Dissociable after-effects of prosocial acts: Effort is costly for others but valued for self

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Abstract

Prosocial behavior requires effort, yet people are often reluctant to exert effort for others' benefit. However, the manner in which effort exertion affects subsequent reward evaluation during prosocial acts remains elusive. Here, we leveraged the temporal precision of electroencephalography, along with a paradigm that independently manipulated effort and reward for self and another person, to uncover the neural mechanism underlying the reward after-effect of effort expenditure during prosocial acts. We found a dissociable reward after-effect between self-benefitting and other-benefitting effort. When the beneficiary was oneself, the reward positivity (RewP) became more positive as effort increased, indicating an effort-enhancement effect. In contrast, when the beneficiary was others, the RewP became less positive as effort increased, demonstrating an effort-discounting effect. Moreover, this dissociation occurred only when reward system was activated and was independent of performance evaluation. Our finding provides novel insights into how prior effort expenditure shape reward evaluation during prosocial behavior.

Keywords: prosocial behavior; effort; reward; after-effect

1 Introduction

Prosocial behaviors are acts that benefit others and often involve some personal costs (Bierhoff, 2002). These actions are crucial for promoting individual physical (Post, 2005) and mental (Raposa et al., 2016) well-being and serve as a powerful force enhancing social cohesiveness and group bonding (Fehr & Fischbacher, 2003). According to the cost-benefit framework (Contreras-Huerta et al., 2020), people help others either because they are highly sensitive to others' welfare or because they are less sensitive to their own costs. However, most studies manipulate only financial costs (Engel, 2011), ignoring the most cost form of effort, a non-contextual factor that represents a physical or cognitive activity for goal-directed behavior (Shenhav et al., 2017). Indeed, prosocial behavior in everyday life requires the investment of varying amounts of effort, whether to help a colleague proofread a paper or to hold an elevator for a stranger. In this study, we examined how effort exertion affects subsequent reward evaluation during prosocial acts.

Effort is typically considered costly and aversive. All else being equal, people usually follow a "law of less work" (Hull, 1943) and prefer lower over higher task demands (Kool et al., 2010), showing as effort discounting (Westbrook et al., 2013). Due to its inherent aversiveness, effort serves an ideal proxy for cost in studying prosocial behavior. Recent studies have characterized the psychological and neurobiological mechanisms underlying prosocial effort. In these studies, participants repeatedly decide whether to invest effort to gain financial rewards for themselves or others. A consistent finding is that participants are less willing to exert effort to benefit others than themselves, specifically when the required effort is high. This prosocial apathy is observed for both physical effort (Lockwood et al., 2017) and cognitive effort (Depow et al., 2022). It is modulated by acute stress (Forbes et al., 2024), aging (Lockwood et al., 2021),

and individual differences in broad affective traits (Contreras-Huerta et al., 2022). Moreover, prosocial acts are energized to a lesser degree during effort exertion than identical self-benefiting ones (Lockwood et al., 2017; Lockwood et al., 2022). Neuroimaging and brain lesion studies have revealed that prosocial effort costs are tracked by neural activity in the anterior cingulate gyrus, anterior insula, and ventromedial prefrontal cortex (Forbes et al., 2024; Lockwood et al., 2024; Lockwood et al., 2022). While these studies have focused on how people choose to exert effort during decision making and energize their actions during effort exertion, they have largely ignored another important aspect of effort expenditure: the reward after-effect of effort expenditure.

The reward after-effect of effort expenditure refers to a temporary tunning toward or amplification of reward-related motivation following effort expenditure (Inzlicht et al., 2018; Kelley et al., 2019). Specifically, people assign more value to obtained things they have put effort into and are more reluctant to share monetary rewards earned through greater effort (Arkes et al., 1994; Norton et al., 2012). The effort-adds-value phenomenon is observed across species (Lydall et al., 2010; Pompilio et al., 2006), suggesting that it is biologically hard-wired. Echoing these behavioral findings, neuroimaging evidence has demonstrated that prior effort investment increases brain activity in reward-related neural circuits including the anterior cingulate cortex, orbitofrontal cortex, and ventral striatum (Dobryakova et al., 2017; Hernandez Lallement et al., 2014; Wagner et al., 2013). Further evidence comes from studies focusing on the reward positivity (RewP) of the event-related potential (ERP) component. The RewP, a reliable neural signature for reward sensitivity, has its neural sources in the anterior cingulate cortex (Gehring & Willoughby, 2002) and ventral striatum (Foti et al., 2011). Some studies found that RewP increased following the execution of high-effort versus low-effort behavior for reward feedback

(Bogdanov et al., 2022; Harmon-Jones et al., 2024; Ma et al., 2014; Umemoto et al., 2023; Yi et al., 2020). While this framework has been used extensively to understand how effort expenditure influences following reward processing during self-benefitting behaviors, surprisingly, it has not been applied to understand the reward after-effect of effort expenditure during prosocial acts.

In this study, we aimed to investigate the reward after-effect of prosocial effort, focusing on the RewP elicited during reward evaluation after effort expenditure. Previous studies examining how people vicariously process others' rewards suggest a critical role of the RewP in prosocial behavior (Kwak et al., 2020; San Martín et al., 2016). In these experiments, participants performed simple gambling or speeding reaction-time tasks to win monetary rewards for themselves and others. A consistent finding is that the RewP is smaller for reward feedback for oneself than for others, including charity programs (San Martín et al., 2016), beneficiaries with closer social distance (Kwak et al., 2020), or anonymous persons (Li et al., 2022). However, rewards in these studies were earned with minimum effort. Crucially, previous research has never considered the impact of prior effort costs.

To address this issue, we recorded the RewP in a prosocial effort task where participants exerted varying physical effort to earn monetary rewards for themselves or an anonymous other person. We hypothesized an effort-discounting effect on the RewP when exerting effort for others, indicated by a reduced RewP as required effort increased. Conversely, we expected an effort-enhancement effect on the RewP when participants put in effort for themselves, shown by a more positive RewP as required effort increased. We predicted this dissociation would be more pronounced when reward system was more activated. To provide a comprehensive picture of prosocial effort, we also examined participants' decision-making tendencies in a following prosocial decision-making task where they chose to exert effort to benefit either themselves or

others. We hypothesized that participants would be less willing to invest effort to earn rewards for others than for themselves.

2 Results

In this study, participants completed a role assignment task (Figure 1A) to become the decider in two subsequent prosocial tasks: a prosocial effort task and a prosocial decision-making task. In the prosocial effort task (Figure 1B), participants exerted physical effort (2–6 levels; Figure 1C) to earn rewards of varying amounts (¥0.2, ¥0.4, ¥0.6, ¥0.8, or ¥1.0) for themselves and an anonymous other person. The five effort levels were fully crossed with the five reward magnitudes, creating 25 unique combinations. Following the effort task, participants engaged in a prosocial decision-making task (Figure 1D) where they chose between a high-effort option (more effort for a larger reward) and a no-effort option (no effort for a smaller reward). The high-effort options comprised 25 unique effort-reward combinations, mirroring those in the prosocial effort task. In both tasks, half of trials benefitted participants themselves, while the other half benefitting others. We measured participants' neural responses to reward obtained after investing effort for themselves and others in the effort task and their willingness to exert prosocial effort in the decision-making task. Additionally, we collected participants' ratings of perceived difficulty, invested effort, and interest on at each effort level when exerting effort for themselves and others during the tasks.

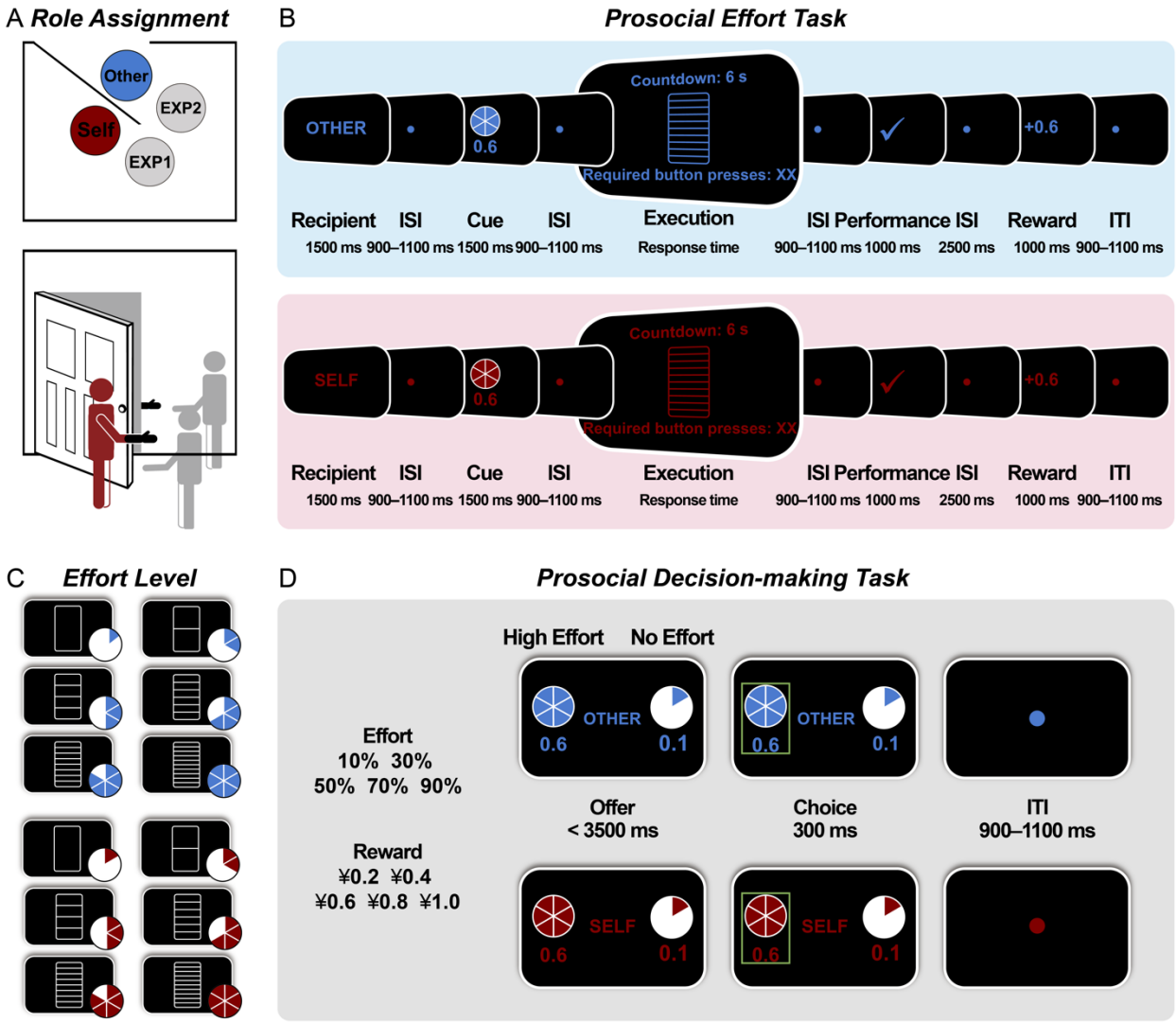

Figure 1. Experimental tasks. (A) The role assignment task. Participants were introduced to another anonymous person and designated as a decider to invest physical effort for monetary rewards for themselves and others. (B) The prosocial effort task. Participants exerted physical effort (2–6 levels) to earn a potential reward of varying amounts (¥0.2, ¥0.4, ¥0.6, ¥0.8, or ¥1.0) for themselves and others. Successful effort had a 50% chance of yielding a reward. (C) Effort levels. The physical task required participants to press buttons with their non-dominant pinky finger within 6000 ms. Effort level was visualized as the height of a vertical bar (10%, 30%, 50%, 70%, or 90% of the participant's calibrated maximum effort). The blank bar indicated no effort. (D) The prosocial decision-making task. Participants chose between a high-effort option (more effort for a larger reward) and a no-effort option (no effort for a smaller reward). ISI = interstimulus interval; ITI = intertrial interval.

3.1 Investing effort for others is less motivated than for self

The maximum effort level (i.e., the average number of button presses across the three trials) was 36.06 (SD = 4.95, range = 26.33–46.00; Figure 2A). A linear mixed-effects model

was used to fit response time (RT) data in the prosocial effort task. Participants took longer to complete the task as the required effort increased (b = 1.65, p < 0.001; Figure 2B) and as the prospective reward decreased (b = -0.01, p = 0.032; Figure 2C). They spent more time exerting effort for others than for themselves (b = 0.03, p < 0.001). The full regression coefficients for RT data are shown in Supplementary Table S1. Moreover, there was no significant difference in success rates between self (M = 97%) and other trials (M = 96%).

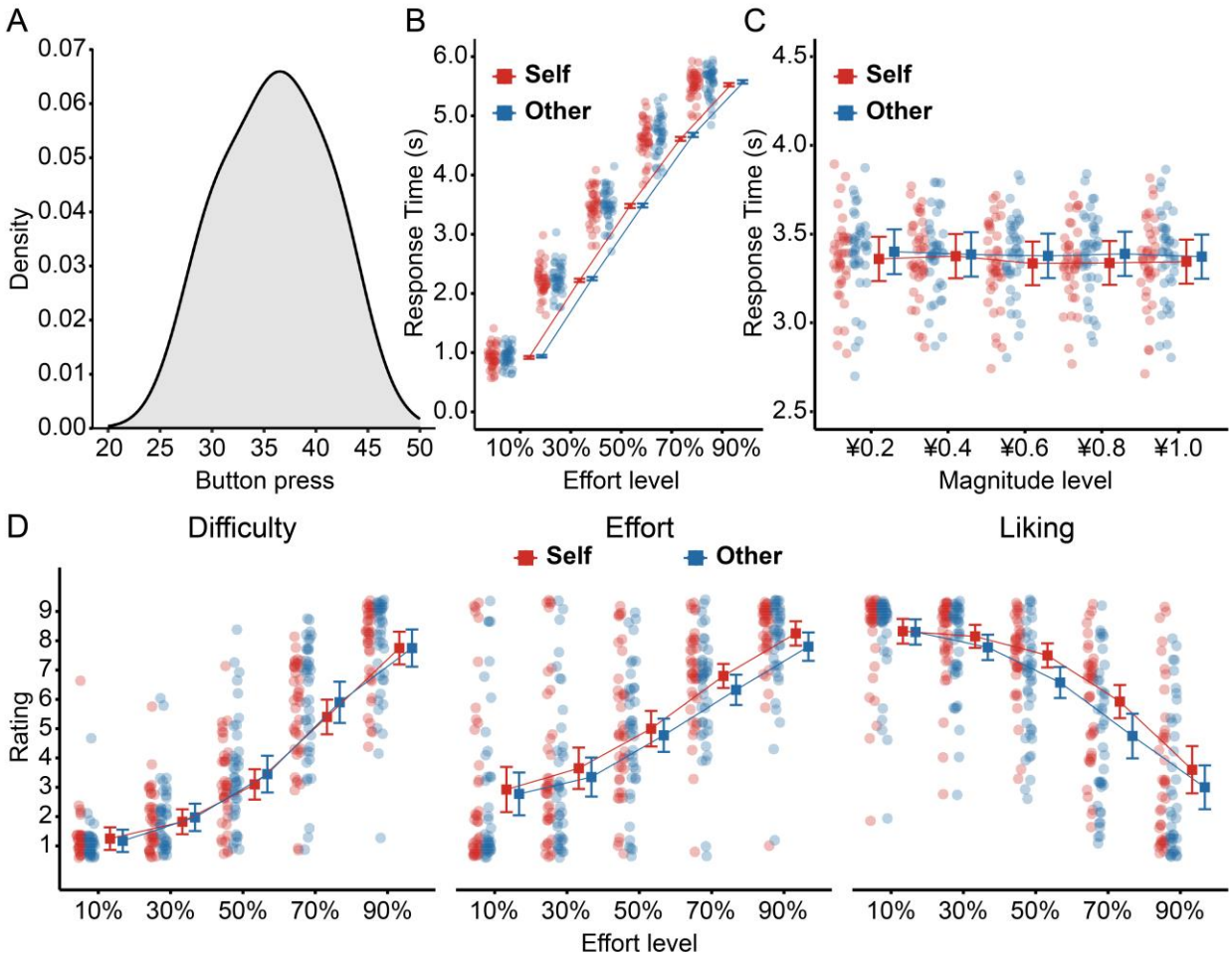

Figure 2. Behavioral and rating results of the prosocial effort task. (A) The distribution of the number of button presses. (B–C) Response time data. Participants took longer to press the button for others than for themselves. They also required more time as effort demands increased and potential rewards decreased. (D) Rating data. Participants felt less effortful and more disliking when exerting effort for others than for themselves. Error bars represent the within-subject standard error of the mean.

As a manipulation check, we examined participants' rating data as a function of effort level and beneficiary using a linear mixed-effect regression model. As expected (Figure 2D), participants perceived increased effort as more difficult (b = 2.38, p < 0.001), more effortful (b = 1.90, p < 0.001), and less likable (b = -1.79, p < 0.001). They felt less effortful (b = -0.32, p = 0.015) and more disliking (b = -0.62, p < 0.001) when the beneficiary was others than themselves. However, they perceived no differences in task difficulty between self-benefitting and other-benefitting trials (b = 0.19, p = 0.254). Moreover, the liking rating data tracked a significant interaction between recipient and effort (b = -0.28, p = 0.023). Follow-up simple slopes analyses revealed that the discounting effect of effort on the liking rating was more pronounced when the beneficiary was others (b = -1.93, 95% CI = [-2.28, -1.58], p < 0.001) compared to when it was themselves (b = -1.65, 95% CI = [-2.00, -1.30], p < 0.001). The full regression coeffects for rating data are shown in Supplementary Table S2. Together, our rating and behavioral data suggest that the effort manipulation was successful. Furthermore, participants were less motivated to invest effort for others than for themselves at both subjective and behavioral levels, despite similar success rates.

3.2 Effort adds reward value for self but discounts reward value for others

In the prosocial effort task, the RewP was evident as a relative positivity over frontocentral areas (Figure 3). We fitted the amplitude of the RewP using a linear mixed-effect regression model with recipient, effort, magnitude, valence, and their interactions as predictors. The full regression estimates for RewP data are shown in Supplementary Table S3. The RewP was more positive for self-benefitting compared to other-benefitting trials (b = -0.68, p = 0.008), for gain compared to nongain feedback (b < -1.08, p < 0.001) and increased as reward magnitude increased (b = 0.43, p < 0.001).

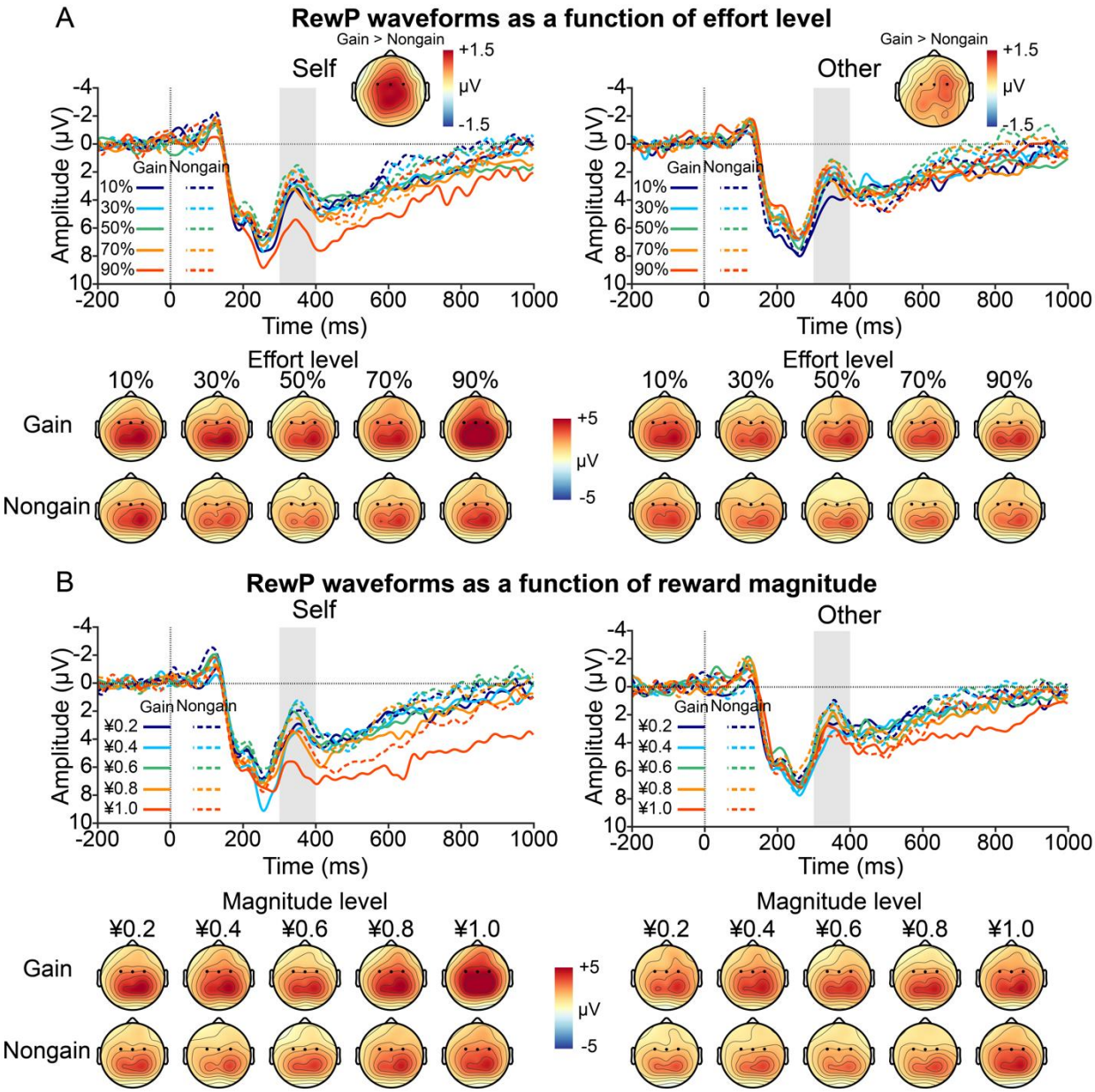

Figure 3. Grand-average ERP waveforms and topographic maps of the RewP as a function of recipient (self vs. other) and valence (gain vs. non-gain) separately for effort (A) and reward (B) trials. Gray shaded bars represent time windows used for quantification.

We observed a significant two-way interaction between recipient and effort (b = -0.55, p = 0.009), which was further qualified by a significant three-way interaction among recipient, effort, and magnitude (b = -0.50, p = 0.018). The predicted effects of the three-way interaction among recipient, effort, and magnitude are shown in Figure 4A. Visual inspection revealed that when the reward stake was low, the RewP was unaffected by the amount of invested effort

across both self-benefitting and other-benefitting trials. However, as the reward amount increased, the effect of effort expenditure on the RewP became more positive when the beneficiary was oneself but became more negative when the beneficiary was others. To provide statistical support for these observations, we conducted post-hoc simple slopes analyses at -1 SD ("Low") and + SD ("High") reward magnitude. These analyses revealed that at low reward magnitude, the RewP did not vary with effort level, regardless of whether the beneficiary was self ($b < 0.01$, 95% CI = [-0.41, 0.41], $p = 0.991$) or others ($b = -0.05$, 95% CI = [-0.47, 0.37], $p = 0.810$). At high reward magnitude, when the beneficiary was self, the RewP became more positive as effort level increased ($b = 0.43$, 95% CI = [0.02, 0.84], $p = 0.041$), indicating an effort enhancement effect. Conversely, when the beneficiary was others, the RewP became less positive as effort level increased ($b = -0.62$, 95% CI = [-1.04, -0.21], $p = 0.003$), indicating an effort discounting effect.

Moreover, we observed a significant three-way interaction among recipient, magnitude, and valence ($b = 0.86$, $p = 0.038$). Subsequent simple slopes analyses (Figure 4B) revealed distinct neural patterns based on the beneficiary. When the beneficiary was self, the RewP became more positive as reward magnitude increased for both gain feedback ($b = 0.75$, 95% CI = [0.34, 1.16], $p < 0.001$) and nongain feedback ($b = 0.46$, 95% CI = [0.06, 0.87], $p = 0.024$). In contrast, when the beneficiary was others, the RewP became more positive as reward magnitude increased for nongain feedback ($b = 0.52$, 95% CI = [0.11, 0.92], $p = 0.012$), but not for gain feedback ($b = -0.02$, 95% CI = [-0.43, 0.38], $p = 0.912$).

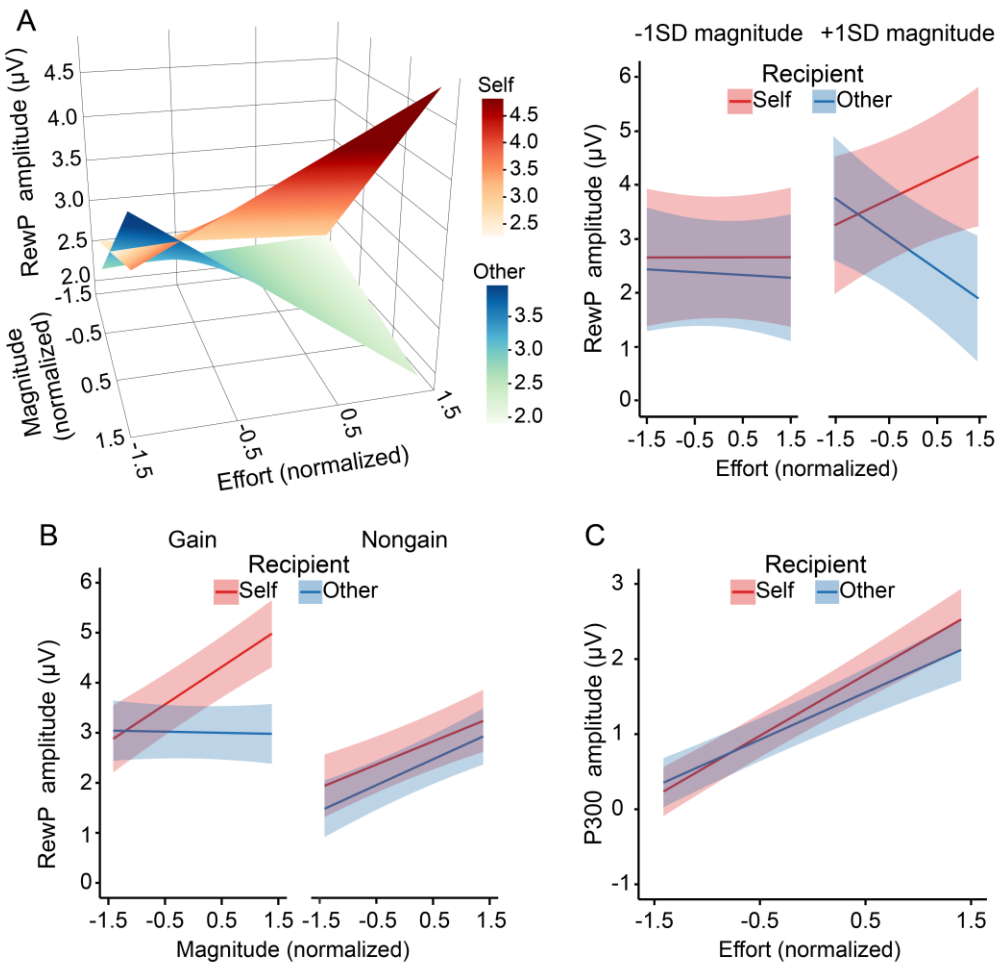

Figure 4. ERP results in the prosocial effort task. (A) Fixed effects of effort and reward on the RewP as a function of recipient during reward evaluation. The left graph displays the fixed effects with two continuous predictors of effort and reward, whereas the right graph shows the fixed effects of effort at one standard deviation (SD) below and above the mean reward magnitude. An effort-enhancement effect emerged when participants invested effort for themselves, whereas an effort-discounting effect occurred when they exerted effort for others. This dissociable after-effect was present only when reward magnitude was low. (B) Fixed effects of reward magnitude on the RewP as a function of recipient and valence during reward evaluation, showing a significant three-way interaction. (C) Fixed effects of effort on the P3 as a function of recipient during performance evaluation. Participants exhibited comparable effort effects across self and other trials. Shaded areas depict the 95% confidence intervals.

To confirm the specificity of our RewP findings, we examined the parietal P3 in response to performance feedback (i.e., effort-completion cues; see Supplementary Figure S1 for the ERP waveforms) using a linear mixed-effect regression model with recipient, effort, magnitude, and their interactions as predictors. We found a main effect of effort on the P3 in response to effort-

completion cues, with its amplitudes increasing as a function of prior effort levels (b = 0.72, p < 0.001). Importantly, this effort effect was equally robust whether the beneficiary was oneself or others (Figure 4C), as revealed by a nonsignificant interaction between recipient and effort (b = -0.19, p = 0.285). No other significant effects were found (see Supplementary Table S4 for the full regression estimates for P3 data).

3.3 Reward is devalued by effort to a higher degree for others than for self

Decision-time data in the prosocial decision-making task were fitted using a linear mixed-effects regression model with recipient, effort, magnitude, and their interactions as predictors. As shown in Figure 5A–B, participants took longer to make decisions as effort level increased (b = 0.04, p < 0.001) and as reward magnitude decreased (b = -0.04, p < 0.001). These effects were further qualified by a significant interaction between effort and magnitude (b = 0.03, p < 0.001). Follow-up simple slopes analyses revealed that decision time became longer as effort level increased at high reward magnitude (M + 1SD: b = 0.07, 95% CI = [0.05, 0.10], p < 0.001), but did not vary with effort level at low reward magnitude (M – 1SD: b = 0.01, 95% CI = [-0.02, 0.03], p = 0.680). Decision time was also longer when the beneficiary was others than when it was self (b = 0.05, p = 0.009). We also observed significant interactions between recipient and effort (b = -0.04, p = 0.001), as well as recipient and magnitude (b = 0.04, p = 0.001). Follow-up simple slopes analyses revealed that decision time became longer as effort level increased in self trials (b = 0.06, 95% CI = [0.03, 0.09], p < 0.001), but not in other trials (b = 0.02, 95% CI = [-0.01, 0.05], p = 0.184). Similarly, increased reward magnitude decreased the decision time more pronouncedly in self trials (b = -0.06, 95% CI = [-0.08, -0.04], p < 0.001) than in other trials (b = -0.02, 95% CI = [-0.04, -0.00], p = 0.031). The full regression estimates for decision-time data are shown in Supplementary Table S5.

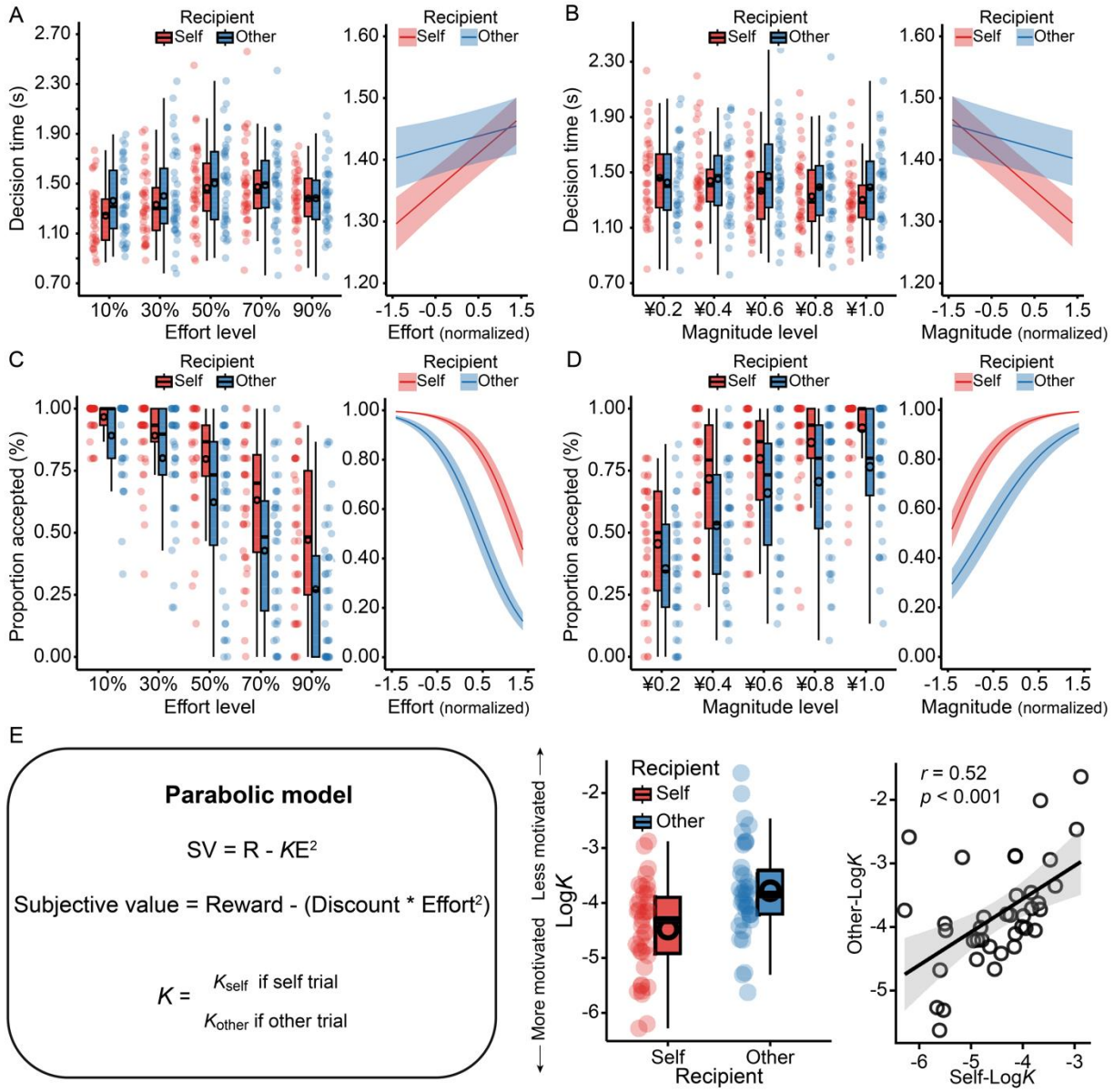

Figure 5. Behavioral and computational results of the prosocial decision-making task. (A–B) Participants took longer to make decisions as effort level increased in self trials but not in other trials (A). Increased reward magnitude decreased the decision time more pronouncedly in self trials than in other trials (B). (C–D) Participants were less willing to invest effort for others than for themselves. (E) Effort exertion discounted rewards to a higher degree when the beneficiary was others compared to when it was themselves (left and middle). A higher discounting rate for others was associated with a higher discounting rate for self (right). The black circles overlaid on the boxplots indicate the mean across participants. Shaded areas depict the 95% confidence intervals. Noted that seven subjects had an accuracy rate of less than 60% on catch trials, but this did not influence the results of the prosocial decision-making task. Moreover, two subjects were removed from discounting rate analysis due to their negative *K* values.

We fitted participants' decision preference using a mixed-effects logistic regression model recipient, effort, magnitude, and their interactions as predictors. As depicted in Figure 5C–D, participants were less willing to invest effort as effort level increased (b = -1.95, p < 0.001) and as reward magnitude decreased (b = 1.48, p < 0.001). They were also less willing to put in effort for others compared to themselves (b = -1.67, p < 0.001), which was further modified by a significant interaction between recipient and magnitude (b = -0.52, p < 0.001). Simple slopes analyses revealed that the facilitation effect of reward on willingness to exert effort was less pronounced when the beneficiary was others (b = 1.22, 95% CI = [1.09,1.35], p < 0.001) compared to when it was participant themselves (b = 1.74, 95% CI = [1.54, 1.93], p < 0.001). The full regression coeffects for choice data are shown in Supplementary Table S5. These findings were further confirmed by following computational modeling (see Materials and methods). As shown in Figure 5E, participants exhibited a higher discounting rate for other-benefiting choices (M = -3.78) compared to self-benefiting choices (M = -4.48, p = 0.001). Furthermore, a higher discounting rate for others was associated with a higher discounting rate for oneself (r = 0.52, p < 0.001), suggesting a baseline motivation that influences effort discounting for self and others.

3 Discussion

Many prosocial behaviors require people to invest effort for benefitting others, yet people are more reluctant to expend effort for others' benefit compared to their own. In this study, we examined how effort expenditure influences subsequent reward evaluation during prosocial acts, a blind spot in previous research. We found a dissociable reward after-effect of effort investment between self-benefitting and other-benefitting acts: prior effort increased reward evaluation when the beneficiary was oneself but decreased it when the beneficiary was others. Moreover, this

dissociation occurred only when the potential reward was large and was independent of performance evaluation.

In our study, despite perceiving no differences in task difficulty and achieving comparable success rates for themselves and others, participants took longer to exert effort, reported feeling less effortful, and disliked the task more as the required effort increased when helping others. Participants exhibited a higher discounting rate for choices benefitting others versus those benefitting themselves, and their decision time was less influenced by effort and reward levels when the beneficiary was others compared to when it was themselves. These finding are largely consistent with previous studies, demonstrating a prosocial apathy when physical effort is required to help others (Contreras-Huerta et al., 2020).

Our most important finding is the dissociation of the reward affect-effect of effort expenditure between self-benefitting and other-benefitting trials. When the beneficiary was oneself, the RewP was more positive as prior invested effort increased. In contrast, when the beneficiary was others, the RewP became less positive as prior invested effort increased. Given that the RewP is considered a reliable neural signature for reward sensitivity (Proudfit, 2015), our data suggest an effort-enhancement effect for self-benefitting acts but an effort-discounting effect for other-benefitting acts. The effort-enhancement effect aligns with previous studies where effort is exerted to obtained rewards (Bogdanov et al., 2022; Ma et al., 2014; Umemoto et al., 2023; Yi et al., 2020). Several theories have been proposed to interpret this effect. For instance, prior effort expenditure enhances the subjective value of a reward through effort justification to reduce the psychological discomfort resulting from having engaged in unpleasant effort (Aronson & Mills, 1959) or the psychological contrast between the aversive state elicited by effort expenditure and the reward that follows (Zentall, 2010). While these perspectives

adequately explain the effort-enhancement effect for self-benefiting acts, they fall short for other-benefitting acts observed here. According to these views, the more aversive state elicited by investing effort for others should lead to stronger justification or a more intense psychological contrast, which consequently increases the reward value to a greater degree. However, we observed an effort-discounting effect when it comes into prosocial acts. This discounting effect may result from heightened salience of opportunity cost in helping others, that is, the value of the next-best use of the effort devoted to the current task (Kurzban et al., 2013).

Interestingly, the dissociable after-effect of effort expenditure occurred only when reward magnitude was high. When reward magnitude was low, prior invested effort did not affect the RewP across self-benefitting and other-benefitting trials. These results suggest that the dissociable effort after-effect relies on the involvement of motivational system, which might be activated only when potential reward was high. This possibility was further supported by our P3 data in response to effort-completion cues during performance evaluation. Specifically, participants exhibited an increased P3 when seeing a feedback stimulus informing them that the required effort has been achieved, whether the beneficiary was self or others. As the P3 is thought to reflect motivational salience based on feedback evaluation (Nieuwenhuis et al., 2005), our results suggest that participants could derive value from their successful effort completion. Unlike reward evaluation, the effort-enhancement effect on the P3 is associated with intrinsic motivation such as pride and achievement because of successful performance (Bowyer et al., 2021; Jiang & Zheng, 2023). Together, our data establishes that the dissociation in the after-effect of prosocial effect occurs only when reward motivation is sufficiently activated.

While previous research on prosocial effort have focused exclusively on cognitive processes before and during effort expenditure (Contreras-Huerta et al., 2020), our findings

provide a comprehensive picture of prosocial effort. We not only replicate the greater effort discounting for prosocial acts compared to self-benefitting acts but also demonstrate a dissociable after-effect of prosocial effort. Our results suggest that the difference between self-benefiting and other-benefitting effort may be quantitative before and during effort expenditure but qualitative after effort expenditure. This after-effect of prosocial effort, together with the established discounting effect before effort exertion, offers a new perspective for facilitating prosocial behavior. When working for oneself, effort expenditure not only prospectively discounts but also retrospectively increases the subjective value of reward, which has been referred to as the *effort paradox* (Inzlicht et al., 2018). However, this paradox is disrupted during prosocial acts, with effort discounting lasting before, during, and after effort expenditure. One possible way to facilitate prosocial behavior is to make the products of one's prosocial effort valuable, thereby restoring the effort paradox observed in benefitting oneself acts (Inzlicht & Campbell, 2022). A related promising direction for future studies is to manipulate the social distance of the other recipient. This approach will help determine whether the after-effect of effort expenditure could shift from an effort-discounting effect to an effort-enhancement effect when the beneficiary is close others, such as friends or family members (Jones & Rachlin, 2006).

One limitation of this study concerns the conflation between temporal delay and effort level. Because high effort level required more time in our task, effort expenditure might not have directly affected following reward evaluation but instead increased participants' delay discounting. If this were the case, one would expect a similar discounting effect on the RewP for self-benefitting trials, as the RewP is less positive as the time to receive the reward increases (Zheng et al., 2023). Moreover, temporal delay is unlikely to affect the RewP due to the

relatively small difference between the lowest and highest effort levels in our task (Weinberg et al., 2012). Nonetheless, future work is needed to evaluate this possibility.

In conclusion, this study demonstrates that prosocial effort can reverse the reward after-effect, changing it from an effort-enhancement effect when benefitting oneself to an effort-discounting effect when benefitting others. This reversal occurred in the presence of a greater discounting effect before and during effort exertion. These findings advance our understanding of how effort investment affects reward motivation during prosocial acts and may inform novel approaches to facilitate prosocial behaviors.

4 Materials and methods

All data and code used for this study are available on OSF at https://osf.io/bvpa2/. This study was not preregistered.

2.1 Participants

Forty-seven right-handed university students were recruited for this study through local advertisements. Seven participants were excluded from data analysis due to the flowing reasons: five never chose to work on either self or other trials, one had a success rate of only 35% on the maximum effort level during the prosocial effort task, and one doubted the impact of their actions on another person. The final sample consisted of 40 participants (20 females; M = 21.55 years, standard deviation [SD] = 2.65). We performed a sensitivity analysis using the *simr* v1.0.6 package (Green & MacLeod, 2016) to compare the regression weight for each effect of interest with the smallest detectable effect size at a power of 80% based on the current sample. The results showed that most of significant effects observed were larger than the smallest detectable effect, suggesting that our sample size provided adequate statistical power. All participants had normal or corrected-to-normal vision and reported no psychiatric or neurological disorders. They

received ¥25 for participation and a bonus of ¥29–¥37 based on their task performance. Each participant provided written informed consent, and this study was approved by a local Institutional Review Board.

2.2 Procedure

Upon arrival at the lab, participants undertook a role assignment task, leading them to believe that they would complete two EEG tasks with a partner. Afterwards, they performed a prosocial effort task and a prosocial decision-making task while their EEG was recorded. Following the EEG tasks, participants used a 9-point Likert scale (ranging from 1 = not at all to 9 = very much) to rate their perceived difficulty, invested effort, and interest on at each effort level when exerting effort for themselves and others during the tasks.

The role assignment task. This task was adapted from a previous study (Lockwood et al., 2017). Participants were led to one side of a door and informed that a second participant (who was in fact a confederate) was also involved in this study (Figure 1A). The confederate, of the same gender as the participant, was then escorted by a different experimenter to the opposite side of the door. Both the participant and confederate were handed a black glove and instructed not to speak for anonymity. They acknowledged each other's presence by waving their gloved hands, without ever being seen by each other. The experimenter then tossed a coin to determine who would choose a ball from a box first. Their roles (a receiver vs. a decider) were assigned based on the outcome. Unbeknownst to participants, they were always designated as the decider, responsible for performing tasks for themselves and others. The confederate was assigned the role of the receiver, responsible solely for completing tasks for themselves. To prevent potential effects of social norms such as reciprocity (Gintis et al., 2003), both the participant and

confederate were informed that they would not be aware of each other's performance and would leave the lab at different times.

The prosocial effort task. This task was designed to measure participants' neural responses to rewards obtained after investing physical effort for themselves and others (Figure 1B). Before the task, participants completed three trials in which they pressed a button as quickly as possible with their non-dominant pinky finger for 6 seconds. The maximum effort level was operationalized as the average number of button presses across these trials. In the prosocial effort task, each trial began with a cue for 1500 ms, indicating whether it was self-benefiting or other-benefiting. Participants exerted physical effort to earn rewards for themselves in self-benefiting trials and for others in other-benefiting trials. Self and other trials were highlighted in different colors (blue and red) throughout the trial, which was counterbalanced across participants. After a jittered interval (900–1100 ms), a pie chart with a number below it appeared for 1500 ms, showing the required effort level (10%, 30%, 50%, 70%, or 90% of their maximum effort level) and the potential reward (¥0.2, ¥0.4, ¥0.6, ¥0.8, or ¥1.0), respectively (Figure 1C). The five effort levels were fully crossed with the five reward magnitudes, creating 25 unique combinations. Following another jittered interval (900–1100 ms), participants entered the effort-execution phase, making the required button presses with their non-dominant pinky finger within 6000 ms. After this phase and another jittered interval (900–1100 ms), a feedback stimulus was shown for 1000 ms, indicating whether the required effort level was achieved. If participants succeeded, a tick was presented, signaling that they were eligible to win the cued reward. If they failed, a cross was displayed, followed by a new trial after a jittered interval of 900–1100 ms. After a 2500-ms interval, a feedback stimulus was displayed for 1000 ms, indicating whether participants received the reward or not. Gains and nongains were equally likely and delivered

pseudorandomly. Each trial ended with an interval varying between 900 and 1100 ms. The task consisted of 200 trials (100 for self and 100 for other, respectively) divided into eight blocks of 25 trials, with a self-determined break between blocks. Eight practice trials familiarized participants with the task before the formal experiment.

The prosocial decision-making task. This task was designed to measure participants' willingness to exert effort for themselves and others (Figure 1D). Participants made decisions between a baseline no-effort (rest) option for ¥0.1 and a high-effort option for a greater reward. The high-effort options were the same as those in the prosocial effort task, including 25 unique effort-reward combinations. Participants had 3500 ms to decide using their left or right index finger. The chosen option was highlighted with a green border for 300 ms. Failure to respond within the time limit resulted in ¥0 and a 1000-ms warning message of "Please respond within 3500 ms". Each trial ended with a jittered interval of 900–1100 ms. The task consisted of 150 trials, with each high-effort option repeated six times. Half of the trials benefitted participants, while the other half benefitted others. To ensure that participants stayed focused on the task, we included 20 catch trials (10 for each beneficiary condition) where participants confirmed the effort and reward levels of the previous high-effort option. To ensure that our task was incentive-compatible, participants were told that they would complete their chosen effort option on 16 randomly selected trials (8 for each beneficiary condition) to determine their final reimbursement. They were instructed to consider each decision carefully because each trial choice would be selected. Before the experiment, participants completed 10 practice trials for familiarization. After the task, participants exerted their effort required for their choices in the 16 selected trials. Finally, they were asked to report whether they believed they were earning rewards for another participant.

2.3 EEG recording and processing

EEG data were recorded using 28 Ag/AgCl channels placed on an elastic cap based on the international 10–20 system. Two additional channels were positioned on the left and right mastoids. The EEG were recorded with a reference channel placed between Cz and CPz. Horizontal and vertical electrooculograms were recorded from two pairs of channels over the external canthi of each eye and the left suborbital and supraorbital ridges, respectively. EEG signals were amplified using a Neuroscan Grael 4K amplifier with a low-pass filter of 100 Hz in DC acquisition mode and digitized at a rate of 512 samples per second. Channel impedances were maintained below 5 KΩ.

The EEG data were analyzed using EEGLAB v2021.0 (Delorme & Makeig, 2004) and ERPLAB v8.10 (Lopez-Calderon & Luck, 2014) toolboxes in MATLAB 2020b (MathWorks, US). The signals were rereferenced to the average of the left and right mastoids and filtered with a bandpass of 0.1–35 Hz using a zero phase-shift Butterworth filter (12 dB/octave roll-off). Channels with poor quality or excessive noise were interpolated using the spherical interpolation algorithm, and portions of EEG containing extreme voltage offsets or break periods were removed. Ocular artifacts were removed using an infomax independent component analysis on continuous EEG with the help of the ICLabel algorithm (Pion-Tonachini et al., 2019). Epochs were then extracted from -200 to 1000 ms relative to feedback onset, with the prestimulus average activity as the baseline. An automatic artifact detection algorithm was applied to remove epochs with a voltage difference exceeding 50 μV between sample points or 200 μV within a trial, a maximum voltage difference less than 0.5 μV within 100-ms intervals, or a slow voltage drift with a slope greater than ± 100 μV. On average, 97.71% of trials were retained for statistical analysis. Single-trial RewP amplitude was measured as mean voltage from 300 to 400 ms post-

feedback onset over frontocentral channels (FC3, FCz, FC4) using an orthogonal selection approach. We also measured the parietal P3 (300–440 ms; averaged across P3, Pz, and P4) in response to performance feedback (i.e., effort-completion cues), given its relationship with motivational salience (Bowyer et al., 2021; Ma et al., 2014). The single-trial data were exported into R v4.2.2 for statistical analyses.

2.4 Data analysis

Our key statistical analyses were based on mixed-effects regression models with random intercepts and slopes (unstructured covariance matrix), implemented in the *lme4* package v1.1.31 (Bates et al., 2015). For the prosocial effort task, we analyzed RT and ERP data separately using a linear mixed-effects regression model, with recipient, effort, magnitude, valence, and their interactions as predictors. For the prosocial decision-making task, we fitted decision time data using a linear mixed-effects regression model and choice data using a mixed-effects logistic regression model with a binomial link function. Both models included recipient, effort, magnitude, and their interactions as predictors. We fitted post-experimental rating data separately using a linear mixed-effect regression model with recipient, effort, and their interactions as predictors. For all models, we contrast-coded categorical regressors (recipient: -0.5 for self and +0.5 for other; valence: -0.5 for gain and +0.5 for nongain) and z-scored continuous regressors (effort and magnitude) within participants. We determined random effects for each model using singular value decomposition to report the maximal possible random effects structure. We performed follow-up pairwise comparisons of significant interactions on estimated marginal means. We excluded trials with failed responses (3.34%) in the prosocial effort task and trials with no responses (0.91%) in the prosocial decision-making task from statistical analyses.

To quantify how participants devalued rewards by effort exertion for self and others, we fitted their choices in the prosocial decision-making task with a parabolic function (the best functional form describing participants' choices):

$$\mathrm{SV} = \mathrm{R} - K\mathrm{E}^2$$

Where SV represents the subjective net value of the high-effort option with a given reward (R) and effort (E). The discount parameter *K* characterizes the degree to which the reward is discounted by required effort. A higher *K* value indicates that the reward is devalued by the effort to a higher degree. The derived SV of the high-effort and no-effort options were compared and transformed into the probability of choosing the high-effort option through a SoftMax function:

$$P_{high\ effort} = \frac{e^{\beta * SV_{high\ effort}}}{e^{\beta * SV_{no\ effort}} + e^{\beta * SV_{high\ effort}}}$$

where β represents the slope of the logistic function, which is a participant-specific parameter and reflects the sensitivity to SV differences between options (Collins & Shenhav, 2022). We normalized the *K* values by taking the natural logarithm (i.e., log*K*) and compared these log*K* values between self and other trials using a paired-*t* test. The model with two separate *K* parameters for self and other trials, plus a single β parameter, has been validated in previous studies using a similar task (Lockwood et al., 2021; Lockwood et al., 2022).

Data availability

Data and code that support the findings of this study are available on Open Science Framework at https://osf.io/bvpa2/.

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Declaration of conflict of interest

The authors declare no conflicts of interests.

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Supplementary Materials

Table S1. Results of a linear mixed-effects model predicting response times in the prosocial effort task

Predictor	*Estimates*	95% CI	*p*
Intercept	3.37	3.30 to 3.43	**< 0.001**
Recipient	0.03	0.02 to 0.05	**< 0.001**
Effort	1.65	1.62 to 1.67	**< 0.001**
Magnitude	-0.01	-0.02 to -0.00	**0.032**
Recipient:Effort	0.01	-0.00 to 0.03	0.084
Recipient:Magnitude	0.00	-0.01 to 0.02	0.769
Effort:Magnitude	-0.01	-0.01 to 0.00	0.108
Recipient:Effort:Magnitude	-0.00	-0.02 to 0.01	0.546
Observations	8000		

Notes. The final model for response times as: Response times ~ Recipient * Effort * Magnitude + (Recipient + Effort | Participant). Effort and magnitude level were standardized before being entered into the model. Statistically significant *p* values (<0.05, two-sided) are shown in bold. CI = confidence interval.

Table S2. Resuslts of linear regression models predicting rating data of difficulty, effort, and liking

	Difficulty			Effort			Liking		
Predictors	*Estimates*	95% CI	*p*	*Estimates*	95% CI	*p*	*Estimates*	95% CI	*p*
Intercept	3.96	3.67 to 4.25	**<0.001**	5.16	4.64 to 5.69	**<0.001**	6.39	6.01 to 6.77	**<0.001**
Recipient	0.19	-0.13 to 0.50	0.254	-0.32	-0.58 to -0.06	0.015	-0.62	-0.97 to -0.27	**0.001**
Effort	2.38	2.20 to 2.56	**<0.001**	1.90	1.55 to 2.25	**<0.001**	-1.79	-2.11 to -1.47	**<0.001**
Recipient: Effort	0.07	-0.16 to 0.30	0.548	-0.11	-0.30 to 0.09	0.269	-0.28	-0.51 to -0.04	**0.023**
Observations	400			400			400		

Notes. The final model for rating data as: Rating ~ Effort * Recipient. Effort level was standardized before being entered into the model. Statistically significant *P* values (<0.05, two-sided) are shown in bold. CI = confidence interval.

Table S3. Results of a linear mixed-effects model predicting RewP amplitudes in response to reward feedback in the prosocial effort task

Predictor	*Estimates*	95% CI	*p*
Intercept	2.94	1.95 to 3.92	**<0.001**
Recipient	-0.68	-1.19 to -0.18	**0.008**
Effort	-0.06	-0.27 to 0.14	0.560
Magnitude	0.43	0.22 to 0.63	**<0.001**
Valence	-1.08	-1.55 to -0.61	**<0.001**
Recipient:Effort	-0.55	-0.96 to -0.14	**0.009**
Recipient:Magnitude	-0.38	-0.79 to 0.02	0.063
Effort:Magnitude	-0.04	-0.24 to 0.17	0.725
Recipient:Valence	0.58	-0.23 to 1.39	0.161
Effort:Valence	-0.19	-0.60 to 0.22	0.368
Magnitude:Valence	0.13	-0.28 to 0.53	0.532
Recipient:Effort:Magnitude	-0.50	-0.91 to -0.09	**0.018**
Recipient:Effort:Valence	0.69	-0.14 to 1.51	0.102
Recipient:Magnitude:Valence	0.86	0.05 to 1.67	**0.038**
Effort:Magnitude:Valence	0.07	-0.34 to 0.48	0.734
Recipient:Effort:Magnitude:Valence	0.70	-0.13 to 1.53	0.097
Observations	7566		

Notes. The final model for RewP as: Amplitude ~ Recipient * Effort * Magnitude * Valence + (Recipient + Valence | Participant). Effort and magnitude level were standardized before being entered into the model. Statistically significant *p* values (< 0.05, two-sided) are shown in bold. CI = confidence interval.

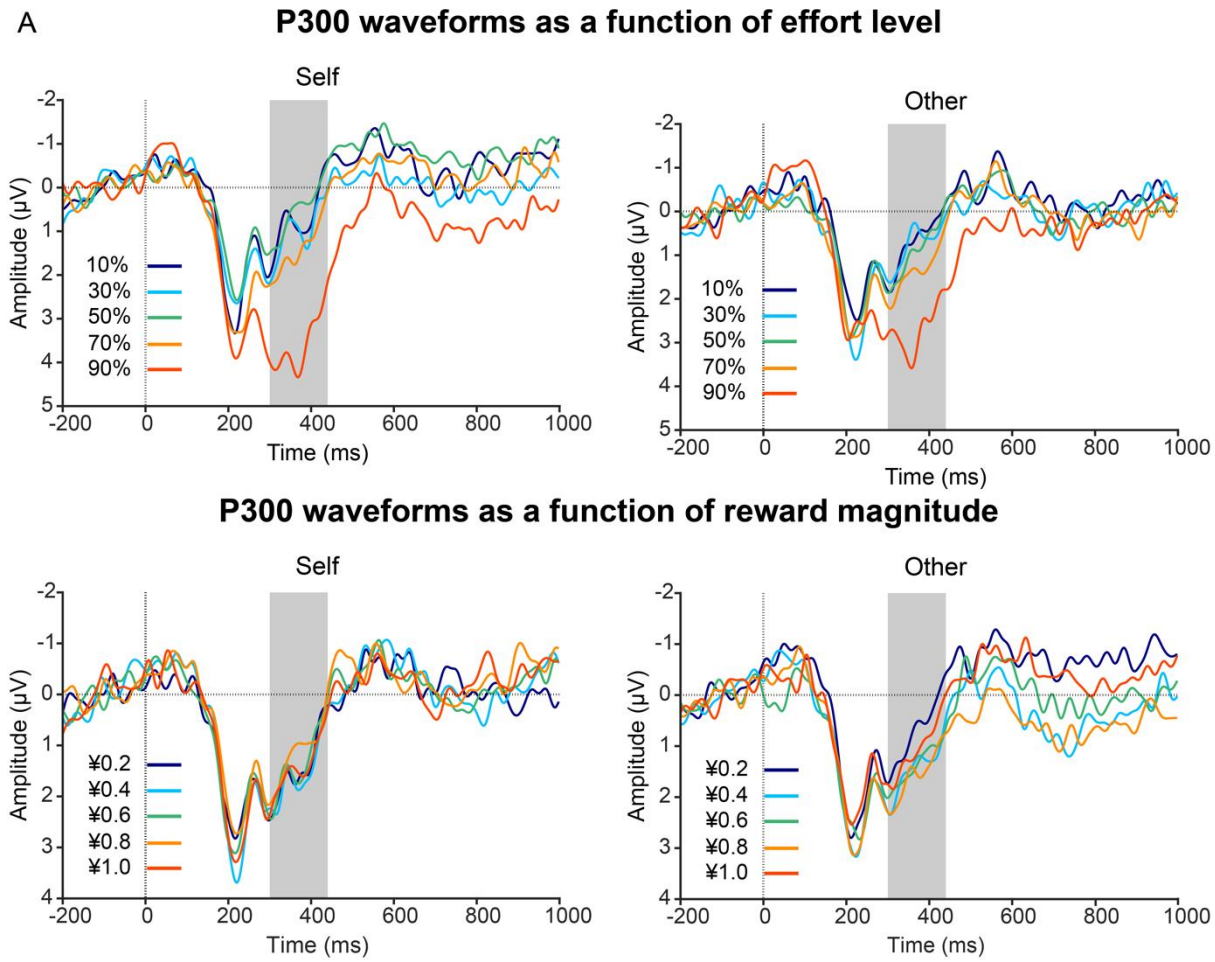

Figure S1. Grand-average ERP waveforms and topographic maps of the P3 as a function of recipient (self vs. other) separately for effort (A) and reward (B) trials. Gray shaded bars represent time windows used for quantification.

Table S4. Results of a linear mixed-effects model predicting P3 amplitudes in response to performance feedback in the prosocial effort task

Predictor	*Estimates*	95% CI	*p*
Intercept	1.31	0.76 to 1.87	**<0.001**
Recipient	-0.15	-0.48 to 0.19	0.393
Effort	0.72	0.46 to 0.98	**<0.001**
Magnitude	0.01	-0.16 to 0.18	0.904
Recipient:Effort	-0.19	-0.53 to 0.16	0.285
Recipient:Magnitude	0.17	-0.16 to 0.51	0.319
Effort: Magnitude	-0.13	-0.30 to 0.04	0.131
Recipient:Effort:Magnitude	0.00	-0.34 to 0.34	0.984
Observations	7469		

Notes. The final model for the P3 as: Amplitude ~ Recipient * Effort * Magnitude + (Effort | Participant). Effort and magnitude level were standardized before being entered into the model. Statistically significant *p* values (< 0.05, two-sided) are shown in bold. CI = confidence interval.

Table S5. Resutls of linear mixed-effects models predicting decision times (left) and choices (right) in the prosocial decision-making task

	Decision times			Choices		
Predictors	*Estimates*	95% CI	*p*	*Log odds*	95% CI	*p*
Intercept	1.41	1.33 to 1.48	**<0.001**	1.69	1.18 to 2.19	**<0.001**
Recipient	0.05	0.01 to 0.09	**0.009**	-1.67	-2.24 to -1.10	**<0.001**
Effort	0.04	0.01 to 0.06	**0.001**	-1.95	-2.08 to -1.82	**<0.001**
Magnitude	-0.04	-0.05 to -0.03	**<0.001**	1.48	1.36 to 1.60	**<0.001**
Recipient:Effort	-0.04	-0.07 to -0.02	**0.001**	0.12	-0.14 to 0.38	0.358
Recipient:Magnitude	0.04	0.02 to 0.07	**0.001**	-0.52	-0.75 to -0.28	**<0.001**
Effort:Magnitude	0.03	0.02 to 0.05	**<0.001**	0.07	-0.04 to 0.17	0.233
Recipient:Effort: Magnitude	0.02	-0.01 to 0.04	0.190	0.08	-0.14 to 0.29	0.481
Observations	5945			5945		

Notes: The final model for decision times as: Decision times ~ Recipient * Effort * Magnitude + (Recipient + Effort | Participant), and for the proportion accepted as: Proportion accepted ~ Recipient * Effort * Magnitude + (Recipient | Participant). Effort and magnitude level were standardized before being entered into the model. Statistically significant *p* values (<0.05, two-sided) are shown in bold. CI = confidence interval.