Behavioural Brain Research 250 (2013) 304–307

Contents lists available at SciVerse ScienceDirect

Behavioural Brain Research

journal homepage: www.elsevier.com/locate/bbr

Research report

Dual-task performance is differentially modulated by rewards and punishments

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HIGHLIGHTS

- Reward anticipation decreases dual-task performance.
- Punishment anticipation increases dual-task performance.
- Dual-task performance is modulated by dopaminergic mechanisms.

ARTICLE INFO

Article history:
Received 2 April 2013
Received in revised form 30 April 2013
Accepted 6 May 2013
Available online 13 May 2013

Keywords:
Dual-task
Psychological refractory period (PRP)
Reward
Punishment
Dopamine
Response selection

ABSTRACT

Dual-task situations play a pivotal role in daily life and are subject to a research in cognitive psychology and neuroscience. From a neuroscience perspective, the response selection bottleneck may be partly constituted by the dopaminergic system. The dopaminergic system plays a pivotal role in reward and punishment effects. In the current study we therefore investigated the effects of rewards and punishments as a potential modulator of dual-tasking processes. We examined dual-task performance in the psychological refractory period (PRP) paradigm, where the task order was either predictable, or unpredictable. Three groups were tested; a punishment group (N = 14), a reward group (N = 18) and a control group (N = 16). The results show that in the punishment condition, dual-task performance is increased relative to controls (i.e., faster RTs). In the reward condition performance decreased relative to controls. The effects observed were of moderate to high effect sizes. However, the effects were only evident when task performance was unpredictable. These divergent effects of rewards and punishments on dual-tasking may be explained by the differential involvement of different dopamine receptors in rewards and punishments, and their effects on the amount and flexibility of task goals in working memory.

1. Introduction

“Multitasking” is challenge in daily life and requires a high level of cognitive control. The underlying mechanisms have been investigated for a long time using dual-task paradigms. A classical dual-task paradigm is the “psychological refractory period” (PRP) paradigm [1]. In this paradigm, responses are required on two successive tasks. The typical finding is that responses on the second task are slower when this task was presented shortly after the first task (=PRP effect) [2,3]. With increasing time between the tasks (i.e., stimulus onset asynchrony, SOA), this effect vanishes [e.g. 4,5]. Even though the precise nature of the slowing of the response to task 2 is still a matter of debate [for review 4], all theoretical accounts assume that the PRP occurs because response selection capacity is limited [2,3,6,7]. Factors that modulate processing capacity should hence also modulate dual-tasking abilities.

Several results suggest that processing capacity, as well as processing chrematistics of a network and response selection processes are modulated by the dopaminergic system. The dual-state theory of the dopamine systems states that network characteristics change depending on whether a dopamine D1, or D2-receptor neural transmission dominates [8,9]. A highly active dopamine D2 system has been shown to allow the establishment of multiple representations in prefrontal cortical networks and working memory, i.e., processing capacity of the network is increased [8,9]. This state is more responsive and flexible, but also more interference-prone compared to a network state dominated by high dopamine D1 receptor turnover. In the dopamine D1 dominated network state processing capacities are more restricted [8]. Modulations of the dopamine D1 and dopamine D2 receptor system may hence affect performance in dual-tasking through their effects on processing characteristics in the neuronal network.

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0166-4328/$ – see front matter
http://dx.doi.org/10.1016/j.bbr.2013.05.010

Interestingly, the dopamine D1 and D2 receptor system can not only be differentially modulated by pharmacological interventions, but also by factors related to rewards and punishments [10,11]. A number of studies suggest that reward processing is mediated via the dopamine D1-system, whereas the effects of punishments are likely mediated via the D2-system [10–14]. The expectancy of punishments in case of low dual-task performance may pro-actively shift the mode of the network towards a 'D2-state'. As a consequence processing capacity may become larger and dual-task performance increases. Opposed to this, the expectancy of rewards in case of good dual-task performance may pro-actively induce a 'D1-network state'. As a consequence, dual-task performance may be lower.

However, besides the considerations of the dopamine D1 and D2 system in terms of processing capacity, these systems are also of importance when considering that the PRP reflects a processing limitation at the response selection stage [2,3]. Response selection processes have frequently been conceptualized as a property of basal ganglia-prefrontal networks [15–19]. Response selection is thought to be constituted by the interaction of two pathways: a selection pathway dominated by dopamine D1 neurotransmission and a control pathway dominated by the D2 receptor system [20,21]. This underlines that besides modulations of processing capacity, dual-task performance may also be modulated because response selection processes are affected by modulating the D1 and D2 receptor systems. However, for the response selection component the flexibility to switch between the tasks is critical [22–24]. It is therefore possible that the degree as to whether rewards and punishments are able to modulate dual-task performance further depends on predictability of required responses during dual-tasking.

2. Materials and methods

2.1. Participants

In this experiment $N=48$ (29 women), healthy right-handed students (23.63 ± 3.79 (SD) years of age) were recruited at the Ruhr-University of Bochum. They were randomly assigned to three different conditions: the punishment group ($N=14$), the reward group ($N=18$) and the control group ($N=16$). All participants had normal or corrected-to-normal vision and normal hearing performance. All participants enrolled into the study had a comparable socio-economic background and comparable monthly income. For the participation the students received financial compensation. The study was approved by the Ethics committee of the Ruhr-University of Bochum.

2.2. Principle outline of the experimental paradigm

A PRP paradigm was used in this study. The two tasks used were an auditory (tone task) and a visual task (letter task). For each task one of two task-specific stimuli was presented, which had to be identified by pressing a stimulus-specific button: Two sine wave tones (a low 500 Hz tone and a high 1300 Hz tone) were presented in the tone task. The participants were instructed to respond to the low tone by pressing a stimulus-specific button with their left index finger and to the high tone with their right index finger. In the letter task we used the white-coloured letters 'H' and 'O' on a dark blue screen (visual angle: $1.8^\circ \times 2.3^\circ$). In this task for the stimulus H the subjects have to press the according button with their left middle finger and for O the corresponding button with their right middle finger. Every stimulus applied a stimulus presentation duration amount of 200 ms. One trial contained both, the tone and the letter task, which were presented successively with one of the four different stimulus onset asynchrony (SOA; 16 ms, 133 ms, 500 ms and 100 ms). The trials started with the presentation of a central fixation cross at the screen. The first stimulus S1 (tone) was presented 1 s later. Then follows the presentation of the second stimulus S2 (letter) in a predefined SOA Participants were told to respond in minimum time and with a maximum of accuracy to each stimulus. In addition there were instructed to place equal emphasis on both tasks and not to group responses [25]. The time window for responding to a stimulus was limited to 2000 ms. Otherwise the trial was considered as a miss. After a missed trial the following trial started within 1500 ms (randomly jittered between 500 and 2500 ms). For the RT data analysis across SOAs the data was screened for trials in which the difference in RT between task 1 and task 2 was 100 ms or less, to account for possible effects of 'response grouping'. The trials following a regular responded trial started after response–stimulus interval (RSI) with a jitter between 1000 and 4000 ms. For the data collection and stimulus presentation we used the software 'Presentation' (Neurobehavioral System Inc.).

2.3. Administration of the PRP task

The PRP task was administered in two different forms: form A and form B. In form A the stimuli were presented in a fixed order (S1 = tone; S2 = letter). In form B, the order of the presentation for the first and the second task (T1 and T2) was randomized (S1 could be tone or letter). Subjects were always requested to respond first to the first stimulus appearing (irrespective of the task). This means that in form B the RT1 and RT2 comprise response to tones and letters. In form A RT1 refers to responses on tones and RT2 refers to responses on letters. Each form (fixed, random) was administered two times in a counterbalanced order (either ABAB or BABA to control block-sequence effects). ABAB and BABA blocks occurred equally frequent within each experimental group. One block of forms A and B consisted of 320 trials. Thus, the whole experiment consisted of 1280 trials.

2.4. Experimental groups

Reward and punishment manipulations were done using a between-subject design. In a within-subject design carry-over effects may affect the results; e.g. it is possible that rewards have a different effect, when reward manipulation is done at the beginning of the experiment, or after a session where the subjects received punishments. Counterbalancing may overcome these problems, but it is easier to run a between-subject experimental design. The control group received a fixed amount of 30 Euros, which was paid at the end of the experiment for participating in the study independent from their achievement (incorrect trials: wrong reaction or exceeding the time limit per reaction >600 ms). The participants in the punishment group received an amount of 30 Euros at the beginning of the experiment. However they were informed to be punished by 3 Euro cents for each incorrect trial and that they receive the amount of 30 Euros minus the sum of the value of each incorrect trial conducted throughout the experiment. In the reward group the participants were informed to receive a reward to the amount of 3 Euro cents for every correct trial which were also paid after the experiment as a sum (also summing up to ~30 Euros). Hence, there was no amount of money allotted to the participants before the experiment. This group was told that their compensation for taking part in the experiment totally depends on their performance.

2.5. Statistical analysis

Statistical analysis was performed using SPSS 20 (SPSS, Inc., 2009, Chicago, IL). Data analysis was conducted using mixed effects and univariate ANOVAs. To test the normal distribution of the variables we calculated Kolmogorov–Smirnov test. All post hoc tests were Bonferroni-corrected. Greenhouse–Geisser correction was used, if necessary. For the statistical analysis of the data, data were not grouped with respect to the modality of the stimulus, but for its occurrence (i.e., first or second stimulus). Hence, data were pooled across the different modalities in the random block. In the statistical analysis the modality of the T1 and T2 stimulus is therefore discarded in the random block.

3. Results

The net amount of money in the punishment group was 24.53 (1.64). This equals 182.22 (55.23) punished error trials. In the reward group the net amount of money was 25.13 (1.55) and thus not different from the punishment group ($p > .4$). The amount of money lost did not differ across blocks (i.e., from A and form B) ($p > .4$). The net amount of money in the reward and punishment group differed from the control group receiving a fixed amount of 30 Euros ($p < .001$).

For task 1 (T1) the mixed effect ANOVA reveal the following results. There was a main effect block ($F(1, 45) = 106.1$; $p < .001$; $\eta^2 = .702$), with reaction times (RTs) being shorter in the predictable condition (529 ± 11) (form A), compared to the unpredictable condition (601 ± 11) (form B). Moreover, there was a main effect group ($F(2, 45) = 3.32$; $p = .045$; $\eta^2 = .129$). Bonferroni corrected pair wais comparisons revealed only a difference between punishment (530 ± 18.6) and the reward group (594 ± 16.4) ($p = 0.41$), but no difference between the control group (571 ± 17.4) and the punishment and the reward group ($p > .4$). All other main or interaction effects were not significant (all $F < 1.01$; $p > .3$).

Considering the task 2 (T2) the mixed effects ANOVA shows a main effect of SOA ($F(3, 45) = 397.9$; $p < .001$; $\eta^2 = .965$) with RTs for the SOA16 ($667.4.9 \pm 11.5$); SOA133 (585 ± 11.2); SOA500