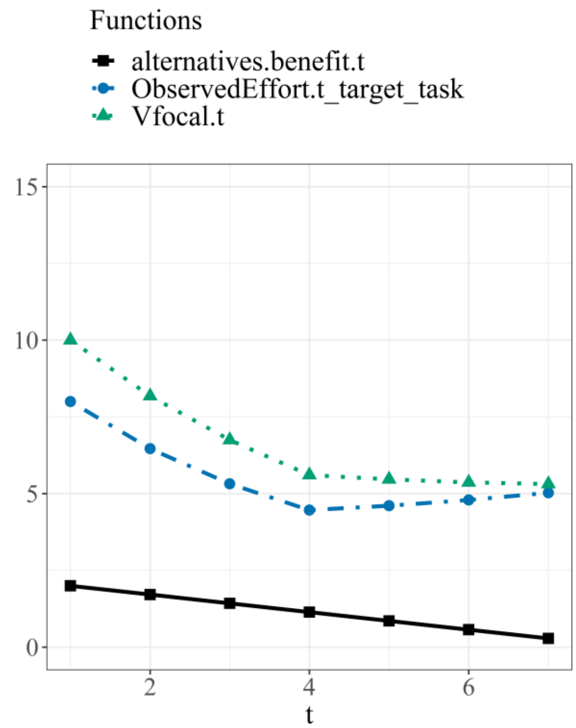
$T = 7;\ \alpha = 0.1;\ \beta = 0.9;\ \gamma = 0.5;\ \delta = 0.3; C = 1; Vfocal = 10; Valternative = 4.$

Figure A1. Observed effort and its components in a deadline-bound task



$$\text{ObservedEffort}_t = f\left(\text{Vfocal}_t - (\text{alternatives.benefit}_t - \text{alternatives.cost}_t)\right)$$

Figure A2. Observed effort and its components in a target-bound task



$$\text{ObservedEffort}_t = f\left(\text{Vfocal}_t - \left(\text{alternatives.benefit}_t\right)\right)$$

Figures A1 and A2 show that our model predicts a steeper goal gradient in observed effort in deadline-bound tasks than in target-bound tasks. This prediction clearly depends on the chosen parameters. For example, the parameter C constrains the extent to which effort could rise close to the deadline. A low value of C (which could capture, for example, situations in which the deadline is not very salient) would produce a shallower goal gradient in deadline-bound tasks than in target-bound tasks. Likewise, a shallow goal gradient in deadline-bound tasks would emerge with a low value of δ. However, as long as $\delta > \alpha$ (which we argued to be the case on theoretical grounds, pp. 8-9), and C is ≥ 1 (which means that we do not assume a-priori that the effort added by the deadline could not exceed the initial level of effort), our model predicts a steeper goal gradient in deadline-bound tasks than in target-bound tasks for a wide range of parameters.

5.2 Introducing a concurrent task to a deadline-bound task

Figure A3 depicts observed effort in deadline-bound tasks as predicted by our model (Equation 6), when a concurrent task is introduced and when it is absent. We set Valternative to 4 when there is no concurrent task and to 8 when there is a concurrent task.

Figure A3. Observed effort in a deadline-bound task with and without a concurrent task

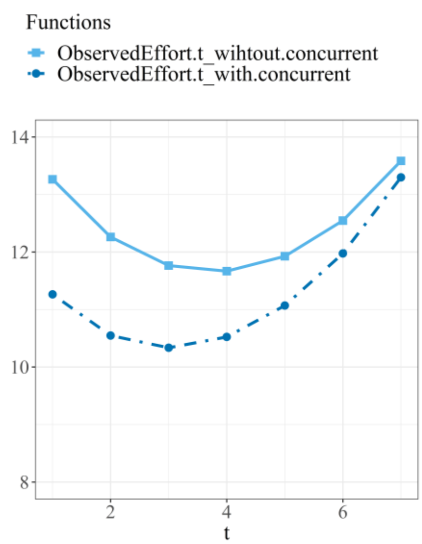
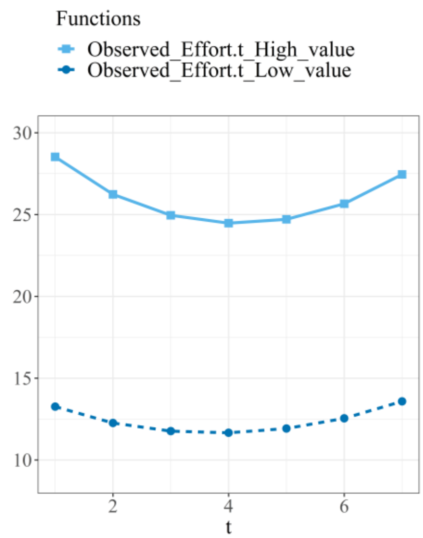


Figure A3 shows that the model predicts a steeper goal gradient when a concurrent task is introduced compared to when it is absent. This prediction is robust to parameters. Note also that the difference between the two lines, which represents the reduction in motivation due to the concurrent task, reflects opportunity cost. The figure shows that this difference diminishes as the deadline approaches. This prediction by the model was supported by the results of Experiment 2, and is depicted in Figure 4 of the main article (p. 23).

5.3 Manipulating the value of the focal action

Figure A4 depict observed effort in deadline-bound tasks as predicted by our model (Equation 6), when the focal action assumes high versus low value. We set the value of the focal task to 10 when it is low and to 20 when it is high.

Figure A4. Observed effort in a deadline-bound task with high vs. low value of the focal task



The figure shows that the model predicts a steeper goal gradient when the value of the focal task is higher. This prediction is robust to parameters.

The figure also shows a steeper initial decline in observed effort in the high value condition than in the low value condition. This difference diminishes as δ gets bigger than α, especially with high values of β.