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When performance and risk taking are related: Working for rewards is related to risk taking when the value of rewards is presented briefly

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ABSTRACT

Valuable monetary rewards can boost human performance on various effortful tasks even when the value of the rewards is presented too briefly to allow for strategic decision making. However, the mechanism by which briefly-presented reward information influences performance has remained unclear. One possibility is that performance after briefly-presented reward information is primarily boosted via activation of the dopamine reward system, whereas performance after very visible reward information is driven more by strategic processes. To examine this hypothesis, we first presented participants with a task in which they could earn rewards of relatively low (1 cent) or high (10 cents) value, and the value information was presented either briefly (17 ms) or for an extended duration (300 ms). Furthermore, responsiveness of the dopamine system was indirectly estimated with a measure of risk taking, the Balloon Analogue Risk Task (BART). Results showed that performance after high- compared to low-value rewards was indeed related to the BART scores only when reward information was presented briefly. These results are suggestive of the possibility that brief presentation of reward information boosts performance directly via activating the dopamine system, whereas extended presentation of reward information leads to more strategic reward-driven behavior.

1. Introduction

Valuable monetary rewards are an effective tool to boost people's performance on a variety of effortful tasks (Camerer & Hogarth, 1999). Traditional models of decision making suggest that this effect can be explained by the fact that people carefully weigh effort investment against the value of the anticipated reward (e.g., Brehm & Self, 1989; Eccles & Wigfield, 2002; Wright, 2008). That is, people may decide after some deliberation that a valuable reward is worth the effort, and then recruit sufficient resources to get it. Recent work, however, suggests that such increases in effortful performance can also be found when the value of rewards is presented very briefly, i.e., below people's threshold of conscious awareness (e.g., Pessiglione et al., 2007). This work suggests that rewards may boost performance more directly, i.e., without the need for an effort-related, strategic decision (Gendolla, Wright, & Richter, 2011; Hassin, 2013). However, the process via which briefly-presented reward cues enhance performance is still rather unclear. The present work was conducted to gain new insight into this question.

A paradigm to study the effects of briefly-presented reward information on performance was developed by Pessiglione et al. (2007). In this paradigm, participants are presented with a coin of relatively low or high value for a short (e.g., 17 ms) or an extended duration (300 ms) on a trial-by-trial basis. Coins are preceded and followed by masks, so that the value of the briefly-presented coins cannot be consciously perceived. Importantly, participants can earn the value of the presented coin by meeting a performance criterion on a subsequent task. Using this paradigm, research has revealed that high-value coins improve performance on various effortful tasks such as squeezing into a handgrip (Pessiglione et al., 2007), updating information in working memory (Capa, Bustin, Cleeremans, & Hansenne, 2011), and mentally rotating letter stimuli (Bijleveld et al., 2014). Notably, these effects have been found irrespective of the duration of the coin presentation (e.g., Capa et al., 2011; Pessiglione et al., 2007; Zedelius, Veling, & Aarts, 2011, 2012). So, it seems that conscious, strategic decisions to employ effort once a high-value coin is at stake do not drive these effects.

To account for these findings, a framework has been proposed that distinguishes between initial and full reward processing (Bijleveld, Custers, & Aarts, 2012b). According to this framework, reward cues receive *initial processing* in a network of subcortical brain structures that includes the ventral striatum (Delgado,

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2007). This mesolimbic dopamine reward system (for the purpose of brevity hereafter referred to as dopamine system) is known to be involved in the recruitment of effort (Phillips, Walton, & Jhou, 2007; Salamone, Correa, Mingote, & Weber, 2005). Also, it has widespread projections to cortical areas that are involved in various aspects of goal-directed behavior (Haber & Knutson, 2009). So, the idea is that these networks involved in processing reward cues soon after they are perceived (i.e., also when they are presented only briefly) can account for the finding that briefly-presented reward cues boost performance on various tasks.

After this initial stage, reward cues are thought to receive *full processing*. This stage is thought to involve brain structures that are involved in making strategic, conscious decisions that require awareness of the value of the reward that is at stake (Cleeremans, 2008; Dehaene & Naccache, 2001), such as the prefrontal cortex. Indeed, such strategic reward-related decisions are only observed when reward cues are presented for an extended period of time (e.g., 300 rather than 17 ms; for examples, see Bijleveld, Custers, & Aarts, 2010, 2012a; Zedelius et al., 2012; for reviews, see Bijleveld et al., 2012b; Capa & Custers, 2014; Zedelius et al., 2014).

In the present research, we take a novel approach to examining the dopamine system's involvement in processing briefly-presented rewards. The reason we sought to address this issue is that previous attempts were rather inconclusive. In an early fMRI study, Pessiglione et al. (2007) found involvement of the ventral pallidum, which is indeed a structure that is part of the dopamine system. However, in the condition in which this effect was found, coins were presented for 50 ms, which is still relatively long (compared to 17 ms). In an EEG study, Capa, Bouquet, Dreher, and Dufour (2012) found that briefly-presented, high-value coins led to a greater contingent negative variation (CNV; suggesting the preparatory recruitment of effort) upon perception of the coin, and to smaller alpha band activity during task performance (suggesting the investment of effort). However, it would be a stretch to infer activity in the dopamine system from this finding. Finally, in a recent fMRI study, no brain effects of briefly-presented, high-value coins were detected at all (which was striking, as these same coins did in fact improve behavioral performance, Bijleveld et al., 2014). Taken together, it is currently not very clear *how* briefly-presented reward cues can influence performance.

Based on the ideas that (a) briefly-presented rewards activate the dopamine system, and that (b) increases in performance due to briefly-presented rewards are a direct effect of this activation, we reasoned that the *sensitivity* of people's dopamine system should predict the extent to which briefly-presented, high-value rewards increase performance. It is important to note that there are strong individual differences in the sensitivity of people's dopamine system (e.g., Buckholtz et al., 2010). Therefore, the present study was designed to examine whether individual differences in the sensitivity of people's dopamine system could predict performance after high-value rewards.

Specifically, in the present research, we test the hypothesis that individual differences in sensitivity of the dopamine system predict the magnitude of the impact of briefly-presented rewards on performance. This prediction is based on the distinction between initial and full reward processing: Although extended presentation of reward information (enabling full reward processing) should initially activate the dopamine system, this activation should be less strongly related to performance (compared to briefly-presented rewards), as higher level cognitive processes may subsequently be recruited (e.g., deliberative strategic considerations to maximize gains in the service of current goals; such as obtaining money to buy lunch). Such subsequent processing may well affect performance independently from mesolimbic dopamine processes. Therefore, we expect individual differences in sensitivity of the dopamine system to be more strongly related to the effect of briefly-presented rewards compared to the effect of longer-presented rewards.

To measure people's sensitivity of the dopamine system, the Balloon Analogue Risk Task (BART; Lejuez et al., 2002) was employed. The BART is a measure of risk-taking behavior in which people repeatedly make choices between two options (a risky vs. a safe option). Higher BART-scores reflect more risk-taking behavior. The reason we selected a risk-taking task to measure individual differences in responsiveness of the dopamine system is that risk taking has been linked to the dopamine system in a number of studies. First, several studies have shown that people's risk-taking tendencies are a function of the availability of dopamine receptors in the midbrain (Buckholtz et al., 2010; Driver-Dunckley, Samanta, & Stacy, 2003; Forbes et al., 2009; Zald et al., 2008). For instance, artificially boosting the dopamine system (using dopamine agonists) can induce pathological gambling tendencies (Driver-Dunckley et al., 2003). Second, risk-taking choices in the BART have been shown to be associated to activity in the dopamine system (e.g., the ventral striatum; Rao, Korczykowski, Pluta, Hoang, & Detre, 2008). Third, and more broadly, people scoring high on BART show behaviors that are plausibly related to the responsiveness of the dopamine system (e.g., they smoke more, have more unprotected sex, respond more strongly to performance pressure; Bijleveld & Veling, 2014; Lejuez, Aklin, Zvolensky, & Pedulla, 2003). Taken together, prior research suggests that people who score high on risk-taking measures, and on the BART specifically, have a more sensitive dopamine system.

To test the hypothesis that the intensity of people's responses to briefly-presented rewards correlate with sensitivity of the dopamine system, we first measured people's performance on a demanding task known to be sensitive to high-value (vs. low-value), briefly-presented rewards (Bijleveld et al., 2012a). Next, participants performed the BART (Lejuez et al., 2003). We expected a positive relation between performance on the BART and performance on high versus low rewarded trials when reward value was presented briefly. However, we did not expect a relation between the BART and performance on high-reward versus low-reward trials when rewards were presented for an extended duration, because in this case behavior is also controlled by more strategic processes (e.g., Bijleveld et al., 2012a).

2. Methods

2.1. Participants and design

Sixty-nine participants were recruited across a period of three weeks in the psychological laboratory at the campus of Utrecht University (a convenience sample). Data of the tapping task was not recorded for one participant and the data for the BART was not recorded for another participant, leaving 67 participants for analyses (35 women; mean age = 22.90, SD = 5.86). Participants received a fixed amount of money for their participation (€3), in addition to money obtained during the performance task (M = €3.05, SD = .66). A 2 (coin duration; extended versus brief) by 2 (coin value: low versus high) within-subjects design was employed with BART score as a continuous predictor.

2.2. Tapping task

To measure performance as a function of coin presentation duration and coin value a task from previous work was used (Bijleveld et al., 2012a). Participants were told that they could earn coins in the upcoming task of low (1 cent) and high value (10 cents), by tapping a space bar within a time limit. Moreover, they read that the coins were sometimes presented very briefly, so that the value could be difficult to perceive. At the start of each trial participants indicated that they were ready by pressing and holding the A button (with their left hand for right handed participants; or L button with their right hand for left handed participants) on a QWERTY keyboard. Next, a fixation cross appeared (1000 ms) followed by a pre-mask (300 ms), the low or high-value coin (17/300 ms), a post-mask (583/300 ms), and another fixation cross (1000 ms). Then 25 circles appeared and participants could tap the G button as fast as possible to earn the coin (i.e., tap 25 times within 3.5 s on experimental trials). To complete a trial participants were required to continuously hold down the A (or L) button (to prevent the possibility of tapping with both hands). After each trial, participants received feedback about whether they had met the performance criterion, and about the total (accumulated) amount of money they had earned.

In the original study (Bijleveld et al., 2012a) task-demands of the tapping task were manipulated by manipulating whether 25 presses needed to be completed within either 3.5 s or 10 s to earn the coins. However, because task demands were not the focus of the current study, and to minimize the amount of trials, we focused only on high demanding trials in the current study (i.e., as reward effects are generally found under demanding conditions; Bijleveld, Custers, & Aarts, 2009; Bijleveld et al., 2012a, 2014). We presented participants with 4 blocks of 12 experimental trials. Trial type order (i.e., brief versus extended and low versus high-value trials) was randomized across participants with the constraint that each trial type was presented 3 times within each block of 12 trials. We still included a minority of low demanding trials as fillers (4 blocks of 4 trials; evenly distributed across trial types) so that the high demanding trials were still relatively demanding within the task context. Filler (low demanding) and experimental (high demanding) trial blocks were presented in an alternating order starting with a filler trial block. Participants received 4 low demanding and 4 high demanding trials as practice. Accordingly, participants received a total of 72 trials (48 experimental trials, 16 filler trials, and 8 practice trials). Performance was operationalized as the time participants took to press the space bar 25 times (see Bijleveld et al., 2012a).

2.3. Coin detection task

Directly after the tapping task participants received a coin detection task. On each trial a low or high-value coin was presented for either 17 ms or 300 ms using the same masking procedure as in the tapping task, and participants were asked to indicate the value of the coin after each presentation. They received 48 trials, 12 trials in each cell of the 2 (duration: extended vs. brief) by 2 (value: low vs. high) design.

2.4. Balloon Analogue Risk Task (BART)

The BART is used to measure people's tendency to take risks—a tendency that is known to mirror sensitivity of the dopamine system. The BART is a valid and reliable measure of risk-taking behavior that has good test–retest reliability ($r = .77$; White, Lejuez, & de Wit, 2008). In this task, participants could earn money by blowing air in a virtual balloon presented on a computer screen by pressing the space bar. Each time they press the space bar, the balloon increases in size, and each press can earn them €0.05. This way they can accumulate money. However, with each press they also run the risk of popping the balloon. The chance of popping the balloon is 1/128 with the first press; 1/127 with the second, 1/126 with the third; and so on until the 128th press, with which the chance is 1/1. If the balloon pops, the accumulated money is lost. Participants are thus continuously presented with the choice between a risky option (blowing air in the balloon to earn more money) and a safe option (keeping the money they accumulate and start over with a new balloon).

Participants read in advance that they would get 30 balloons to earn money. Before starting the task, participants read that although they would not receive the money they accumulated, the participant with the best score received a gift card worth €50 in addition to their regular payment. This procedure is similar to previous work employing this task (e.g., Lejuez et al., 2003). Consistent with previous work (e.g., Bijleveld & Veling, 2014; Lejuez et al., 2002, 2003), the BART score was computed by averaging the number of times people pumped per balloon for balloons that did *not* pop. Accordingly, a higher score indicates more risk-seeking behavior (for more details see Lejuez et al., 2003).

2.5. Questionnaires

In addition to the behavioral tasks participants filled-out questions with regard to their demographic background, and a number of questionnaires for exploratory reasons. Because of their exploratory nature these questionnaires will not be discussed further.

2.6. Procedure

Participants were greeted by an experimenter, and escorted to a cubicle containing only a chair, table and a desktop computer. Participants were instructed that all task instructions would be displayed on screen, and the experimenter then left the cubicle. Participants worked alone through the tasks. They first received the tapping task, directly followed by the coin detection task. This was followed by a filler questionnaire participants filled out on the computer (i.e., they rated the attractiveness of food images for approximately 2 min), and the BART. We presented the tapping task always before the BART to minimize between-subjects error variance. Finally, participants filled out questionnaires, were debriefed, and received payment.

2.7. Data preparation and analyses

First, and in accordance with previous work (Bijleveld et al., 2012a), we removed tapping trials with tapping times beyond three standard deviations of the mean tapping time within each participant (1.3% of the trials), and computed mean scores in each cell of the 2 (coin duration: extended vs. brief) by 2 (coin value: low vs. high) design. Next, we computed a difference score between performance after low-value coins and performance after high-value coins (i.e., so that higher scores indicate better performance when a high-value coin was at stake), separately for extended and brief duration trials (creating extended and brief performance scores respectively). These difference scores were used for computing correlations with BART, and for the regression analysis reported below. In addition, we computed the BART score as described in Section 2.4. Then, we tested our hypothesis using a General Linear Model (GLM), with performance as the dependent variable, and coin duration (extended versus brief, within-subjects), coin value (low versus high, within-subjects), and BART (standardized continuous, between-subjects) as independent variables. We also performed this analyses adding trial block (1 versus 2 versus 3 versus 4) as an additional within-subject factor to explore possible learning effects. In addition, we computed Pearson correlations between the performance scores and the BART score. Furthermore, we regressed the Bart score on extended and brief performance scores in a multiple linear regression. Finally, we analyzed people's accuracy to detect the value of the coins.

3. Results

Two participants were excluded from the reported analyses (one participant's extended performance score was more than 5 standard deviations above the mean; another participant's standardized residual from the multiple regression analysis was >3.29, which is generally considered an extreme outlier (e.g., Field, 2013), and it has been recommended that such values be removed as they can greatly influence the regression coefficient; e.g., Osborne & Overbay, 2004). However, the significance and direction of the reported effects remains the same when these participants are included in the analyses (unless otherwise indicated). The average BART score ($M = 36.70$; $SD = 16.31$) in this sample is comparable to BART scores observed in previous work (e.g., Lejuez et al., 2002, 2003). Descriptive information of the tapping task is presented in Table 1. Amount of money earned in the tapping task was not related to performance in the BART ($r = -.20$, $p = .11$).

A General Linear Model (GLM) including coin duration, coin value and BART score as factors showed a significant main effect of coin value (better performance for high-value trials compared to low-value trials; see Table 1), $F(1,63) = 27.89$, $p < .01$, $\eta_p^2 = .31$, a duration by coin value interaction, $F(1,63) = 31.83$, $p < .01$, $\eta_p^2 = .34$, and the expected interaction between all three factors, $F(1,63) = 5.81$, $p = .02$, $\eta_p^2 = .08$ (see Fig. 1). This interaction effect indicates that the BART is related to performance as a function of coin value differently for extended and brief trials.

Follow-up analyses using the GLM separately for extended and brief trials including the factors coin value and BART score were conducted to examine the nature of the three-way interaction. For extended-duration trials, there was a main effect of coin value, $F(1,63) = 35.40$, $p < .01$, $\eta_p^2 = .36$ (better performance for high-value trials compared to low-value trials; respective means $M_{\text{high value}} = 3144$, $SD_{\text{high value}} = 335$; $M_{\text{low value}} = 3276$, $SD_{\text{low value}} = 385$), which was not moderated by the BART score, $F(1,63) = 1.13$, $p = .29$, $\eta_p^2 = .02$.

For brief-duration trials, the predicted interaction between coin value and the BART score was significant, $F(1,63) = 9.10$, $p < .01$, $\eta_p^2 = .13$. The main effects of coin value and BART score were not significant, Fs < 1. In a subsequent analysis we used an estimation procedure in the GLM that allows for a test of the effect of coin value within brief-duration trials for low and high BART participants separately (i.e., participants scoring respectively 1 standard deviation below or above the mean standardized BART score) without conducting a median split, and while retaining all observations in the analysis (see Aiken & West, 1991 for this regression analysis). This analysis revealed a significant effect of coin value among participants with a relatively high BART score (i.e., 1 standard deviation above the mean standardized BART score), $F(1,63) = 6.74$, $p = .01$, $\eta_p^2 = .10$ (better performance for high-value trials compared to low-value trials; see Fig. 1), but not among participants with a relatively low BART score (i.e., 1 standard deviation below the mean standardized BART score), $F(1,63) = 2.85$, $p = .10$, $\eta_p^2 = .04$ (see Fig. 1). So, consistent with our hypothesis, findings indicated that high-BART (vs. low-BART) participants responded more strongly to the briefly-presented high-value (vs. low value) rewards.

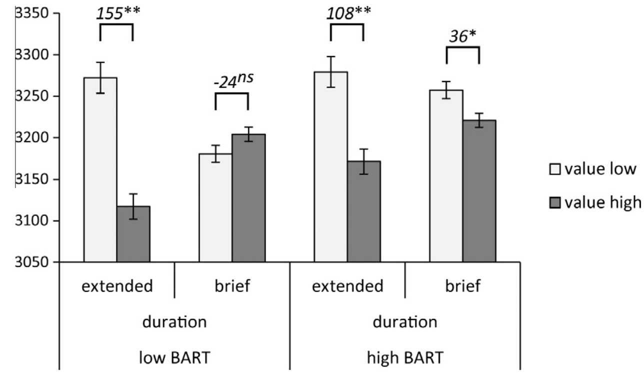

Fig. 1. Estimated marginal means of the tapping task as a function of BART score, coin value, and duration; *represents $p = 0.01$; **represents $p < 0.01$; ns = not significant; Error bars represent the within-subjects standard error (Cousineau, 2005). Accordingly, error bars may help to interpret the effects of coin value and duration; they cannot be used to interpret effects that involve BART.

For the sake of completeness, we also examined the nature of the three-way interaction by conducting separate analyses for low and high-value trials. For low-value trials, the main effect of duration was significant (indicating better performance for brief trials), $F(1,63) = 11.64$, $p < .01$, $\eta_p^2 = .16$, which was qualified by an interaction with BART score, $F(1,63) = 4.37$, $p = .04$, $\eta_p^2 = .07$ (this effect was no longer significant, $p = .281$, when the 2 participants with extreme scores were included in this analysis). Interestingly, for low-value rewards participants with a relatively low BART score performed worse on extended trials than on brief trials, $F(1,63) = 15.12$, $p < .01$, $\eta_p^2 = .19$, whereas this effect was absent among participants scoring relatively high on the BART, $F < 1$ (see Fig. 1). For high-value trials only a main effect of duration was observed (indicating better performance on extended trials; see Fig. 1), $F(1,63) = 36.57$, $p < .01$, $\eta_p^2 = .37$, which was not qualified by the BART score, $F(1,63) = 2.72$, $p = .10$, $\eta_p^2 = .04$.

To gain further insight into the relation between BART and reward effects, we computed performance difference scores, separately for extended and brief trials (i.e., $RT_{\text{low value}} - RT_{\text{high value}}$; higher performance scores reflect better performance on high versus low-value trials). Overall, means of this score were positive for both extended ($M = 131.24$ ms, $SD = 178.02$; positive value for 52 of 65 participants) and brief trials ($M = 6.39$ ms, $SD = 84.70$; positive value for 34 of 65 participants). More important, and consistent with the analyses presented above (see also Fig. 1), BART was not significantly correlated with the performance difference score for extended trials ($r = -.13$, $p = .29$; see Fig. 2). However, there was a positive correlation between BART and the

Table 1
Descriptive information of the tapping task for each of the experimental conditions.

Duration coin value	Extended low value	Extended high value	Brief low value	Brief high value
Reaction time	3275 (48.13)	3144 (41.72)	3219 (43.87)	3212 (43.94)
Reaction time low BART	3272 (68.33)	3117 (59.23)	3181 (62.29)	3204 (62.38)
Reaction time high BART	3279 (68.33)	3172 (59.23)	3257 (62.29)	3221 (62.38)
Starting time	288 (10.99)	275 (6.28)	292 (8.24)	307 (15.03)
Starting time low BART	305 (15.60)	280 (8.91)	282 (11.70)	320 (21.33)
Starting time high BART	270 (15.60)	269 (8.91)	302 (11.70)	294 (21.33)
Trials < 3500 ms	8.83 (.44)	10.31 (.37)	9.92 (.37)	9.71 (.38)
% < 3500 ms	73 (3.73)	85 (3.00)	83 (3.01)	81 (3.17)
% < 3500 ms low BART	75 (5.30)	91 (4.25)	89 (4.28)	85 (4.50)
% < 3500 ms high BART	71 (5.30)	80 (4.25)	77 (4.28)	77 (4.50)

Notes: Values represent means (or estimated means 1 standard deviation below and above the mean BART score for the low and high BART groups respectively) with standard errors presented between brackets; Reaction time is the time to complete the 25 responses, and starting time is the mean reaction time of the first response out of these 25 responses; % < 3500 ms represents the percentage of trials in which participants earned the coin.

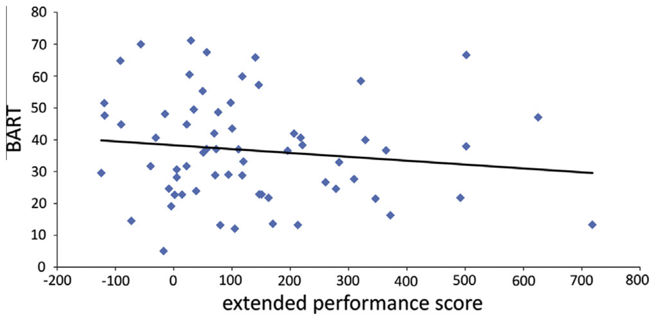

Fig. 2. Scatterplot of the correlation between the BART score and the extended performance score.

performance difference score for brief trials ($r = .36$, $p < .01$; see Fig. 3). Again, this correlation indicated that people higher in BART responded more strongly to the value of briefly-presented rewards.

Moreover, we regressed the standardized BART score on the extended and brief performance difference scores. Results of this multiple linear regression indicated the two predictors explained 16.2% of the variance ($R^2 = .16$, $F(2,62) = 6.00$, $p < .01$). This analysis further showed that the extended performance score did not significantly predict the BART score ($\beta = -.19$, $t(64) = -1.63$, $p = .11$), and that the brief performance score significantly predicted the BART score ($\beta = .39$, $t(64) = 3.27$, $p < .01$).

Furthermore, we explored whether reward learning effects could be detected in our data, i.e., whether people responded more strongly to rewards over the course of the experiment. We conducted this exploration by re-running our main GLM (which included coin duration, coin value and BART score as predictors), with trial block (1 vs. 2 vs. 3 vs. 4) as an additional within-subjects factor. This analysis showed no main effect of trial block. Also, trial block did not moderate any of the previously reported effects (e.g., four-way interaction test, $F(3,60) = 1.13$, $p = .28$, $\eta_p^2 = .06$).

Finally, we analyzed people's accuracy to detect the value of the coins. Unsurprisingly, participants were much more accurate to indicate the value of the coin when presented for an extended duration ($M = 1.0$, $SD = .01$) compared to a brief duration ($M = .55$, $SD = .10$). However, accuracy of detecting the briefly-presented coins was significantly above chance (.50) in this sample, $t(64) = 4.06$, $p < .01$. Therefore, we repeated the reported analyses controlling for accuracy of detecting the briefly-presented coins (i.e., by entering accuracy as a covariate in the reported GLM analyses; or by computing partial correlations between BART and the performance difference scores using accuracy as the control variable), but this did not change the results. Moreover, when re-running the analyses on a subsample of participants who on average could not detect the briefly-presented coins above chance ($M = .51$; by selecting a group with accuracy scores <.60; $N = 49$), the same significant results are obtained as reported above, with the exception that the extended performance score in this subsample now negatively predicts the BART score in the multiple regression analysis, $\beta = -.26$, $t(48) = -2.03$, $p = .049$.

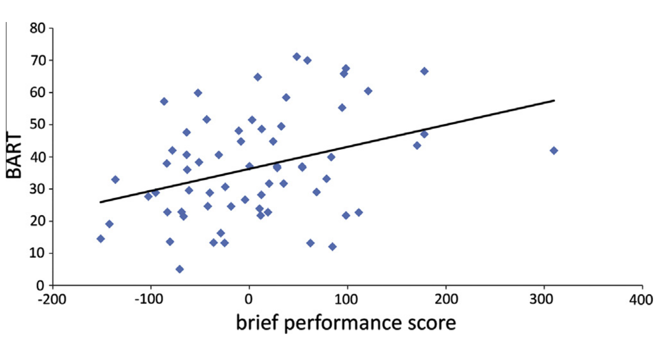

Fig. 3. Scatterplot of the correlation between the BART score and the brief performance score.

4. Discussion

The present study showed two differences between effects of rewards presented for an extended versus brief duration. First, the main effect of reward value on performance was significant for rewards presented for the longer duration. This finding is consistent with previous work employing the same performance task (Bijleveld et al., 2012a), and appears to be caused by both a strategic decrease in performance on low-value trials, and an increase in performance on high-value trials. More important, in line with our prediction, a positive relation between performance after high-value (vs. low-value) rewards and the BART was found, but only when reward information was presented briefly. In contrast, when reward information was presented for an extended duration, this relation was negative and not significant.

These results may be explained by previous theorizing that behavior after briefly-presented reward information depends partly on different brain structures compared to behavior after extended presented reward information. Specifically, briefly-presented valuable rewards are assumed to lead to initial reward processing, which primarily involves activation of the dopamine system. This system may subsequently boost performance via projections to task-related brain structures. Although valuable rewards that are presented for an extended period of time are also assumed to lead to initial reward processing, these are subsequently processed more fully. Such full reward processing may involve strategic decision making, such as about when to trade off accuracy for speed (or vice versa), mediated by higher-level brain areas. In line with this idea (Bijleveld et al., 2012b; Zedelius et al., 2014), we interpret the current findings as an indication that briefly-presented valuable rewards may boost performance via recruitment of the dopamine system, as indirectly measured via the BART. The absence of this relation for extended reward trials may be explained by the engagement of strategic decision-making processes (e.g., inhibit effort once it is clear that only a low-value reward can be gained; Bijleveld et al., 2012a), which weaken this relationship.

It is important to point out that—in the interpretations of our findings—we use low-value brief trials as a baseline to evaluate performance on all other trial types. Building on prior work (Pessiglione et al., 2007), the reason for this choice of baseline is that low-value brief trials are not affected by (a) performance increases due to high-value rewards that are at stake, or (b) performance decreases due to low-value rewards at stake that can clearly be perceived (Bijleveld et al., 2012a). As such, low-value brief trials are a comparison standard, allowing for a interpretation other cell means. Using this baseline, findings thus indicate that high-BART participants *increased* their performance on high-value brief trials, while participants low in BART did not show this effect.

However, it is important to consider potential, alternative interpretations of our findings. Specifically, previous work suggests that relatively high BART scores reflect non-strategic impulsive risk-seeking tendencies, rather than controlled calculations to deliberately maximize payoff (Helfinstein et al., 2014; Lejuez et al., 2003). Extending this argument, it may be the case that low-BART (vs. high-BART) people generally take decisions in a more strategic fashion. When accepting this premise, one could argue that low-BART participants in our study increased effort on trials in which rewards were presented briefly (regardless of the reward's value), in order to maximize their potential payoff. Such a conscious response strategy may well overrule any further performance enhancement of briefly-presented, valuable coins. However, if this strategic interpretation were true, there should have been a main effect of BART. That is, generally, relatively low-BART people should have performed better than relatively high-BART people on trials in which rewards were briefly-presented. This was not the case; there was no hint of such a main effect (also not for brief low-value trials only; correlation between BART and reaction times on brief low-value trials, $r = .11$, $p = .39$). However, because this main effect of BART concerns a between-subjects comparison on mean reaction times, it can still be the case that this main effect exists, but that the current study did not have sufficient statistical power to detect it. Hence, we cannot rule out the possibility that the absence of a value effect on brief trials among low BART participants is due to an increase in performance on low-value brief trials.

The findings further suggest that low-BART people may be inclined to employ conscious strategies when presented with visible rewards. Specifically, when rewards were clearly visible, low-BART (vs. high-BART) participants tended to slow down more when rewards were *not* valuable. So, more so than high-BART participants, low-BART participants seemed to strategically inhibit effort when the potential payoff was very low. Perhaps, they chose this strategy to save their effort for future, more fruitful trials (for related discussion, see Bijleveld et al., 2012a). Future research is required to further examine this possibility.

Another question raised by the present findings is whether the effect of BART on performance on brief trials is the result of differences in (feedback) learning. For instance, it could be that participants scoring high in BART more strongly learned the association between the high reward cue and the instrumental behavior, which may in turn have facilitated performance on high-value brief trials. However, in line with previous work (Zedelius et al., 2012), we did not find evidence for any reward learning effects. The absence of such learning can be explained by the fact that people are already very familiar with earning promised monetary rewards for performing well on clear tasks. However, importantly, our task was not developed to examine possible differences in reward learning (e.g., Niv, Edlund, Dayan, & O'Doherty, 2012), so differences in reward learning between people scoring high versus low on BART may still be observed in other tasks.

The present research has a number of important limitations. First, our study design was correlational, rather than experimental. As a result, and as noted above, we cannot exclude the possibility that the relationship between BART-scores and reward-related changes in performance can be (partially) explained by differences in baseline performance between low and high BART participants. Specifically, though this relationship was not significant, lower BART scores were associated with better performance on low brief trials (i.e., higher baseline performance). As a consequence, it may be the case that low-BART participants increased performance on low brief trials, thereby suppressing any potential effect of value on brief trials. In future work, it would thus be informative to manipulate risk-taking tendencies, perhaps even in a within-subjects design (e.g., Verbruggen, Adams, & Chambers, 2012). Such future work would help exclude baseline-related alternative interpretations, and would give more direct evidence for a causal relation between risk-taking tendencies and reward-related performance after briefly presented rewards.

Second, the BART can only be considered an indirect correlate of dopamine system sensitivity. That is, although (a) targets of the dopamine pathways are activated when people carry out the BART (in group-level analyses; Rao et al., 2008), and although (b) individual differences in BART predict plausible dopamine-driven behaviors (e.g., self-reported, real-life risk taking; Lejuez et al., 2003), this does not necessarily entail that individual differences in sensitivity of the dopamine system can reliably be tapped with the BART. Moreover, other neuromodulators (e.g., serotonin), have also been proposed to explain BART scores (Crişan et al., 2009). So, more research is needed to further validate the BART as a correlate of individual differences in sensitivity of the dopamine system. In addition, and more generally, research is needed that employs more direct measures of dopamine system sensitivity to more directly relate activation in this system to performance after briefly-presented reward information (cf. Bijleveld et al., 2014; Pessiglione et al., 2007).

Finally, the employed methods do not give insight into the proximal mechanism driving increased performance after (briefly presented) high value rewards. For instance, enhanced performance after briefly presented high value rewards could be explained in terms of broad enhanced recruitment of cognitive resources. Alternatively, briefly presented high value coins associated with a rewarding outcome may elicit specific task-relevant instrumental responses that are also associated with that outcome (e.g., Dickinson & Balleine, 1994). The question of how to best explain performance increases after briefly presented reward information is a topic of ongoing debate (e.g., Bijleveld et al., 2014).

Previous work has suggested the possibility that performance effects after briefly-presented valuable rewards are caused by engagement of the dopamine system (e.g., Bijleveld et al., 2014; Capa et al., 2012). One recent study examined this possibility using eye-blink rate and error related negativity amplitude as indicators of dopamine sensitivity (Pas, Custers, Bijleveld, & Vink, 2014). The present study examined this possibility by using BART scores as an indicator of dopamine sensitivity. Results of both studies are consistent in that the indirect dopamine sensitivity indicators correlate with performance after briefly presented reward information, but not with performance when reward information is presented for an extended duration. Together, these studies suggest it could be fruitful to examine the causal role of the dopamine system in driving performance after briefly presented rewards. Such future work may give more insight into the intriguing question of how briefly presented reward information boosts performance.

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