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PAPER

Differential effects of social and non-social reward on response inhibition in children and adolescents

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Abstract

An important issue in the field of clinical and developmental psychopathology is whether cognitive control processes, such as response inhibition, can be specifically enhanced by motivation. To determine whether non-social (i.e. monetary) and social (i.e. positive facial expressions) rewards are able to differentially improve response inhibition accuracy in typically developing children and adolescents, an 'incentive' go/no-go task was applied with reward contingencies for successful inhibition. In addition, the impact of children's personality traits (such as reward seeking and empathy) on monetary and social reward responsiveness was assessed in 65 boys, ages 8 to 12 years. All subjects were tested twice: At baseline, inhibitory control was assessed without reward, and then subjects were pseudorandomly assigned to one of four experimental conditions, including (1) social reward only, (2) monetary reward only, (3) mixed social and monetary reward, or (4) a retest condition without reward. Both social and non-social reward significantly improved task performance, although larger effects were observed for monetary reward. The higher the children scored on reward seeking scales, the larger was their improvement in response inhibition, but only if monetary reward was used. In addition, there was a tendency for an association between empathic skills and benefits from social reward. These data suggest that social incentives do not have an equally strong reinforcing value as compared to financial incentives. However, different personality traits seem to determine to what extent a child profits from different types of reward. Clinical implications regarding probable hyposensitivity to social reward in subjects with autism and dysregulated reward-seeking behaviour in children with attention-deficit/hyperactivity disorder (ADHD) are discussed.

Introduction

From early infancy onward, goal-directed behaviour is guided by internal states such as affect and motivation (Mischel, Shoda & Rodriguez, 1989). The developing child learns that some stimuli (or situations) are associated with rewarding experiences, whereas others are less rewarding or even punishing. Facial expressions of caregivers, in particular, seem to serve a 'communicatory function' (R.J. Blair, 2003). Faces convey important information to the observer as to whether the stimuli can be approached or should be avoided. Thus, positive and negative facial expressions act as reinforcers that alter the probability of a specific behaviour being executed in the future (W. Schultz, 2004). Indeed, children's behaviour is regulated by both positive (e.g. joy) and negative (e.g. anger) expressions of caregivers (Sorce, Emde, Campos & Klinnert, 1985), and they usually seek appetitive stimuli such as smiles and friendly faces (Depue & Morrone-Strupinsky, 2005). One reason for this might be that happy and smiling faces induce hedonic feelings in the observer, and thus are perceived as social rewards (Chakrabarti, Bullmore & Baron-Cohen, 2006; O'Doherty, Winston, Critchley, Perrett, Burt & Dolan, 2003). In addition to social stimuli, the probable most influential reward is money (Lea & Webley, 2006; Vohs, Mead & Goode, 2006). Money is a so-called secondary reward, as it reinforces behaviour only after its reward value has been learned through association with primary reinforcers such as food or water (e.g. money can be used to obtain food). In children, both the interest in and understanding of the concept of money considerably increases between ages 5 and 7, and are fully established by age 8 (Berti & Bombi, 1981; Grunberg & Anthony, 1980).

Recently, much interest has been shown in the effects of anticipation and 'consumption' of rewards on goal-directed behaviour (Miller & Cohen, 2001), especially on processes of cognitive control (Hare & Casey, 2005; Watanabe, 2007). Cognitive control refers to the ability to suppress or override rival behavioural responses in favour of goal-directed responses (Casey, Tottenham & Fossella, 2002).

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Previously, a range of experimental paradigms has been used to study cognitive control abilities in children and adolescents, including go/no-go tasks (Eigsti, Zayas, Mischel, Shoda, Ayduk, Dadlani, Davidson, Aber & Casey, 2006), Stroop-like tasks (Ciairano, Visu-Petra & Settanni, 2007), antisaccade tasks (Klein & Foerster, 2001), and the stop-signal task (Bedard, Nichols, Barbosa, Schachar, Logan & Tannock, 2002; A.C. Carver, Livesey & Charles, 2001). Developmental studies applying such paradigms have consistently shown that performance (as indexed by false alarm rates and mean reaction times) continues to ameliorate over childhood and appears to reach adult level by mid to late adolescence (see for reviews Bunge & Wright, 2007; Casey *et al.*, 2002). It is suggested that young children's immature inhibitory control is characterized by susceptibility to interference from competing salient information. At the brain level, maturation of cognitive control abilities has been linked to the development (more fine-tuned, focal activations) of the prefrontal cortex, posterior parietal, and striatal brain regions (Casey, Galvan & Hare, 2005).

Ignoring irrelevant information becomes even more complicated when emotional contents are involved (Hare, Tottenham, Davidson, Glover & Casey, 2005; Lewis, Todd & Honsberger, 2007; Maxwell, Shackman & Davidson, 2005). Children and adolescents show greater susceptibility to emotional signals in goal-directed attention tasks than adults (Jazbec, Hardin, Schroth, McClure, Pine & Ernst, 2006; Levesque, Joanette, Mensour, Beaudoin, Leroux, Bourgouin & Beauregard, 2004; Lewis, Lamm, Segalowitz, Stieben & Zelazo, 2006; Lewis *et al.*, 2007; Monk, McClure, Nelson, Zarahn, Bilder, Leibenluft, Charney, Ernst & Pine, 2003), indicating that young individuals' behaviour is more strongly biased by emotional as well as motivational information (Hare & Casey, 2005; Nelson, Leibenluft, McClure & Pine, 2005).

According to Hare and Casey's neurobiological model of cognitive control (2005), interactions of motivational and cognitive processes play a significant role in guiding children's goal-directed behaviour. This model proposes that a higher-order control system (mainly associated with the prefrontal cortex) and a basic motivational approach-avoidance system (linked to limbic structures such as the ventral striatum and amygdala) reciprocally modulate each other in order to facilitate goal-directed controlled behaviour. For instance, signals from the ventral striatum (including the nucleus accumbens) to the prefrontal cortex may initiate approach behaviour towards positive and rewarding stimuli. During development, it seems as if puberty in particular is associated with increased susceptibility to emotional or rewarding stimuli (Ernst, Pine & Hardin, 2006; Nelson *et al.*, 2005; Yurgelun-Todd, 2007). In line with this, Hare and Casey (2005) reported a U-shaped response pattern in an emotional go/no-go task with adolescents showing faster reactions than younger children and adults when approaching positive emotional face expressions. However, so far, the majority of studies have focused on the effects of non-social incentive signals such as monetary rewards, or tokens, on task performance in children and adolescents (Jazbec *et al.*, 2006; Konrad, Gauggel, Manz & Scholl, 2000; Kuntsi, Andreou, Ma, Borger & van der Meere, 2005; Lamm, Zelazo & Lewis, 2006; Lewis *et al.*, 2006). Recently, Jazbec and colleagues (2006) reported that adolescents showed lower performance accuracy than adults in an antisaccade control task, with monetary incentives aligning accuracy to that of adults. This finding suggests that non-social monetary rewards improve inhibitory control to a higher developmental level, probably associated with enhanced neural activation in higher-order control structures (Ramnani & Miall, 2003).

Focusing on the effects of non-social rewards on response inhibition neglects the fact that emotionally loaded (social) stimuli might also be able to affect cognitive control performance (Hare *et al.*, 2005; Lewis *et al.*, 2007; Maxwell *et al.*, 2005). However, recent neuroimaging studies reported that financial reward, in comparison with verbal or other informative reinforcement, is perceived as more motivating to adults. This variation in the affective salience of different feedback types also was shown to modulate brain responses, as measured with fMRI or PET, leading to increased basal ganglia activity when adult subjects were rewarded with stronger incentives (Delgado, Stenger & Fiez, 2004; Kirsch, Schienle, Stark, Sammer, Blecker, Walter, Ott, Burkart & Vaitl, 2003; Thut, Schultz, Roelcke, Nienhusmeier, Missimer, Maguire & Leenders, 1997). No comparable data (either behavioural or neural) are available for children and adolescents.

Thus, the objective of this study was to investigate the extent to which social (positive facial expressions) and non-social (monetary) rewards are able to differentially modulate cognitive control processes in children aged 8 to 12 years. We developed an incentive go/no-go paradigm in order to assess the interactions between response inhibition and facial and monetary reinforcers in typically developing boys. We hypothesized that both social and non-social rewards could enhance children's cognitive control accuracy in a go/no-go task (i.e. reducing false alarms), but that monetary incentives would improve response inhibition even more than social incentives. In addition, we assessed how age and individual differences in personality traits (such as reward sensitivity and empathy) are associated with the effects of reward on cognitive control in the incentive go/no-go task (Colder & O'Connor, 2004). We expected that older subjects and subjects with higher reward-seeking tendencies would benefit more from reward, in particular from monetary reward (Scheres & Sanfey, 2006), than younger children and children with lower reward-seeking scores. In addition, we hypothesized that children with high empathic abilities would profit more from social reward than children with poorer empathy skills.

Method

Subjects

A total of 65 typically developing boys participated in the study, with ages ranging from 8 to 12 years (M = 9.9, SD = 1.1). All children attended a regular primary or grammar school in Germany and showed average performance levels according to their teachers' ratings. All participants who were referred to any psychiatric or educational services due to attention problems, emotional disorders or developmental disorders such as dyslexia were excluded from the study. All subjects were also free from medication. Children with a T-score above 63 in the Internalizing, Externalizing, and Total Problems scales of the Child Behavior Checklist (CBCL 4–18) were excluded. Subjects were recruited through local schools and through advertisement in the research centre Jülich. Each child received 10 Euros plus a participation certificate after finishing the experimental procedure. Prior to testing, informed consent was obtained from all participants and their parents. The study was approved by the Ethics Committee of the University Hospital, Aachen. All 65 children were pseudorandomly assigned to one of four experimental groups (Group 1/social reward, n = 18; Group 2/non-social reward, n = 15; Group 3/mixed reward, n = 16; Group 4/control, n = 16) based on their false alarm rates in the first go/no-go block (see next paragraph for details of the task). We decided for this procedure to ensure that the four groups started the experiment with the same amount of false alarm errors on average. Table 1 summarizes the major group characteristics.

Experimental procedure

'Incentive' go/no-go task

For our 'incentive' go/no-go task (see Figure 1), the letter 'X' served as the no-go stimulus, while the stimuli for the go trials were the letters 'A' through 'E'. The stimuli were pseudorandomly presented in the centre of the computer screen for 500 msec with a fixed intertrial interval (ISI) of 1500 msec. Every no-go trial was preceded and followed by one to four go trials. Children were instructed to respond with their dominant hand as quickly as possible for all go signals, but to inhibit a response for all no-go signals. Feedback – uninformative or informative (see below) – was given after no-go trials and was shown 1500 msec after the offset of the no-go signal for 1500 msec. Feedback stimuli were pseudorandomly presented.

The 'incentive' go/no-go task consisted of two experimental blocks, each block with 150 trials (60% go signals, 40% no-go signals). Block duration was about 5 minutes, and a 10-minute break was scheduled between the two blocks. In the first experimental block, children in all four groups performed the same non-reward condition (baseline condition). In this condition, meaningless feedback was given for successful as well as for

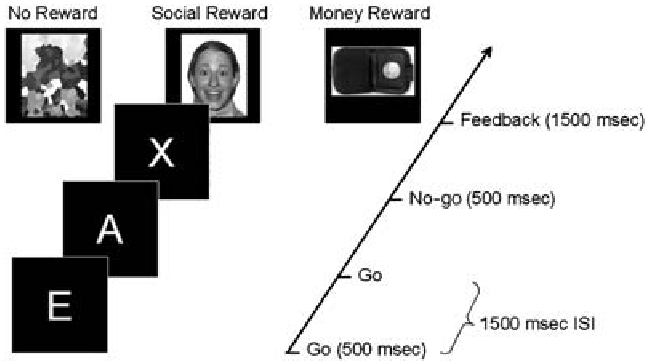

Figure 1 *Illustration of the 'incentive' go/no-go task with the letters 'A' and 'E' as go signals and the letter 'X' as the no-go stimulus. Correct inhibitions were either rewarded with social incentives (i.e. happy facial expressions), with non-social incentives (i.e. money), or remained unrewarded in the non-incentive baseline condition.*

Table 1 *Main characteristics, subjective motivation ratings, and overall performance on the incentive go/no-go task for the total sample and separated for the four experimental groups*

	Total group (N = 65)	Social reward group (n = 18)	Non-social reward group (n = 15)	Mixed reward group (n = 16)	Control group (n = 16)	Group differences (p-values)
Age (M, SD)	9.9 (1.1)	9.8 (1.1)	9.9 (1.3)	10.0 (1.1)	10.0 (0.9)	.93
CBCL (parent rating; T-scores; M, SD)						
Internalizing	52.1 (8.9)	52.7 (7.5)	52.8 (7.8)	51.3 (10.7)	52.0 (9.8)	.97
Externalizing	51.8 (7.6)	51.9 (9.9)	53.0 (5.7)	50.0 (6.6)	52.7 (7.9)	.72
Attention	54.0 (5.1)	56.3 (6.6)	54.3 (4.5)	53.0 (4.7)	52.9 (4.4)	.27
Motivation 1st Block (Mdn)	3	3	3	3	3	.78[a]
Motivation 2nd Block (Mdn)	3	4	4	4	2	<.001[a]
FA 1st Block (M, SD)	29.7 (13.2)	30.0 (10.0)	30.0 (13.9)	29.9 (14.5)	29.1 (15.4)	.99
FA 2nd Block (M, SD)	19.8 (11.3)	20.6 (9.6)	14.2 (10.7)	18.5 (9.6)	25.2 (13.2)	.049
RT hits 1st Block (M, SD)	441 (56)	439 (69)	472 (53)	437 (46)	419 (41)	.07
RT hits 2nd Block (M, SD)	419 (55)	422 (58)	438 (59)	415 (49)	400 (54)	.25

FA = false alarm rate; RT = reaction time.
CBCL = Child Behavior Checklist. CBCL was available from 56 subjects.
[a] p-values are for Kruskal-Wallis χ^2.

failed inhibitions. Children were told that after every no-go 'X', irrespective of their performance, a meaningless mosaic picture would be shown (see Figure 1, left). We decided to include uninformative or meaningless pictures because during pilot testing subjects reported confusion when the timing of the task was changed from the first experimental block (no-go trials were followed by no picture) to the second (no-go trials were followed by feedback pictures).

Depending on group membership, children from the three reward groups were reinforced for successful inhibitions in the second experimental go/no-go block. In the social reward group, happy and exuberant facial expressions served as positive reinforcers (see Figure 1, middle). Neutral facial expressions were shown after false alarms. Caucasian facial stimuli were chosen from the NimStim set (Tottenham, Tanaka, Leon, McCarry, Nurse, Hare, Marcus, Westerlund, Casey & Nelson, in press). In a pre-study, 35 healthy subjects (all students, 11 male, mean age = 28.1, *SD* = 3.3) judged the faces for attractiveness (Adolphs, Tranel & Damasio, 1998). Based on this rating, the most attractive Caucasian faces – five female, five male faces – were included in this study (NimStim numbers 01, 03, 06, 09, 10, 22, 24, 25, 34, 36). In addition, pilot ratings of children revealed that positive facial expressions were perceived as more rewarding, and negative facial expressions (i.e. angry faces) as more punishing than neutral faces. Based on these data, we decided to use happy facial expressions as socially rewarding feedback and neutral facial expressions as socially neutral feedback in our experimental task. All facial stimuli were coloured and equal in size and luminance. Altogether, 20 social stimuli, 10 happy and 10 neutral facial expressions, were used.

Children's correct inhibitions in the non-social group were positively reinforced with money, symbolized by different coloured wallets each filled with a 50 Eurocent coin (see Figure 1, right). Empty wallets were shown after false alarms. Altogether, 20 non-social stimuli – 10 filled wallets and 10 empty wallets – were used. Children in the non-social reward group won an additional three Euros, irrespective of their performance, although they were told that a better performance would result in a higher amount of money paid after the experimental session.

Successful inhibitions in the mixed reward group were reinforced with facial as well as with money rewards presented block-wise (one block = six rewards of the same type). Each child in the mixed reward group also won an additional three Euros, irrespective of his performance, although they were told that a better performance would result in a higher amount of money paid after the experimental session.

Children in the three reward groups were instructed not to count their rewards, because during pilot testing subjects reported counting the rewards after each no-go trial and being distracted from the task. All subjects seemingly followed this instruction, since no volunteer was able to report afterwards the amount of reward he earned.

The control group were instructed to perform the non-reward task twice. Control stimuli were 20 different meaningless mosaic pictures produced with Adobe Photo-Deluxe Home Edition 3.0 (Adobe Systems Incorporated).

Participants were reminded at the beginning of each experimental block to react quickly while maintaining a high level of accuracy. All children were additionally told that they had to press the response button for the go signals within a short time frame of 1 second; otherwise the computer would not be able to record the response. We included this instruction to avoid speed–accuracy trade-offs, particularly in the reward conditions (slowing down the reaction time for go signals to improve accuracy for no-go stimuli).

We decided not to include response cost manipulations in our go/no-go task (e.g. losing money for false alarms in the non-social condition) because we mainly focused on motivational effects of rewarding stimuli but not punishment or punishment avoidance.

To ensure that all children understood the task instructions, all experimental blocks were preceded by 20 practice trials, with the opportunity to repeat the practice trials if needed. After each block, children were required to complete a subjective rating questionnaire to assess self-reported motivation and the child's insight into his performance and aspects of task manipulations. The whole experimental procedure lasted about 40 minutes.

Subjective rating questionnaire

Following each experimental block, children were interviewed with a rating questionnaire. The questionnaire was developed to assess self-reports on the subjective experiences associated with performing the different experimental manipulations. A 5-point Likert-type scale was applied, ranging from 0 to 4. The children were asked (1) how motivating, and (2) how difficult they found the task, (3) how satisfied they were with their performance, and (4) how rewarding they found the different feedback stimuli.

Parental questionnaires

The parents completed the Behavioral Inhibition/Behavioral Activation Scale (BIS/BAS) for their children. According to Carver and White (1994), two motivational systems – a Behavioral Activation System (BAS) and a Behavioral Inhibition System (BIS) – are assessed within this questionnaire. The BIS is sensitive to signals of non-reward, punishment, and novelty and thus inhibits behaviour that may lead to negative outcomes. The BAS, on the other hand, is sensitive to signals of reward, non-punishment, and escape from punishment, and thus causes behavioural activations toward goals. We used the German version of the 24-item BIS/BAS questionnaire (Strobel, Beauducel, Debener & Brocke, 2001) that was modified as a parental report (see for an English version of a BIS/BAS parent report, C. Blair, Peters & Granger, 2004). In order to obtain a composite measure of BIS/BAS sensitivity, we calculated a BIS/BAS difference score by subtracting the *z*-transformed BIS score from the *z*-transformed BAS score (Sutton & Davidson, 1997). A positive difference score indicates relatively greater responsiveness to incentives. Parents additionally completed the Griffith Empathy Measure (GEM). The GEM (Dadds, Hunter, Hawes, Frost, Vasallo, Bunn, Merz & El Masry, 2008) is an adapted parent version of Bryant's Index of Empathy for Children and Adolescents (Bryant, 1982). To apply the questionnaire in this study, the original 23 English items of the GEM were translated into German, and the translation was checked for virtual identity by a native English speaker who is fluent in German. On a 9-point Likert scale, ranging from –4 (strongly disagree) to +4 (strongly agree), parents rated the cognitive and affective empathy of their children.

Statistical analysis

The dependent measures of the go/no-go task – false alarms and reaction times for hits – were analyzed within an ANOVA model with group as the between-subjects factor (four levels) and experimental block as a within-subjects repeated factor (two levels). In cases of significant group effects, further post-hoc comparisons were applied using the Ryan-Einot-Gabriel-Welsh (REGW) *F*-test to control for multiple comparisons. The alpha level was set at .05. In addition, effect sizes were calculated using partial eta squared (η_p^2). Since omission errors were very infrequent (below 3%), they were not included in the analysis.

To analyze the effects of reward feedback and task repetition on subjective rating scores, the Wilcoxon test for related samples was employed. The Kruskal-Wallis test was applied to assess between-group differences, followed by pairwise contrasts using the Critical Difference $D_{\bar{T}(crit)}$, a non-parametric post-hoc test procedure with implicit alpha error protection (Bortz & Lienert, 2003):

$$D_{\bar{T}(crit)} = \sqrt{\chi^2_{crit(\alpha=.05,\, df=3)} \times \frac{N \times (N+1)}{12} \times \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}.$$

In addition, Pearson product-moment correlations were computed to examine the relationship between task performance and (a) age and (b) personality traits (such as empathy and behavioural inhibition/activation) separately for each group. For this purpose, a relative change index was calculated for false alarm rates, accounting for individual performance differences in the baseline condition with the following formula: (false alarm rate first block – false alarm rate second block)/false alarm rate first block. For instance, an individual change index of +1 indicates an improvement of 100%, an index of –1 indicates a decline of 100% from the baseline condition to the second experimental block. Bonferroni corrections were applied in order to adjust the alpha level to multiple comparisons.

Results

Groups did not differ with respect to age ($p = .9$), parental ratings of psychopathology (all CBCL T-scores: $p > .2$), and in the parental ratings of their BIS/BAS system and their empathy (*p*s > .1).

Subjective ratings

The self-ratings after the first block revealed that the groups did not differ in their motivation to complete the task ($\chi^2(3) = 1.1$, *ns*), in their ratings of task difficulty ($\chi^2(3) = 1.7$, *ns*), or in their satisfaction with task performance ($\chi^2(3) = 4.5$, *ns*).

In contrast, after the second experimental block, children in the three reward groups, but not in the control group, rated the task as more motivating than the first block (social reward group: $Mdn_1 = 3$, $Mdn_2 = 4$; $Z = -2.4$, $p = .009$; non-social reward group: $Mdn_1 = 3$, $Mdn_2 = 4$; $Z = -3.2$, $p < .001$; mixed reward group: $Mdn_1 = 3$, $Mdn_2 = 4$; $Z = -2.9$, $p = .001$; control group: $Mdn_1 = 3$, $Mdn_2 = 2$; $Z = -1.1$, *ns*; see Figure 2). The Kruskal-Wallis test showed that groups differed in their motivation to perform the second experimental block ($\chi^2(3) = 17.6$, $p < .001$). Pairwise comparisons showed that the three reward groups were more motivated during the second go/no-go block than the control group: control vs. social reward, $D_{\bar{T}(crit)} = 18.17 < 22.37$, $p < .05$; control vs. non-social reward, $D_{\bar{T}(crit)} = 19.00 < 21.20$, $p < .05$; control vs. mixed reward, $D_{\bar{T}(crit)} = 18.69 < 24.28$, $p < .05$. These data demonstrate that our experimental manipulation was successful.

Concerning satisfaction with task performance, the non-social and the mixed reward groups, but not the social reward and the control groups, reported higher levels of satisfaction in the second go/no-go block as compared to the first (social reward group: $Mdn_1 = 3$, $Mdn_2 = 3$; $Z = -1.1$, *ns*; non-social reward group: $Mdn_1 = 2$, $Mdn_2 = 4$; $Z = -3.3$, $p < .001$; mixed reward group: $Mdn_1 = 2.5$, $Mdn_2 = 4$; $Z = -2.6$, $p = .004$; control group: $Mdn_1 = 2$, $Mdn_2 = 2$; $Z = -0.5$, *ns*). Groups generally differed in their satisfaction ratings in the second experimental block ($\chi^2(3) = 23.7$, $p < .001$). Pairwise comparisons showed that the non-social reward group as well as the mixed reward group were more content with their performance in the second go/no-go block than the social reward and the control groups: control vs. non-social reward, $D_{\bar{T}(crit)} = 19.00 < 29.29$, $p < .05$; control vs. mixed reward, $D_{\bar{T}(crit)} = 18.69 < 23.28$, $p < .05$. No other significant group contrasts were found.

No significant group differences were detected in the second go/no-go block for the subjectively perceived task difficulty ($\chi^2(3) = 6.7$, *ns*).

When children rated the reward value of the feedback stimuli, only the three reward groups perceived the feedback after successful inhibitions as more rewarding in the second experimental block than in the baseline

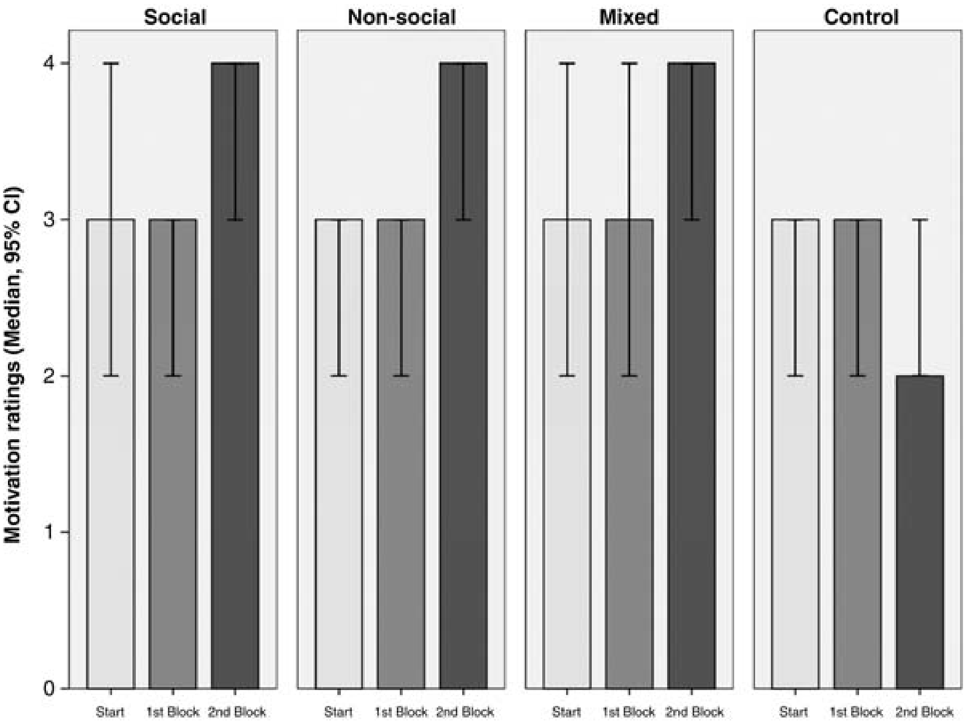

Figure 2 *Motivation rating of the four experimental groups, assessed at the beginning of the experimental procedure, after the first experimental block (non-reward condition), and after the second block. Motivation ratings of the three reward groups after the respective reward condition indicate a possible ceiling effect. Median and 95% confidence interval (CI) are depicted since the distributions of the rating data were skewed.*

condition (social reward group: $\text{Mdn}_1 = 2$, $\text{Mdn}_2 = 3$; $Z = -3.8$, $p < .001$; non-social reward group: $\text{Mdn}_1 = 2$, $\text{Mdn}_2 = 4$; $Z = -3.5$, $p < .001$; mixed reward group: $\text{Mdn}_1 = 2$, $\text{Mdn}_2 = 4$; $Z = -3.5$, $p < .001$; control group: $\text{Mdn}_1 = 2$, $\text{Mdn}_2 = 2$; $Z = -1.7$, *ns*). Groups generally differed in their incentive ratings in the second go/no-go block ($\chi^2(3) = 36.3$, $p < .001$). Here, pairwise comparisons showed that children in the three reward groups perceived the feedback after successful inhibitions as more rewarding than the control group, but reward groups did not differ from each other: control vs. social reward, $D_{\bar{T}(crit)} = 18.17 < 25.55$, $p < .05$; control vs. non-social reward, $D_{\bar{T}(crit)} = 19.00 < 32.77$, $p < .05$; control vs. mixed reward, $D_{\bar{T}(crit)} = 18.69 < 31.69$, $p < .05$.

Task performance

As expected by our pseudorandomized selection of subjects to the four conditions, neither false alarm errors nor RT for hits differed in the first go/no-go block among the four groups ($F(3, 120) = 0.22$, *ns*). Since age was significantly negatively correlated with both false alarm errors ($r = -0.31$, $p = .01$) and reaction time for hits ($r = -0.21$, $p = .05$) in the baseline condition, age was entered as a covariate in the analysis of the performance data.

Group characteristics and task performance for the four groups are summarized separately in Table 1. A 4×2 (Group $\times$ Block) repeated measures MANOVA with age as a covariate, and false alarm rates and RT for hits as dependent measures, revealed a significant main effect for Block, $F(2, 59) = 7.51$, $p = .001$, and a significant Group $\times$ Block interaction, $F(6, 120) = 4.1$, $p = .001$, $\eta_p^2 = 0.17$, indicating that all children improved their performance in the second experimental block, but that feedback type differentially affected performance in the four groups. The following univariate ANOVAs showed that significant Block effects and Group $\times$ Block interaction effects were only related to the false alarm rates (Block effect: $\eta_p^2 = 0.20$; Group $\times$ Block effect: $\eta_p^2 = 0.26$), but not to RTs. The Group $\times$ Block interaction for commission errors is depicted in Figure 3. Post-hoc comparisons using the Ryan-Einot-Gabriel-Welsh (REGW) *F*-test revealed that false alarm rates in the second go/no-go block differed significantly between the non-social reward and the control group ($p = .05$). No other significant group contrasts were found.

Possible speed–accuracy trade-off effects were inspected by calculating correlations between RT for hits and false alarm errors within each of the four groups for the two experimental blocks separately. However, all correlation coefficients were found to be non-significant (*p*s > .1). Moreover, with respect to possible changes in performance strategies from baseline to the second experimental block in terms of slowing down reaction times in order to improve accuracy, we also controlled for associations between ΔRT (RT for hits in the second block minus RT for hits in the baseline) and the individual change index

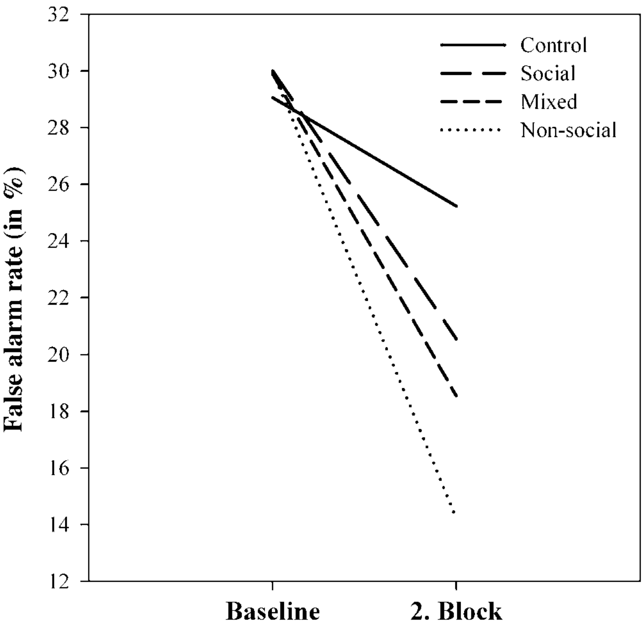

Figure 3 *Change in false alarm rate from the first to the second experimental go/no-go block separated for each group (control group, social reward group, mixed reward group, and non-social reward group).*

for false alarm rates within each of the four groups (see Figure 4). Again, all correlation coefficients were found to be non-significant (*p*s > .1), suggesting that the improvement in task accuracy, on the group level, cannot be simply explained by changes in performance strategies. As illustrated in Figure 4, the majority of subjects became faster and more accurate in the second block across all groups; however, there were also some subjects, in particular in the control group, who performed faster and less accurately at the second assessment. None of the subjects showed increased RTs and reduced accuracy. However, most interestingly there was a small group of individuals (on the right side of the reference line for $x = 0$ and above $y = 0$), who obviously changed their response behaviour by slowing down reaction times to improve inhibition accuracy in the second experimental block (control group: $n = 1$ (6.3%); mixed reward group: $n = 3$ (18.8%); non-social reward group: $n = 1$ (6.7%); social reward group: $n = 3$ (16.7%)). Groups did not differ with regard to number of 'strategy changers' ($\chi^2 = 1.92$, *ns*).

In a final step, we therefore reanalyzed the performance data by excluding those eight subjects from the MANOVA analysis; however, all results remained unchanged.

In addition, we calculated the false alarm error means for each quartile and plotted the four means for the first and second experimental block of the incentive go/no-go task to check for possible bottom effects in performance. Small or no improvements were detected in controls in the first and second quartile, indicating a bottom effect only for task repetition. No bottom effects were visible for quartiles of the three reward groups. Generally,

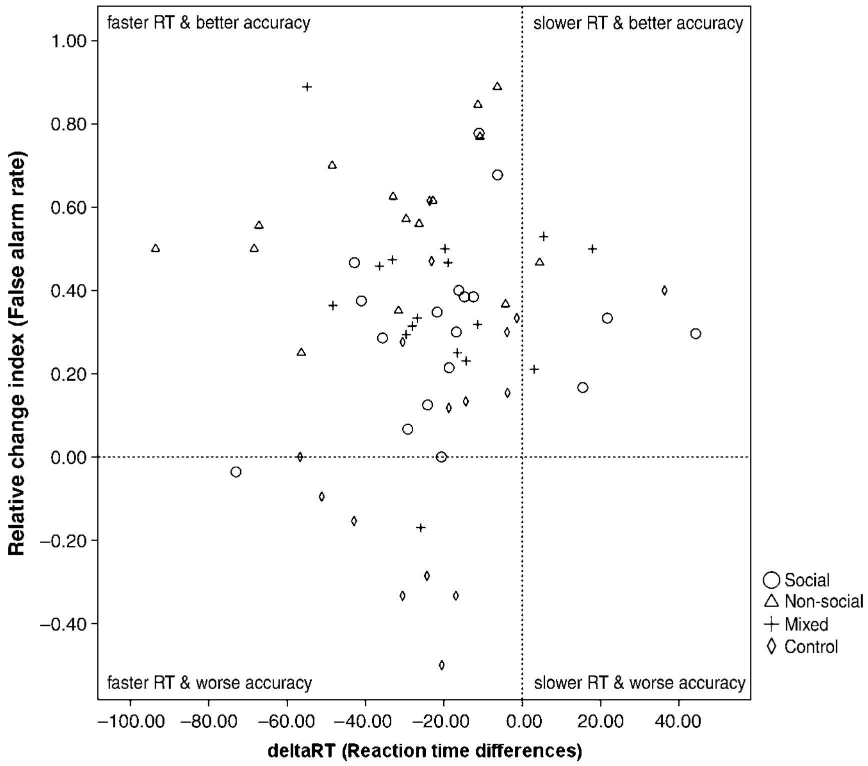

Figure 4 *Scatterplot (with reference lines at* x = 0 *and* y = 0*) shows associations between ΔRT (positive values indicate RT slowing from baseline to the second block) and relative change index for false alarm rates (positive values indicate improvement of inhibition performance from baseline to the second block) within each of the four groups (control group:* r = 0.38, p = .14*; social reward group:* r = 0.24, p = .33*; mixed reward group:* r = –0.19, p = .47*; non-social reward group:* r = 0.31, p = .26*).*

irrespective of group membership, children in the third and fourth quartiles showed a larger decrease in false alarm errors from the first to the second block than children in the first and second quartiles. However, the three reward groups generally showed larger decreases in false alarm errors for all four quartile means than the control group, whereas the non-social reward group showed the biggest improvement.

Association between improvements of cognitive control and individual differences

In the next step, we investigated whether the improvement of cognitive control between the baseline condition and the second experimental block – assessed with the relative change index for false alarm rates – was associated with (a) children's age, (b) parental ratings of BIS/BAS sensitivity, and (c) parental reports on empathy separately for each group.

Age was significantly and negatively correlated with the relative change index only in the control group ($r = -0.62$, $p = .01$). This demonstrates that the older the subjects, the less inhibitory performance improved during task repetition. Contrary to our prediction, correlations were found to be non-significant for the three reward groups, suggesting that age did not impact on the effects of social and non-social incentives.

A positive correlation between the BIS/BAS difference scores and relative change index was found only within the non-social reward group ($r = .66$, $p = .02$), suggesting that children with higher reward sensitivity showed larger improvements of cognitive control with monetary reward. In addition, there was a trend for a positive correlation between GEM scores of empathic abilities (parental rating) and relative change index only in the social reward group ($r = .53$, $p = .05$). However, this correlation did not survive correction for multiple comparisons. No other significant correlations were found.

Discussion

In the present study, we investigated how social incentives in comparison to non-social reward impact on cognitive control performance in typically developing children and adolescents. As expected, we found that both social and non-social reward improved go/no-go inhibition, with monetary rewards being associated with larger improvements in task performance. The effect of mixed incentives (social and monetary) was intermediate. Contrary to our hypothesis, we did not find an age-dependent modulation of response inhibition by reward. However, children's personality traits (such as reward seeking and empathy) were associated with differential effects of social and financial reward responsiveness.

Thus, in line with previous studies (e.g. Hardin, Schroth, Pine & Ernst, 2007; Huang-Pollock, Mikami, Pfiffner & McBurnett, 2007; Jazbec *et al.*, 2006; Jazbec, McClure, Hardin, Pine & Ernst, 2005; Konrad *et al.*, 2000; Kuntsi *et al.*, 2005; Michel, Kerns & Mateer, 2005; Scheres, Oosterlaan & Sergeant, 2001), our results confirmed that reward conditions could enhance performance (i.e. reducing false alarms) in a cognitive control task in children and adolescents. This finding could not be explained by a simple repetition effect. In addition, we could demonstrate that not only monetary incentives but also social incentives acted as effective reinforcers, boosting response inhibition accuracy. The magnitude of these effects is large (effect size for the Group × Block interaction: $\eta_p^2 = 0.26$) (Keppel & Wickens, 2004). Our data support the assumption that smiles and friendly faces are visual rewards that positively reinforce human behaviour (Kringelbach & Rolls, 2003; Sorce *et al.*, 1985). Previously, Garretson and colleagues (Garretson, Fein & Waterhouse, 1990) reported that verbal praise ('Good work!'), another kind of social reward, seemed to help children in maintaining vigilance for a longer period of time in a sustained attention paradigm. However, Garretson's study did not include a non-reward baseline condition, so the effects of social reward could not be clearly determined.

Consistent with our prediction, monetary incentives had a substantially stronger effect in improving response inhibition performance than social incentives. Additionally, those two experimental groups who were monetarily rewarded reported higher levels of satisfaction with task performance. These data suggest that social incentives do not have an equally strong reinforcing value compared to financial incentives. Our findings are consistent with recent neuroimaging studies and behavioural data from adults (Delgado *et al.*, 2004; Kirsch *et al.*, 2003). It has been repeatedly shown that non-social (e.g. money) and social (e.g. facial expressions) incentives activate neural structures that also respond to primary reinforcers such as food or sexual signals (Chakrabarti *et al.*, 2006; Hare *et al.*, 2005; Knutson & Wimmer, 2006; O'Doherty *et al.*, 2003; W. Schultz, 2000). Kirsch and colleagues (2003), for instance, observed worse behavioural performance and significantly reduced brain activations in the neural reward circuit (i.e. nucleus accumbens, orbitofrontal cortex) during the anticipation of social (i.e. verbal) as compared to monetary reinforcement. The authors interpret their results as mirroring the reward-related brain reactivity, with weaker motivating incentives leading to smaller neural activations compared to stronger motivating incentives (see also Delgado *et al.*, 2004). In addition, one could speculate that monetary rewards in our incentive go/no-go task could have caused a significantly stronger effect on response inhibition performance by inducing larger neural activations in structures of cognitive control such as the prefrontal cortex (Hare & Casey, 2005). However, this explanation can be tested only in future neuroimaging studies including children and adolescents.

Alternatively, but not mutually exclusively, it is also plausible that the happy faces used in our study as social reinforcers were less effective incentives, because they represent immediately available and 'consumable' rewards with near-term effects. By contrast, the monetary rewards had longer lasting, and probably stronger, effects since they could be collected and later exchanged for other goods. Recently, several studies addressing delayed gratification in humans supported the finding that subjects are more willing to wait for financial rewards than for directly consumable reinforcers such as food or drink (Estle, Green, Myerson & Holt, 2007; Rosati, Stevens, Hare & Hauser, 2007). According to Estle and colleagues (2007), the different patience level might reflect that money, unlike primary reinforcers such as food, drink, and possibly social rewards, maintains its utility, despite the fluctuation and 'satiation' of desire for this type of reward. Such factors might also contribute to the smaller effects of social compared to monetary rewards on response inhibition.

Although we found the typical association between age and inhibitory control performance in the baseline condition (see for a review Casey *et al.*, 2002) as well as between age and retest effects in the control group (e.g. Günther, Herpertz-Dahlmann & Konrad, 2005), contrary to our prediction, older subjects did not benefit more from reward than younger ones. Recently, Jazbec *et al.* (2006) and Hardin *et al.* (2007) found that monetary incentives had a stronger influence on adolescents compared to adults in an antisaccade control task. Similar findings were reported by Hare and Casey (2005) for social incentives in an emotional go/no-go task. One possible explanation for the inconsistent finding in our study might be that our sample was simply too young and mainly consisted of preadolescent subjects to detect an age effect on reward benefit. Here, future studies including older subjects (checked for pubertal stages) are needed.

In line with our hypothesis, we found that children with higher reward-seeking tendencies showed larger improvements in cognitive control performance than children with lower levels of this personality trait, but only if monetary rewards were used. On the other hand, there was a tendency for an association between benefits from social reward and empathy skills. These results, taken together, indicate that different factors apparently exist which determine to what extent a child profits from different types of reward. Moreover, these results extend the findings of previous studies which have documented individual differences in the efficiency of cognitive control in children and adolescents, perhaps linked to genetic variability (Eigsti *et al.*, 2006; Fan, McCandliss, Sommer, Raz & Posner, 2002; Fossella, Posner, Fan, Swanson & Pfaff, 2002).

The results of this study may also have some noteworthy implications for clinical groups such as attention-deficit/hyperactivity disorder (ADHD) or autism. Current research on ADHD debates to what extent excessive inattention, hyperactivity, and impulsivity, the core symptoms in this patient group, could result from unregulated reward-seeking behaviour (Geurts, van der Oord & Crone, 2006; Luman, Oosterlaan & Sergeant, 2005; Nigg & Casey, 2005; Sagvolden, Johansen, Aase & Russell, 2005). In an earlier behavioural study, Konrad and colleagues (2000) found that impulsive response behaviour in children with ADHD could be ameliorated through non-social incentives, improving accuracy to that of healthy controls. Their observation seems to be in line with our finding that higher reward-seeking tendencies are strongly and positively correlated with improvements in cognitive control accuracy through monetary reward. Our study may also contribute to the current discussion about hyposensitivity to social reward in children with autism (Grelotti, Gauthier & Schultz, 2002; R.T. Schultz, 2005). Different authors assume that the severe deficit in empathy observed in individuals with autism derives from a lack of sensitivity to social reward (e.g. Dawson, Toth, Abbott, Osterling, Munson, Estes & Liaw, 2004). In line with this, we found a tendency for empathic abilities to be associated with responsiveness to social reward in typically developing children. In future studies, it could be promising to use both non-social and social incentives to explore the way in which different types of response contingencies work in different psychiatric disorders. For instance, the application of the incentive go/no-go task in studies including children with autism spectrum disorder might help to obtain deeper insights into the nature of a hypothesized social hyposensitivity in pervasive developmental disorders (see e.g. Garretson *et al.*, 1990). Of particular interest would be the combined use of both incentive types – social as well as non-social – within one paradigm (see our mixed reward condition), allowing a direct comparison of reward responsiveness to social and non-social incentives. Future studies would also benefit from using brain imaging techniques (fMRI, ERP) to increase our understanding of the neural basis of individual differences in reward sensitivity.

There are some limitations to our study that need to be considered. One shortcoming relates to our sample, which consisted solely of boys. Thus, our conclusions are restricted to this gender and cannot be extended to girls. This is particularly relevant concerning the effects of social reward on task performance, since females have been credited with relatively greater appreciation for social-emotional signals than males (e.g. Baron-Cohen & Wheelwright, 2004).

Our experimental observation, that monetary and social rewards had differential effects on response inhibition performance, need to be replicated. It is possible that facial expressions, in particular, have a less powerful reward value compared to other kinds of social reward (e.g. verbal praise, social movies) (Blatter & Schultz, 2006). It will be important for future research to examine this question using different sorts of social incentives in comparison with financial incentives.

It should also be noted that in our task design better inhibition performance influenced earnings at the end of the experiment only in the monetary reward group(s), not in the pure social reward group. This possible confound may have contributed to the stronger effect of monetary reward on response inhibition improvement. Although this is one possibility, it is unlikely that this fully accounts for the patterns reported here. Social and non-social rewards generally differ in themselves with respect to properties such as collectability (i.e. money is collectable, but not social reward), and immediacy of effect (Estle *et al.*, 2007). A direct comparison of the effectiveness of social and monetary reward on behaviour will probably always be biased by such general differences. Future developmental studies are needed to determine why monetary rewards become so strongly influential on young children's behaviour although the developing child is less experienced with this kind of reward compared to social incentives. It seems as if even a limited exposure to money – probably already in early life – is able to systematically modify people's actions and goals, by enhancing individualism and self-sufficiency (Vohs *et al.*, 2006).

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