Processing of Motor Performance Related Reward After Stroke

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Abstract Performance dependent reward activates the striatum, a key region of the reward system. However, stroke patients were identified to show reduced brain activations to rewarding feedback in cognitive tasks when compared to healthy age-matched controls. This was reflected in impaired reinforcement learning. Whether their response to reward derived from preceding motor performance is also reduced, is, however, still unknown. Using functional magnetic resonance imaging, striatal activity linked to performance dependent monetary reward was measured during the training of a repetitive arc-tracking task. Pilot results of nine stroke patients and nine age-matched healthy individuals point towards a tendency for reduced responsiveness of ventral parts of the striatum in stroke patients, while the dorsal striatum, although to a smaller extent, shows an opposite trend. This is of particular interest as ventral striatal activation was found to be the key factor for successful overnight consolidation in an earlier study using a similar task.

1 Introduction

A monetary reward (MR) that depends on preceding motor task performance activates the striatum [1, 2]. In addition, such reward has been shown to improve consolidation/retention in motor skill learning studies [2, 3]. This is possibly mediated by a reward related increase of the activity of dopaminergic projections originating in reward-coding brain regions and targeting the motor cortex (M1). As shown in rodents, these projections enable motor learning and long-term

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potentiation in cortico-cortical projections [4, 5]. However, plasticity in M1 also occurs during recovery/rehabilitation after stroke and likely contributes to its success [6]. In stroke survivors, activity of this dopaminergic pathway may not only be reduced because rewards are small, but also because patients after stroke have deficits in reward processing [7]. In [7], using a probabilistic classification task, this was reflected in impaired reinforcement learning as compared to age-matched healthy individuals. Whether the processing of reward derived from the performance in a motor task is also impaired after stroke, is, however, unclear. In a pilot study using functional magnetic resonance imaging (fMRI), we investigated the neural response to performance dependent MR feedback during the performance of a repetitive arc-tracking task in stroke survivors and healthy age-matched peers.

2 Materials and Methods

2.1 Participants

Nine stroke survivors and nine healthy elderly subjects (control) were recruited. Stroke patients were included if they had suffered an ischemic stroke and were measured during inpatient rehabilitation (subacute phase; 48 (25) days post-stroke, mean (SD)). They had to be able to give written informed consent and to understand the task. Exclusion criteria were severe aphasia, dementia or depression, uncorrectable visual disorders or any contraindication to MRI. For subject characteristics see Table 1. The study was approved by the regional Ethics Committee (EKNZ-LU 13054). All participants provided written informed consent.

"Characteristics of stroke patients and controls including age as well as results from Montreal Cognitive Assessment (MoCA) and Beck's Depression Index (BDI). Data are presented as mean (SD)."

2.2 fMRI Task

To assess motor reward related brain activity, participants performed two blocks of fifty trials of a modified arc-pointing task [2] in a MRI scanner (Philips Ingenia 3.0T). Having a spherical reflective marker attached to the knuckle of the index

Table 1. Subject Characteristics

Measure	Stroke Patients (n = 9)	Controls (n = 9)
Age	59.8 (11.3)	66.1 (6.1)
MoCA	24.2 (3.2)	28.2 (2.0)
BDI	7.4 (4.4)	2.7 (2.3)

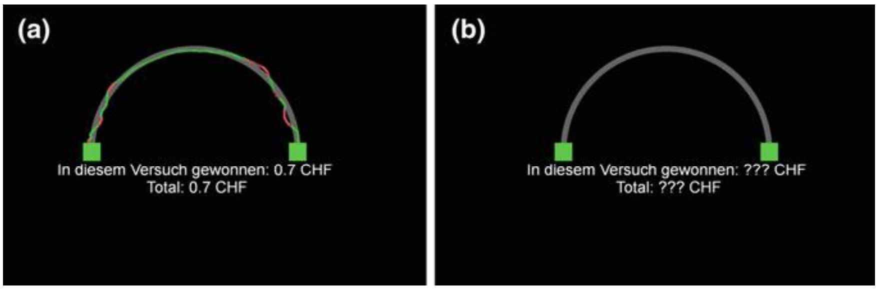

Fig. 1. **a** Monetary reward feedback and **b** visual control stimulus. In the latter, numbers specifying the monetary reward were replaced by question marks and the cursor's trajectory was omitted

finger of their unaffected (stroke patients) or dominant (controls) hand that was continuously tracked with an MRI-compatible motion capture system (Qualisys AB) enabled them to control a computer screen cursor by moving their wrist while the arm was rested on a cushion.

The task required subjects to steer the cursor through a semicircular channel from a start to a target box in clockwise direction in their preferred movement speed. Thus, no time constraints were imposed. The fraction of samples (at 60 Hertz) laying within the arc-channel (PCTin) was calculated for each trial and was used as main performance measure determining MR.

The assessment started with a familiarization period consisting of twenty trials. Here, PCTin was used to adapt task difficulty (i.e., the width of the channel) to make sure all participants are able to perform the rewarded task at a similar performance level. In the main part, a MR was given after well-solved trials, while a neutral visual control stimulus was presented after the other half of the trials (Fig. 1). MR depended on PCTin, so that a maximum of 1 Swiss Franc (CHF) could be won per trial.

For the analysis of fMRI data, the presentation of either of the two stimuli was modeled as separate regressors and the contrast "MR versus control stimulus" was defined and used for a region of interest (ROI) analysis.

3 Results

Stroke patients and controls earned similar amounts of money over the course of the experiment (32.23 (6.96) CHF and 30.87 (6.12) CHF, respectively). In one-tailed one-sample t-tests, both groups showed significant activations of the ventral striatum (t = 2.74, p = 0.013 and t = 4.48, p = 0.001, respectively) and the Nucleus Accumbens (t = 3.30, p = 0.005 and t = 5.68, $p < 0.001$) to the "MR versus control stimulus" contrast. The dorsal striatum, on the other hand, was only

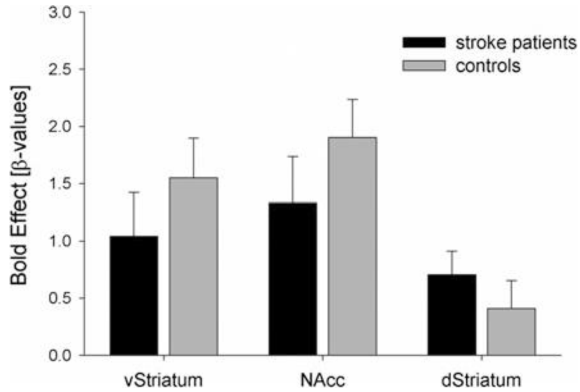

Fig. 2. Bold effect to the "monetary reward versus control stimulus" contrast expressed as β-values in ventral (vStriatum) and dorsal striatal (dStriatum) regions of interest (ROIs), as well as in Nucleus Accumbens (NAcc). $N = 18$. Mean and standard error (SE)

activated in stroke patients ($t = 3.42$, $p = 0.005$), but not in healthy controls ($t = 1.68$, $p = 0.07$).

With the current sample size, no between group differences were found in any of the three ROIs, but tendencies emerged mainly in Nucleus Accumbens ($t = 1.09$, $p = 0.143$), but also in the ventral ($t = 0.986$, $p = 0.169$) and the dorsal striatum ($t = 0.925$, $p = 0.184$). Interestingly, trends in ventral and dorsal parts of the striatum go in opposite directions (Fig. 2).

4 Discussion

In this pilot study, we have investigated the integrity of the reward system after stroke using a newly developed tool to measure the neural response to motor performance derived MR. There was a tendency towards lower responsiveness of ventral parts of the striatum, while the dorsal striatum, although to a smaller extent, showed an opposite trend when compared with age-matched healthy subjects. The tendency observed in the ventral striatum is in line with [7]. This study found reduced brain activation to smiley feedback in stroke subjects, although using a probabilistic classification instead of a motor task. Interestingly, ventral striatum activation was found to be the key factor for successful overnight task consolidation in an earlier study with healthy young subjects [2]. There, we suggest that the increased ventral striatum activity of the corresponding study group can be taken as a surrogate for increased midbrain dopaminergic activity [8] facilitating motor learning dependent plasticity in M1 via dopaminergic projections from the midbrain to M1 [4, 5].

This study is limited by the small sample size. It shows the possibility, however, with enough subjects, to generate normative data and judge individual activation levels.

5 Conclusions

Our data implies that there is a tendency towards altered processing of motor performance derived reward after stroke. Influencing factors (e.g. post-stroke depression, age, lesion location,…) as well as the impact on the rehabilitation progress will be addressed in a larger follow-up study.

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