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Citation for published version:
Jin, X, Zhang, D & Chevalier, N 2024, 'Influences of social and non-social rewards on cognitive control in childhood', *Cognitive Development*, vol. 69, 101413. https://doi.org/10.1016/j.cogdev.2023.101413

Digital Object Identifier (DOI):
10.1016/j.cogdev.2023.101413

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Conflict of interest disclosure

- We have no conflict of interest to declare

Acknowledgement

- This research project is supported by Science Foundation of Beijing Language and Culture University (supported by "the Fundamental Research Funds for the Central Universities") (22YJ250003). We would like to thank the parents and the children who participated in the research.

Data availability statement

- The data that support the findings of this study are available on reasonable request from the corresponding author: Xiaoyu Jin. The data are not publicly available due to privacy or ethical restrictions.

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Research Highlight

- Social rewards, but not non-social rewards, promoted cognitive control in children when the two reward types were matched on other important reward dimensions.
- Social rewards did not modify the reactive or proactive mode of control engagement.

Abstract

The modulation of cognitive control by rewards has long been discussed, but there is scarce evidence of how social and non-social rewards influence cognitive control in childhood, especially in the preschool years. Critically, sociality has often been confounded with other important reward dimensions (e.g., tangibility) in prior studies, hence potentially misestimating the effect of social rewards. Thus, the present study re-examined the effects of social and non-social rewards on cognitive control, particularly on proactive and reactive control engagement during childhood. Thirty 5- to 6-year-olds and thirty 9- to 10-year-olds completed an AX-Continuous Performance Task (AX-CPT) during an online session in three conditions: control, social reward, and non-social (i.e., monetary) reward conditions. Social rewards increased younger and older children's response accuracy, suggesting greater cognitive control. However, no influence on how children engage cognitive control (i.e., proactively or reactively) was observed. The provision of non-social rewards did not influence cognitive performance in either group of children. When controlling for other reward dimension, we found evidence that social rewards, but not non-social rewards, can promote cognitive control performance in childhood.

Keywords

Children; Cognitive control; Social reward; Non-social reward

1. Introduction

Cognitive control refers to the higher-order processes that allow individuals to flexibly regulate and coordinate thoughts and behaviour in accordance with internal goals or plans (Miller & Cohen, 2001). It is a key predictor of some important life outcomes, such as academic achievement (e.g., Kubota et al., 2020). As children grow up, they gradually engage cognitive control more efficiently, including better recruitment of proactive control during early childhood. Efficient cognitive control engagement requires the dynamic adjustment of cognitive resources to fulfil moment-to-moment variations in task demands. Such adjustment includes the engagement of cognitive control either proactively or reactively (Braver, 2012; Braver et al., 2008). Proactive control is achieved through the anticipation of upcoming task demands in order to minimise the subsequent interference, and hence is advantageous when upcoming task demands are foreseeable. Conversely, reactive control is a "late-correction" mechanism that involves overcoming current interference after it has occurred, which is advantageous when upcoming task demands are unpredictable. Children, who initially rely mostly on reactive control engagement, start to engage proactive control spontaneously around the age of 5 to 6 years (despite being already capable of this control mode before then) and gradually engage either control mode more flexibly as a function of task demands over the school years (Chatham et al., 2009; Chevalier et al., 2020; Gonthier et al., 2019).

Given the pivotal role of cognitive control in human development, there has been longstanding research interest in identifying the factors that may support cognitive control processes in childhood. This research has stressed the role of external rewards, a commonly used motivator for facilitating children's performance at school and home. By providing non-social “monetary” rewards (e.g., stickers, stamps), prior works have shown that reward prospects can improve children’s cognitive control performance (Atkinson et al., 2019; Qu et al., 2013; Tarullo et al., 2018). However, in practice, parents and teachers also often use social rewards (e.g., smiles, verbal praise, honour certificates) to encourage and motivate children to stay on task and perform well. Chief among such social rewards is social acceptance (i.e., a positive evaluation of the self by others in the society) and social status (i.e., being at the top of the social hierarchy) (Saxe & Haushofer, 2008; Zink et al., 2008). Neuroimaging studies suggest that there are not only overlaps but also differences between neural processing of social and non-social rewards (for a review, see Ruff & Fehr, 2014). Recent evidence shows that the elaborate process of social rewards is relied on relatively more cortical areas (Atzil et al., 2023). Research on clinical populations also points at different processes for each reward type (for a review, see for Bottini, 2018). For instance, autism, which is characterised by social impairment, has been argued to be associated with aberrant processing of social but not non-social rewards (Chevallier et al., 2012; but note there is disagreement in the literature, see Clements et al., 2018). The main difference between social and non-social rewards seems to be whether the feedback stimulus is embedded with social messages.

The few existing studies that have examined the effect of social rewards on cognitive control during childhood have yielded mixed findings. Some studies have shown that social rewards can increase cognitive performance in preadolescents aged 8 to 12 years as effectively as non-social rewards (Demurie et al., 2011, 2012; Wang et al., 2020), while others have found a weaker effect compared to non-social rewards (Kohls et al., 2009; Wang et al., 2017). Among preschoolers, an fNIRS study found that the provision of social rewards (i.e., mother’s smiley face), but not non-social rewards, enhanced brain activation in the right inferior frontal gyrus (IFG) – a brain region related to cognitive control functioning

(Lertladaluck et al., 2020). Such a finding was also observed on the behavioural level recently in 7- to 9-year-old children (Liu et al., 2022). Younger children may be more responsive to social than non-social rewards. As “social animals”, human beings are often thought of as being “pre-wired” to prefer social to non-social stimuli from an early stage of life throughout the life span (Legerstee, 1991; Stavropoulos & Carver, 2014; Vernetti et al., 2018; Weisberg, 1963).

However, aside from this recent empirical evidence, little is known about the effect of social rewards on cognitive control during the preschool years, and especially its influence on how children engage cognitive control. Social rewards delivered as verbal praise can encourage children to believe that their intelligence is malleable rather than fixed, leading them to focus on what they can learn through effortful activities (Haimovitz & Dweck, 2017). In prior works, such metacognitive monitoring has been associated with increased proactive control engagement in childhood (e.g., Hadley et al., 2020). Accordingly, social rewards may encourage children to metacognitively monitor how to best engage cognitive control and hence increase proactive control in early childhood. Given that monetary non-social rewards have already been shown to increase proactive control engagement in childhood (Jin et al., 2020; Strang & Pollak, 2014), empirical studies are needed to determine whether social rewards can influence preschoolers’ cognitive control in general and proactive mode of cognitive control in particular to a greater extent than non-social rewards.

Although social and non-social rewards are labelled by their difference in sociality, they often differ in multiple other reward dimensions, which makes it difficult to draw conclusions about whether and how social and non-social rewards differentially influence cognitive control (Matyjek et al., 2020). Specifically, in most of the developmental studies mentioned above, children were promised *tangible* (i.e., concrete, substantial, and easily measurable) bonus money/stickers for accurate and prompt responses in non-social reward conditions but only received an *intangible* (i.e., abstract and less measurable) smiley face in return for good performance in social reward conditions. Besides, a simple smiley face (social reward) and monetary bonus (non-social reward) may also potentially differ in their *temporal property* (immediate feedback vs. delayed gratification), *primacy* (primary reinforcer stemming from innate biological states vs. secondary reinforcer acquired with experience) and *familiarity* (familiar vs novel feedback stimuli). Importantly, some of these reward dimensions have indeed been found to influence children's and adolescents' cognitive performance (Demurie et al., 2012; Pankert et al., 2014; Woolley & Fishbach, 2016). For instance, only tangible (but not intangible) social rewards can enhance preadolescents' cognitive performance as effectively as non-social monetary rewards (Demurie et al., 2012). Thus, the previously observed different influences of social and non-social rewards on children's cognitive control may not necessarily reflect differences in sociality. Therefore, the question of whether and how social and non-social rewards may differently influence children's cognitive control needs to be revisited while the two reward types are matched as much as possible on other important reward dimensions.

Furthermore, children's responsiveness to social and non-social rewards may also be influenced by their personality traits, which may predispose some children to be more easily encouraged in real life. Children with higher reward sensitivity, compared to children with a lower tendency for reward seeking, may tend to prioritise activities that could bring positive outcomes or reward gains. In addition, when exploring the role of social rewards, it is important to consider to what extent a child is susceptible to social-emotional feedback. For instance, children with higher empathy levels may understand social-emotional signals better and thus may value such social feedback from others more (Findlay et al., 2006; Zajdel et al., 2013). In particular, children with greater sensitivity to reward motivations (i.e., responsiveness to reward incentives over punishments; that is, a reward-seeking tendency) and social-emotional signals (i.e., the empathic ability to understand and sense other people's emotions or feelings) seem to benefit more from non-social and social rewards respectively when it comes to cognitive control in middle childhood (Kohls et al., 2009). However, such associations were not observed in preschoolers (Lertladaluck et al., 2020). Given the paucity of studies, it is difficult to decide whether these mixed findings reflect a growing association between children's personality traits and the influence of social rewards with age or simply differences in the social rewards used across studies. There is a need to further examine the association between children's personality traits, such as reward sensitivity and social-emotional competence (e.g., empathy), and their responsiveness to different types of rewards by directly comparing preschoolers with older children.

The present study aimed to re-examine the influence of social and non-social rewards on cognitive control engagement in childhood, while efforts were made to match social and non-social rewards on other reward dimensions. We targeted 5- to 6-year-old preschoolers, who are new to proactive control engagement (Chevalier et al., 2020; Lucenet & Blaye, 2014; Troller-Renfree et al., 2020), and 9- to 10-year-old schoolers, who are able to engage proactive control more efficiently (Chevalier et al., 2015; Lorsbach & Reimer, 2010), as the likelihood to observe reward-based changes in reactive vs proactive modes of control may depend on children's proficiency with proactive control. Both groups of children completed an AX-Continuous Performance Task (AX-CPT) in three reward conditions: social, non-social, or no reward. We expected both social and non-social rewards to enhance cognitive control and, specifically, to encourage proactive control engagement in both younger and older children. These rewards should yield a greater shift to proactive control in younger than older children, since preschoolers do not engage proactive control as skilfully as school-age children. Also, if social signals are especially salient, the effect of social rewards should be stronger than non-social rewards. We additionally assessed children's reward sensitivity and empathic ability in order to explore their associations with the influence of social and non-social rewards on cognitive control. We hypothesized that children with higher empathy levels and reward sensitivity would benefit more from social rewards and non-social rewards respectively, relative to those with poor empathy and lower reward sensitivity.

2. Method

2.1 Participants

A total of 60 typically developing children participated in the current study, including thirty 5- to 6-year-olds (M = 6.44 years, SD = 0.47 years, 14 girls) and thirty 9- to 10-year-olds (M = 10.14 years, SD = 0.76 years, 17 girls). A priori power analysis with G*Power 3.1 (Faul et al., 2009) indicated that, to achieve a statistical power of 0.85 with a medium effect size of 0.25 (Cohen, 1969), a minimum sample size of 22 participants was needed for each age group. Considering the sample sizes in this very field (Lertladaluck et al., 2020; Liu et al., 2022; Wang et al., 2017) and the potential difficulty that the online data collection could be facing (e.g., experimental errors), we conservatively stopped data collection when the sample size for each age group reached at 30 participants. All participants were recruited from the database of the Wee Science lab at the University of [***] in Scotland. Before starting the session, informed online consents were obtained from the children's parent, and all children provided their oral consents to participate in the study. After completing the session, each child received an honour certificate and a £3 Amazon voucher, while their accompanying parents received a £10 Amazon voucher as compensation for their time. Both the certificate and the vouchers were sent to the family via the parent's email.

2.2 Materials and procedure

First, before the session, parents were emailed a set of parental questionnaires, which were needed to be completed and emailed back before the online testing, and the link to the online task was emailed to the family soon afterwards. Then, a trained experimenter tested all children in a 30-minute online session. Throughout the whole online session, the experimenter monitored the experiment (both the shared screen of the participant's computer and the computer camera) through Skype or Zoom window. After a quick warm-up via Skype or Zoom calls, all children followed the experimenter's instruction and completed the AX Continuous Performance Task (AX-CPT, introduced as the "Where is the Cat" game) three times via a child-friendly online platform called Gorilla (www.gorilla.sc; Anwyl-Irvine et al., 2020), each time (block) with a different reward type: control, social reward and non-social. To prevent potential order effects, the reward condition order was counterbalanced across participants using a Latin Square design. Besides, a 3-minute rest was provided between each two blocks and the testing session was kept within 30 minutes to prevent the fatigue or boredom of children. Critically, we tried to match the social and non-social rewards provided in the task on several important reward dimensions. In the social reward condition, children were told they would win an honour certificate if they performed well in the game. Further, each correct response was rewarded with a picture of the experimenter's praise face whereas errors were followed by a picture of the experimenter's neutral face. Positive facial expressions, likely acting as reinforcers that alter the probability of a particular behaviour will be carried out in the future (Schultz, 2004), have been found to regulate children's task performance when they were provided as response feedback (Kohls et al., 2009; Liu et al., 2022; Sorce et al., 1985). Furthermore, infants show greater activation in the medial frontal cortex (MFC) and orbitofrontal cortex (OFC) - both involved in the reward network – following exposure to smile faces (Minagawa-Kawai et al., 2009), suggesting that positive facial expressions are perceived as a social reward from early on. In the non-social reward condition, children were told they would win some pocket money if they performed well. Correct responses and errors were followed by a coin win-or-lose picture, respectively. As a result, both types of reward were tangible (certificate vs. money; dimension of *tangibility*) and had both immediate and delayed effects (rewarding feedback after each trial and delayed tangible rewards at the end of the session; dimension of *temporal property*). Also, since social and non-social rewards were either provided as social praise from a stranger (the experimenter) or a financial symbol (money), they were also balanced on the dimensions of *familiarity* (i.e., novel rewards) as well as *primacy* (i.e., secondary reinforcer acquired from learning and experience).

During the testing session, parents were only allowed to help their children set up the computer and to scaffold them while the task instructions were not fully understood, such as how to use the keyboard and how to start the task, between each formal test. Other than that, parents were asked to sit behind their children quietly and allow their children to complete the task independently.

2.2.1 The AX continuous performance task (AX-CPT)

The AX-CPT, adapted from Chatham et al., 2009, was used to measure the dynamics between proactive and reactive control engagement and administered online using the Gorilla platform (www.gorilla.sc; Anwyl-Irvine et al., 2020). In the AX-CPT, children had to respond to a series of prime-probe combinations. They were asked to provide a target response to a specific prime-probe combination (A prime followed by X probe, i.e., AX trials), and a non-target response to all other combinations (A prime followed by Y probe, B prime followed by X or Y probe, i.e., AY, BX, and BY trials). There were two cartoon pictures presented as the prime (i.e., penguin and dog) and two cartoon pictures presented as the probe (i.e., cat and monkey). Children were instructed to help the penguin find the cat to have fish meals together, because only penguin and cat love eating fish. Children had to press the “feeding bowl” button (target response) when the penguin (i.e., A prime) was followed by the cat (i.e., X probe; AX trials), and to press the cross button (non-target response) for any other animal combinations (i.e., penguin-monkey, AY trials; dog-cat, BX trials; dog-monkey, BY trials). The computer keyboard was the only input device allowed. Children's responses were collected via the keyboard connected to their computer with the "f" and "j" buttons used as target and non-target response keys. The AX target trial was the most frequent combination, which occurred with 70% frequency, randomly intermixed with other three types of non-target trials (i.e., AY, BX and BY trials) that each occurred with 10% frequency.

Children could either proactively maintain the prime and prepare for the most likely response for this prime before the onset of the target probe, or reactively retrieve the prime and decide on the relevant response after the onset of the probe, hence allowing for the assessments of proactive and reactive control engagements. Due to the high frequency of AX trials, an X probe (cat) most likely followed after the A prime (penguin). If children engaged in proactive preparation, they would expect and prepare for a "bowl" response after seeing the A prime, leading to lower accuracy and slower response time on the infrequent AY trials where the Y probe actually followed the A prime. On the contrary, if children approached the task reactively, they would erroneously retrieve the A prime on the X probe onset, leading to slower and less accurate responses on the infrequent BX trials where the B prime actually preceded the X probe. Hence lower performance (i.e., more errors and longer reaction time) on AY than BX trials indicated proactive control engagement, whereas lower performance on BX than AY trials indicated reactive control engagement.

Each trial (Figure 1a) started with a fixation cross presented for 500 ms, which was followed by a cue prime (penguin or dog). After 500 ms, the prime was replaced by a 1500-ms fixation, followed by a probe (cat or monkey). The probe was presented until a response was made or for up to 3 s, whichever came first. Then, the feedback was presented on the screen for 1000 ms, which was varied across three conditions (Figure 1b). In the control condition, a green checkmark "√" and a red cross "×" were used as feedback signalling correct and incorrect responses respectively, and no additional reward information was provided. In the social reward condition, children saw a praise picture of the experimenter with a thumbs-up and a reward counting message (e.g., “You’ve won 5 points”) after a correct response, or a neutral face of the experimenter and with the message “You’ve lost the point” after an incorrect response. Further, children were told that they would receive an honour certificate (introduced as the “Wee Scientist Certificate”) after the game if they responded correctly in more than 90% of the trials. In the non-social reward condition, a cartoon picture of a coin in a box with a reward counting message (e.g., “You’ve won 5 coins”) was presented after a correct response, whereas a cartoon picture of a red cross in a box with a coin-losing message (e.g., “You’ve lost the coin”) was presented after an incorrect response. Children were also informed that they would win a virtual gold coin after each correct response, which could be accumulated and later exchanged for real money at the end of the game.

Children first experienced four demonstration trials with task instructions explained by the experimenter. Then, each child completed eight practice trials without any guidance from neither the experimenter nor the accompanying parent. The demonstration and practice trials could be repeated if necessary. After making sure that all children understood the task, each child then completed two test blocks of 20 trials each in all three conditions (control, social reward, non-social reward conditions; 120 formal test trials in total), which are sufficient to index proactive control engagement in children (Chatham et al., 2009; Chevalier, 2018).

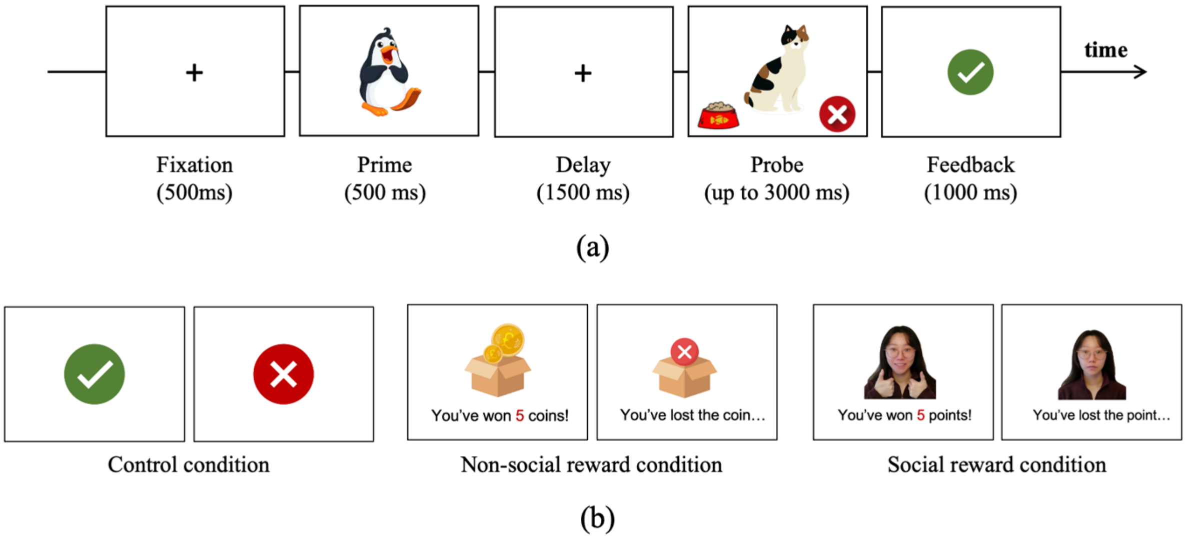

Figure 1. The AX-CPT. (a) Illustration of the AX-CPT (an example of the AX trial). Children were instructed to help the penguin (A prime) find the cat (X probe) to have fish meals together. Another prime (B prime) used in the task was a dog, while another probe (Y probe) was a monkey. Response keys, "feeding bowl" and "X" buttons were presented simultaneously with the probe onset to remind children to respond. (b) Feedback used for the control, non-social reward and social reward conditions.

<u>2.2.2 Subjective rating scale</u>

After each condition, children answered questions related to a subjective rating scale (i.e., three times in total). The scale was adopted from Kohls et al. (2009) to assess children's self-reflection on their experience associated with performing the task in different reward conditions. Children were asked questions about (1) *like* – "how much do you like the game?", (2) *difficulty* – "how difficult do you think the game was?", (3) *performance* – "how well do you think you did in the game?", and (4) *want* – "how much do you want to play the game again?". While the 'difficulty' and 'performance' question aimed at measuring children's self-reflection on task performance, the 'like' and 'want' question assessed how much they were motivated by different rewards. Evidence from the neurobiology of reward motivation have highlighted two dissociated neural systems of motivation (Berridge &

Robinson, 2003): a ‘liking’ component and a ‘wanting’ component. 'Liking' a reward is related to the mesolimbic opioid system, representing the hedonic enjoyment received by an individual for reward consuming, while 'wanting' a reward is related to the mesolimbic dopaminergic system, representing the incentive salience that motivates an individual to seek and to obtain the reward.

Children were asked to report their responses in percentages by dragging a button on a slider (from 0 - “not at all” to 100% - “very much”) using a computer mouse. Evidence has shown that drag-and-drop is an appropriate movement procedure for both preschoolers and elementary school children (Donker & Reitsma, 2007; Grünzweil & Haller, 2009). Nonetheless, considering young children’s inexperience with computer mice, we allowed parents to help them enter their responses using the slider based their children’s oral responses during the subjective rating phrase.

2.2.3 Parental questionnaires

The **Behavioural Inhibition/Activation Scale** (Carver & White, 1994) was used for assessing children’s reward sensitivities. The Behavioural Inhibition System (BIS; Gray, 1990; Gray & McNaughton, 2000) is an aversive motivational system that is sensitive to signals of non-reward, punishment or novelty, and hence leads individuals to inhibit behaviours that may result in negative outcomes (e.g., driving children to avoid making a mess in the room because of being afraid of punishment). On the other hand, the Behavioural Activation System (BAS; Gray, 1990; Gray & McNaughton, 2000) is sensitive to signals to reward, non-punishment, and escaping from punishment, and therefore leads to movements toward goal-related activities. Before online testing, all parents completed the English version of 24-item BIS/BAS (Blair et al., 2004) based on their children’s daily performance on a 7-Likert scale from 1 “extremely untrue” to 7 “extremely true”. Both BIS (Cronbach’s α = 0.70) and BAS (Cronbach’s α = 0.84) showed acceptable internal consistency. In order to reflect children's reward sensitivity, a BAS-BIS difference score was calculated by subtracting the *z*-transformed BIS score from the *z*-transformed BAS score (Kohls et al., 2009; Lertladaluck et al., 2020), which has been reported with higher test-retest stability than the separate scale scores (Sutton & Davidson, 1997). A positive BAS-BIS difference score indicates that a relatively greater sensitivity to reward incentives.

Parents also completed the **Griffith Empathy Measure** (GEM, Dadds et al., 2008) before the online testing session. They were asked to rate the cognitive and affective empathy (i.e., the ability to understand others' emotional states) of their children on a 9-Likert scale from -4 "strongly disagree" to 4 "strongly agree", so that a greater score corresponds to a higher level of empathy. The GEM also showed acceptable internal consistency, Cronbach's $\alpha = 0.86$.

2.3 Data processing and analysis

Reaction times (RTs) were log-transformed to correct for skewness and only correct trials were then analysed after removing values less than 200 ms or over $M \pm 3MD$ (total of 2.24% trials). Given that the gender distribution was balanced between age groups, χ^2 (1) = 6.01, $p = .438$, boys and girls were collapsed for all the reported analyses.

Mixed-model repeated measures analyses of variance (ANOVAs) were performed on both accuracy and log-transformed RTs. Age group (younger children, older children) were added to the models as a between-subject variable, whilst reward condition (control, social reward, non-social reward) and trial type (AX, AY, BX, BY) were added as within-subject variables. Models were fitted using the afex packages (Singmann et al., 2021) in R 4.0.2 (R Core Team, 2020). Greenhouse-Geisser correction was applied if the assumption of sphericity was violated. Subsequent pairwise comparations were then conducted using the emmeans package (Lenth et al., 2020) with Bonferroni correction.

Multiple Pearson correlations were conducted to explore the relationship between task performance and personality traits (i.e., empathy and reward sensitivity) for each age group. For this purpose, an index of proactive control engagement – proactive control behavioural index (PBI, Braver et al., 2009) – was computed by reward condition. PBI is calculated by (AY - BX)/(AY+BX) for both error rates and RTs. A higher positive score indicates more proactive control, while a negative score indicates more reliance on reactive control. To account for multiple comparisons, the Benjamini-Hochberg correction with a false discovery rate of 10% was applied (Benjamini & Hochberg, 1995).

In order to examine the potential effects of different reward types on children's self-reflections, 2 (age group: younger, older children) × 3 (reward conditions: control, social, non-social reward) mixed ANOVAs were run on four subjective rating scores (i.e., "like", "want", "difficulty" and "performance") respectively. Similar to analyses of response accuracy and log-transformed RTs, all analyses were conducted in R with afex and emmeans packages.

3. Results

3.1 Accuracy

Accuracy (Figure 2a) varied as a function of age group, F (1, 58) = 22.25, $p < .001$, $\eta_p^2 = .277$, reward condition, F (1.74, 101.15) = 3.35, $p = .045$, $\eta_p^2 = .055$ and trial type, F (1.79, 103.94) = 5.55, $p = .007$, $\eta_p^2 = .087$. Older children (95.54 %) showed significantly higher accuracy than younger children (86.93%). Compared with the control condition (89.70%), both groups of children responded more accurately in the social reward condition (93.02%), $p = .035$ (Figure 2c). No difference was found between the non-social reward condition (90.98%) and the other two conditions, ps > .352. Children's accuracy for AY (88.19%) and BX (85.56%) trials was significantly lower than BY (96.11%) and AX (95.08%) trials, ps

$< .003$. Yet, no difference was found between AY and BX trials or between AX and BY trials, *p*s > .999. There was an interaction between age group and trial type, F (1.79, 103.94) = 5.55, $p = .007$, $\eta_p^2 = .087$. Younger children had higher accuracy in AY (85.00%) than BX (76.39%) trials, $p = .013$, suggesting a trend of reactive mode. In contrast, no difference between AY (91.39%) and BX (94.72%) trials was found in older children, $p > .999$, suggesting balanced engagement of proactive or reactive control at the group level. No other effects were found, *p*s > .450.

3.2 Reaction times

Log-transformed RTs (Figure 2b) were affected by age group, F (1, 58) = 62.46, $p < .001$, $\eta_p^2 = .541$, and trial type, F (2.20, 116.44) = 53.92, $p < .001$, $\eta_p^2 = .504$. Older children (6.44 log-ms) responded faster than younger children (6.89 log-ms). Children's response speed was significantly slower in AY trials (6.90 log-ms) than in BX (6.60 log-ms), AX (6.59 mog-ms) and BY (6.57 log-ms) trials, *p*s < .001, while no difference was found among the other three trial types (i.e., BX, BY, AX trials), *p*s > .999. There was also an interaction between age group and trial type, F (2.20, 116.44) = 5.62, $p = .004$, $\eta_p^2 = .096$. Although response speed slowed down from BX to AY trials in both younger (BX: 6.85 log-ms, AY: 7.12 log-ms, $p < .001$) and older children (BX: 6.34 log-ms, AY: 6.67 log-ms, $p < .001$), the difference between AY and BX trials increased with age (younger children: $M_{difference} = 0.27$ log-ms, older children: $M_{difference} = 0.33$ log-ms), suggesting greater proactive control engagement with age, and no differences across reward conditions. No other effects were found, $p > .324$.

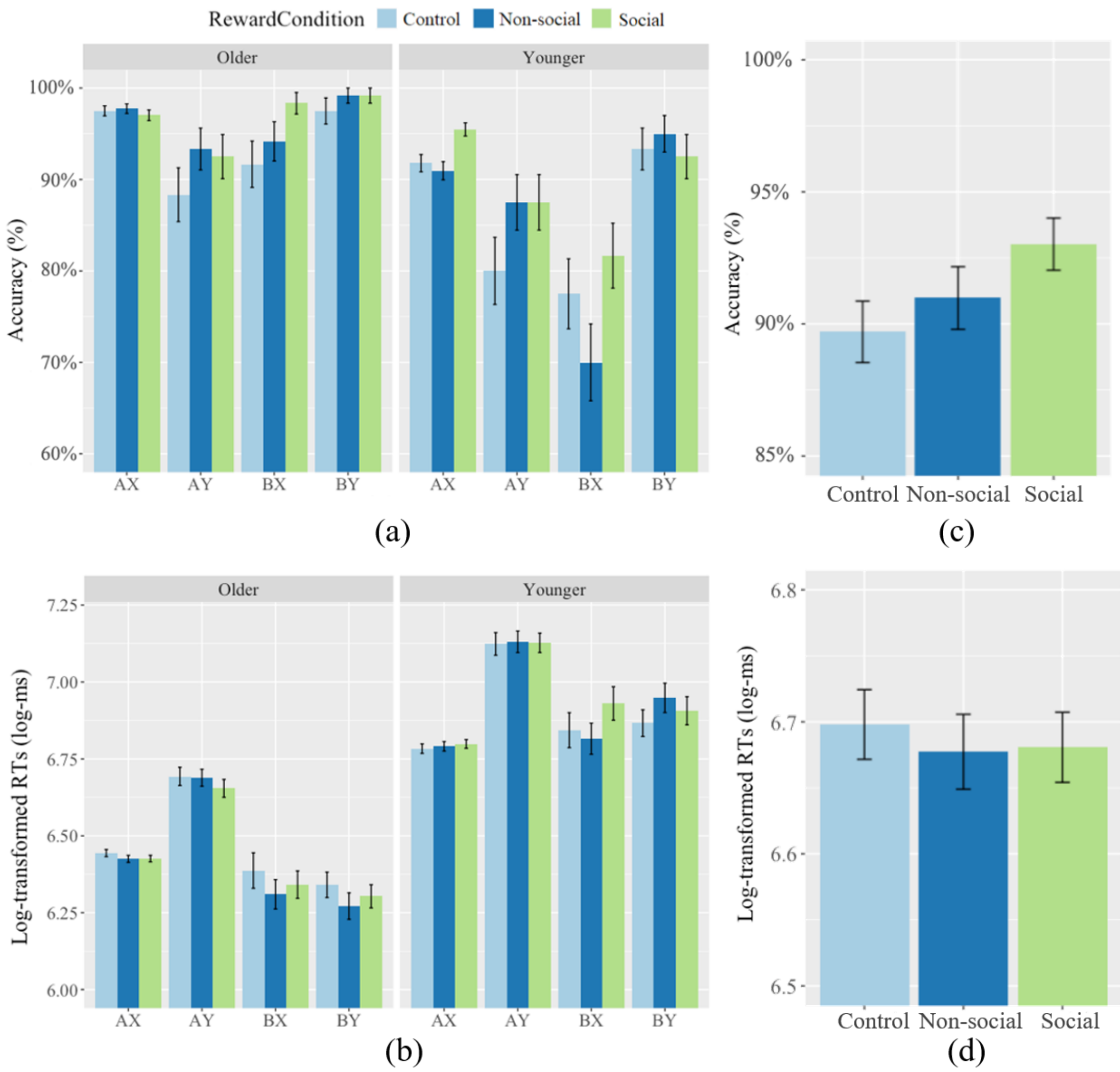

Figure 2. Children's performance in the AX-CPT task. (a) Response accuracy and (b) log-transformed reaction times of younger and older children by reward conditions and trial types, as well as (c) response accuracy and (d) reaction times averaged across all variables except reward conditions. Bars represent standard errors of the mean. Both younger and older children responded more accurately in the social reward condition than in the control condition, while older children showed higher accuracy and faster responses than younger children.

3.3 Associations between cognitive control performance and individual differences

Further, we investigated whether children's task performance (i.e., accuracy, log-transformed RTs, PBI-errors, PBI-RTs) in different reward conditions was associated with parent-reported (1) GEM score of empathic ability and (2) BIS/BAS difference (i.e., reward sensitivity) separately for each age group (Table 1).

In younger children, a positive correlation between response accuracy and empathy was found only in the social reward condition, $r = 0.38$, $p = .038$, suggesting that younger children with higher empathy showed higher accuracy with social rewards. Also, a positive correlation between PBI-errors and the BIS/BAS difference score was found in the control condition, $r = 0.39$, $p = .033$, suggesting that younger children with higher reward sensitivity tended to engage cognitive control more proactively even when no reward was promised. However, neither of these two correlations survived the Benjamini-Hochberg correction for multiple comparisons. No other significant correlations were found, *p*s > .130.

Table 1. Bivariate correlations among task performance, empathy and reward sensitivity

Condition	Task performance	Younger children: Reward sensitivity (Z_{BAS} - Z_{BIS})	Younger children: Empathy	Older children: Reward sensitivity (Z_{BAS} - Z_{BIS})	Older children: Empathy
Control	Accuracy	0.07	0.22	-0.34	0.22
	RTs	0.08	-0.03	0.27	0.01
	PBI-errors	0.39*	0.19	-0.11	-0.18
	PBI-RTs	-0.09	0.07	0.09	-0.02
Non-social reward	Accuracy	-0.28	0.14	-0.06	0.01
	RTs	-0.01	-0.08	0.16	0.11
	PBI-errors	-0.02	0.15	-0.02	-0.06
	PBI-RTs	-0.06	0.31	0.06	-0.15
Social reward	Accuracy	-0.17	0.38*	-0.09	-0.06
	RTs	-0.03	-0.09	0.18	0.05
	PBI-errors	0.10	0.12	-0.13	0.09

PBI-RTs	-0.01	0.31	-0.12	-0.27

* $p < .050$

3.4 Subjective rating

There was an effect of reward condition on children's subjective rating in the "want" question, F (1.79, 103.81) = 5.03, p = .010, η_p^2 = .080. Children wanted to play the non-social reward game (73.45%) more than the control game (64.62%), p = .008, while no difference was found between the social reward game (66.44%) and the other two games, ps > .084. There was also a marginally significant interaction between age group and reward condition on children's self-reflection on their task performance, F (1.88, 109.11) = 2.98, p = .058, η_p^2 = .049. Younger children tended to believe that their performance in the non-social reward condition was worse than in the control condition, p = .051. No other effects were observed, ps > .123 (Table 2). In sum, children seemed to be oblivious to the fact that rewards, especially social rewards, influenced their motivation level or their actual task performance.

Table 2. Result summary of children's subjective rating on the experience associated with performing the task in different reward conditions

Subjective rating	Age group	Control M (SD)	Non-social M (SD)	Social M (SD)	ANOVA Age group	Reward Condition	Interaction
"How much do you *like* the game?"	Younger (n = 30)	77.10% (31.06%)	85.10% (23.14%)	80.00% (30.97%)	F (1, 58) = 0.01, p = .916, $\eta_p^2 < .001$	F (1.91, 110.62) = 1.07, p = .344, $\eta_p^2 = .018$	F (1.91, 110.62) = 0.97, p = .378, $\eta_p^2 = .017$
	Older (n = 30)	79.40% (25.07%)	79.87% (22.13%)	81.07% (23.21%)			
"How much do you *want* to play the game again?"	Younger (n = 30)	62.30% (43.36%)	72.93% (34.61%)	67.93% (39.84%)	F (1, 58) = 0.01, p = .904, $\eta_p^2 < .001$	F (1.79, 103.81) = 5.03, p = .010, $\eta_p^2 = .080$	F (1.79, 103.81) = 1.13, p = .323, $\eta_p^2 = .019$
	Older (n = 30)	66.93% (25.47%)	73.97% (26.83%)	64.97% (27.21%)			
"How *difficult* do you think the game was?"	Younger (n = 30)	22.97% (28.83%)	31.23% (31.79%)	27.23% (31.44%)	F (1, 58) = 1.05, p = .310, $\eta_p^2 = .018$	F (1.96, 113.61) = 2.14, p = .123, $\eta_p^2 = .036$	F (1.96, 113.61) = 0.06, p = .939, $\eta_p^2 = .001$
	Older (n = 30)	18.13% (20.85%)	24.07% (26.44%)	21.67% (19.89%)			
"How *well* do you think you did in the game?"	Younger (n = 30)	89.57% (18.46%)	79.90% (24.58%)	86.40% (20.38)	F (1, 58) = 0.01, p = .904, $\eta_p^2 < .001$	F (1.88, 109.11) = 0.58, p = .561, $\eta_p^2 = .010$	F (1.88, 109.11) = 2.98, p = .058, $\eta_p^2 = .049$
	Older (n = 30)	82.83% (18.60%)	86.80% (17.65%)	84.73% (21.39%)			

4. Discussion

The current study examined the effects of social and non-social rewards on children's cognitive control engagement, while efforts were made to match other important reward dimensions. With the provision of social rewards, both preschool and school-age children responded more accurately than in the control condition but showed no changes in the mode of control engagement. In contrast to our hypothesis, no effect of non-social rewards was observed on children's cognitive control performance, and no robust association was found between children's personality traits (i.e., reward sensitivity and empathy) and their responsiveness to social and non-social rewards.

In line with our hypothesis, social rewards enhanced children's response accuracy, which suggests that social rewards support cognitive control during childhood (Demurie et al., 2011; Wang et al., 2017). Importantly, the current finding is consistent with the previous study on 5- to 6-year-olds, revealing the effective role of social rewards during preschooler years (Lertladaluck et al., 2020). This result supports the assumption that children are sensitive to social signals (Stavropoulos & Carver, 2014) and are responsive to social motivations (Barker et al., 2021; Fischer et al., 2018). Previous research mostly used verbal praise as social rewards and showed that this particular format was effective for enhancing cognitive-related performance in children (Garretson et al., 1990; Lucca et al., 2019). Our results show that non-verbal praise in the form of an experimenter's praise picture and honour certificate also promotes cognitive control in preschoolers. Social praise, whether verbal or non-verbal, may promote cognitive performance through greater intrinsic motivation and self-competence perception (Deci et al., 2001; Dhillon, 2017). It may also promote the perception of seeing effort as important and necessary for learning (Dweck, 2008; Haimovitz & Dweck, 2017), leading to higher willingness to engage more cognitive efforts in order to face the challenge. However, the mechanisms through which social praise affects preschoolers' cognitive control are only speculative at this point and should be addressed directly in future studies.

No effect of non-social rewards was found on children's cognitive performance, which differed from prior evidence showing a beneficial effect of non-social (monetary) rewards on cognitive control in early childhood (Jin et al., 2020; Kohls et al., 2009; Tarullo et al., 2018). Unlike prior in-lab research, the present study was conducted online, including a video meeting and online testing for a videogame-like task, which could have raised children's interest in the task. It is possible that the videogame-like format may have already increased children's motivation across the board, leaving less room to observe the potentially more modest effect of non-social rewards on cognitive control. This seems to be also supported by children's subjective ratings of their experience: though children wanted to play the non-social reward game more than the social reward game ('want' question), no preference ('like' question) was observed for any one of the games (i.e., control, social reward, non-social reward), suggesting an overall high interest in the present tasks. Therefore, the current finding calls for future replications, especially with better controls of children's initial motivation level.

Given the lack of the non-social reward effect in the current study, it appears that the social reward may affect cognitive control to a greater extent than the non-social reward when important reward dimensions (except sociality) are matched as much as possible. This observed pattern aligns with prior studies in 5- to 6-year-old preschoolers (Lertladaluck et al., 2020) and 7- to 9-year-old schoolers (Liu et al., 2022). Unlike the understanding of and interest in money, which is emerging during childhood (Grunberg & Anthony, 1980), sensitivity to social feedback may be "pre-wired" from early on (Goldstein & Schwade, 2008; Stavropoulos & Carver, 2014). Importantly, in the present study, our findings disambiguate prior findings by showing that this effect is likely not driven by other reward dimensions since efforts were made to match reward dimensions other than sociality, including reward tangibility. This is not to say that tangibility does not contribute to the effect of rewards on cognitive control performance. Although tangibility has long been regarded as one of the prominent characteristics of non-social (i.e., monetary) rewards, it may serve as a shared driver of motivating effect regardless of reward sociality. A prior study found that only tangible (but not intangible) social rewards increased task performance in preadolescents (Demurie et al., 2012), highlighting the potentially critical impact of reward tangibility. That is to say, sociality and tangibility have clearly separate (and possibly additive) effects.

Although we originally hypothesised that social rewards offered by means of social praise would encourage children to better reflect on how to best engage control, and consequently lead to more proactive control engagement, no evidence for changes in control modes (i.e., proactive/reactive control) was observed across reward conditions. Both younger and older children showed generally enhanced cognitive control performance (i.e., increased response accuracy) with the provision of social rewards than in the control condition, but they kept the same mode for engaging control. This may be surprising given prior findings showing that monetary rewards can encourage proactive engagement in both children and adults (Jin et al., 2020; Magis-Weinberg et al., 2019; Yee & Braver, 2018). Yet, a similar pattern, enhanced cognitive control with no modification of control mode, was observed in a prior study where social context (i.e., cooperation vs competition) was manipulated (Fischer et al., 2018). This may hint at the relatively lower effectiveness of social motivation in modulating the mode of control engagement than in influencing cognitive control in general. Nevertheless, since children's high interest in the game may already motivate them to engage in the task proactively as discussed above, there have been less room for detecting changes in proactive engagement between reward conditions. Indeed, both younger and older children responded significantly slower in AY trials than in BX trials across all reward conditions, indicating an inclination towards a proactive mode of control even when no reward was provided.

It is also worth noting that the observed effect of social rewards on children's cognitive control performance was modest (with the effect size of η_p^2 = .055). In previous studies, such a similar effect was mainly detected in brain activations but not behavioural performance (Barker et al., 2021; Lertladaluck et al., 2020). Children appear to be responsive to social motivation and thus engage more cognitive effort, but this increase in effort deployment may not necessarily be substantial enough to translate into a behavioural benefit. Given that the present study examined the effect of social rewards at the behavioural level only, they should be complemented with measures (e.g., pupillometry, neuroimaging) that may reveal the potentially subtle effect of social rewards, and more generally social motivation, on children's cognitive control in future work.

Unlike a prior study which found that preadolescents with higher reward sensitivity and empathy levels tended to benefit more from non-social and social rewards respectively (Kohls et al., 2009), we did not observe any robust association between children's personality traits and their cognitive control performance in any reward conditions. Again, this finding appears to be consistent with a previous study with preschoolers (Lertladaluck et al., 2020). Nevertheless, there was a tendency towards an association between empathy and benefits from social rewards in younger children, which seems to suggest that individual differences may affect the efficiency of reward motivation (Hirsh et al., 2008) even in early childhood. If anything, the current finding suggests that previous mixed findings do not reflect the fact that the relationship between social reward effects and personality traits may grow with age. However, since such an effect was not tested as robustly in the present study, this tendency needs to be further examined and confirmed in future work with deliberate designs.

Social rewards, such as social praise, may increase children's perceived self-competence (Dhillon, 2017) and focus on what they can learn through perseverance and effort (Brummelman et al., 2014; Davison et al., 2020) so that they value the necessity of effort in completing challenges and engage more cognitive effort more willingly. This could be informative for supporting cognitive control development in early childhood. Although previous evidence suggested that non-social monetary rewards could be useful for improving cognitive control, there may potentially be practical and ethical issues associated with providing such rewards in the context of education and parenting. The present finding showed that, with other reward dimensions being matched, children also seemed to be responsive to social rewards when it comes to increasing cognitive control, suggesting that parents and teachers could also try to encourage cognitive performance with the help of social rewards when working with children.

Nonetheless, alternative interpretations and methodological issues must be addressed before concluding. First, though positive facial expressions were commonly used as social rewards in previous studies, one may argue that social reward (especially smiling faces) enhanced performance not (or not exclusively) because they perceived as social reinforcers, but because they elicited a positive mood. Qu and Zelazo (2007) found that smiling face targets facilitated children's cognitive flexibility performance, an effect that they argued was driven by positive mood given that neutral and sad face targets did not enhance performance. It is plausible that social reward enhances performance both because of their social nature and because they elicit a positive mood. (Of course, negative social feedback, i.e., the neutral face, would not elicit a positive mood but given high accuracy, the social reward condition likely elicited a positive mood overall.) However, a positive mood is unlikely to account fully for the present findings, as the positive feedback presented in all three conditions are likely to have elicited a positive mood and there is no a priori reason to suspect that a smiling face should elicit a more positive mood than earning money. Importantly, previous evidence have shown that positive facial expressions activate brain regions involved in the reward system (Minagawa-Kawai et al., 2009) and are perceived as rewarding when individuals believe it is contingent to their performance (Krach et al., 2010; Matyjek et al., 2020). Thus, children in the present study likely perceived the praise face that appeared after their correct response as social reinforcers. Nonetheless, future work is needed to understand the respective and possibly cumulative roles of positive stimuli and social rewards in cognitive control during childhood.

Second, another important consideration is whether the social and non-social rewards were equally important to children. If not, importance, rather than sociality, may have driven the difference observed across conditions. Indeed, prior evidence has showed that rewards with higher magnitude are likely to promote cognitive performance (Liu et al., 2022; Wang et al., 2017) and to elicit greater brain activation (Diekhof et al., 2012; Smith et al., 2009) than rewards with lower magnitude. A limitation of the current study is that we did not directly assess how children value these two types of rewards. Yet, their responses on the "want" question may yield some insight. Children wanted to play the game more in the non-social reward condition, suggesting that, if anything, they may have valued non-social rewards more than social rewards (i.e., wanted the non-social reward game more than the other two games). Yet, only social rewards enhanced response accuracy. Thus, perceived reward importance is unlikely to have driven the findings. Nevertheless, future work should look directly into this issue to better understand the role of social and non-social rewards in children's cognitive development.

Third, while the online testing method has important benefits especially when participants cannot visit the lab in person, admittedly it also brings challenges to developmental studies. For instance, children's prior experience with computer and the less-controlled environment at home (e.g., distance to the screen, lighting) are likely to affect task performance. In the current study, we used synchronous (or moderated) online testing to monitor children's responses in real-time with a video-conferencing platform to ensure the assessment was carried out in a satisfactory condition. Besides, to control the potential influence of prior experience with computer, all children had to pass the practice block with responding all trials correct before starting the formal task. Yet, as an interesting new form of data collection, online testing still may corrupt the data unexpectedly. That said, in future, it will be important to design and implement the online developmental study with caution (Zaadnoordijk & Cusack, 2022) and replications for the current study is needed.

In sum, our finding suggests that social rewards can increase cognitive control performance during preschool and school years but without modifying the reactive or proactive mode of control engagement on the behavioural level. In contrast, the effect of non-social monetary rewards is not detectable when other reward dimensions other than the sociality dimension are balanced between the two reward types, suggesting that social rewards may be more promising for promoting cognitive control in children.

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