YNIMG-12219; No. of pages: 8; 4C: 3, 5

NeuroImage xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

NeuroImage

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

Subjective illusion of control modulates striatal reward anticipation in adolescence

Robert C. Lorenz [a,b,*,1], Tobias Gleich [a,c,1], Simone Kühn [a,d], Lydia Pöhland [a], Patricia Pelz [a], Torsten Wüstenberg [a], Diana Raufelder [e], Andreas Heinz [a], Anne Beck [a]

[a] Department of Psychiatry and Psychotherapy, Charité—Universitätsmedizin Berlin, Campus Mitte, Charitéplatz 1, 10117 Berlin, Germany
[b] Institute of Psychology, Humboldt Universität zu Berlin, Rudower Chaussee 18, 12489 Berlin, Germany
[c] NeuroCure Excellence Cluster, Charité—Universitätsmedizin Berlin, Charitéplatz 1, 10117 Berlin, Germany
[d] Center for Lifespan Psychology, Max Planck Institute for Human Development, Lentzeallee 94, 14195 Berlin, Germany
[e] Department of Educational Science and Psychology, Free University, Habelschwerdter Allee 45, 14195 Berlin, Germany

A R T I C L E   I N F O

Article history:
Received 11 June 2014
Accepted 9 May 2015
Available online xxxx

Keywords:
Reward anticipation
Illusion of control
Adolescence
fMRI

A B S T R A C T

The perception of control over the environment constitutes a fundamental biological adaptive mechanism especially during development. Previous studies using an active choice condition compared to a passive no-choice condition showed that the neural basis of this mechanism is associated with increased activity within the striatum and the prefrontal cortex. In the current study, we aimed to investigate whether subjective belief of control in an uncertain gambling situation induces elevated activation in a cortico-striatal network.

We investigated 79 adolescents (age range: 13–16 years) during reward anticipation with a slot machine task using functional magnetic resonance imaging. We assessed post-experimentally whether the participants experienced a subjective illusion of control on winning or losing in this task, which was objectively not given.

Nineteen adolescents experienced an illusion of control during slot machine gambling. This illusion of control group showed an increased neural activity during reward anticipation within a cortico-striatal network including ventral striatum (VS) as well as right inferior frontal gyrus (rIFG) compared to the group showing no illusion of control. The rIFG activity was inversely associated with impulsivity in the no illusion of control group.

The subjective belief about control led to an elevated ventral striatal activity, which is known to be involved in the processing of reward. This finding strengthens the notion that the subjectively perceived control, not necessarily the objective presence of control, affects striatal reward-related processing.

Introduction

Self-determination and autonomy are essential concepts in many political, philosophical and psychological theories (Ryan and Deci, 2006; Taylor and Ntoumanis, 2007). Grawe defined in his "consistency theory" about the psychological function of human beings (Grawe, 2007) that the feeling of control is one of the four basic needs (besides need for attachment, need for self-esteem enhancement, and need for pleasure). Thus, the perception of control may constitute a fundamental psychological mechanism strongly related to the individual well-being (Bandura et al., 2003; Ryan and Deci, 2006; Shapiro et al., 1996). A lack of perceived control could evoke feelings of helplessness and has been shown to be associated with depression (Mineka and Hendersen, 1985), whereas strong perceived self-efficacy (Bandura et al., 2003) seems to be adaptive, in striving for academic achievement e.g. (Leotti et al., 2010). However, in situations of uncertainty, perceived control might lead to false beliefs: in gambling situations like playing a slot machine it is evident that no true control is possible. Nevertheless, many people do perceive control in these situations. This phenomenon was termed *illusion of control* (Langer, 1975) and is mostly pronounced in problem gamblers (Goodie, 2005). The illusion of control is characterized by the erroneous belief that skill is involved in gambling. For example slot machine gamblers reported that their "specialist play features (e.g. "nudge", "hold" and "gamble" buttons, etc.)" are perceived as learned skills and lead to an overestimation of personal chance of winning and therefore to an illusion of control (Griffiths, 1994).

Leotti et al. (2010) showed in their review about the neurobiological basis of perceived control that it is associated with cortico-striatal networks including the basal ganglia and prefrontal cortex (PFC, Leotti et al., 2010). The striatum is known to be involved in reward processing and goal-directed behavior, whereas the PFC is involved in the top-down regulation of emotional and motivational processes (Kouneiher et al., 2009; Ochsner and Gross, 2005). A study of Tricomi et al. (2004) has shown that this cortico-striatal network is also involved in the perception of control. Both the striatum and the prefrontal cortex respond

* Corresponding author at: Department of Psychiatry and Psychotherapy, Charité—Universitätsmedizin Berlin, Campus Mitte, Charitéplatz 1, 10117 Berlin, Germany.
E-mail address: robert.lorenz@charite.de (R.C. Lorenz).

[1] These authors contributed equally.

http://dx.doi.org/10.1016/j.neuroimage.2015.05.024
1053-8119/© 2015 Published by Elsevier Inc.

Please cite this article as: Lorenz, R.C., et al., Subjective illusion of control modulates striatal reward anticipation in adolescence, NeuroImage (2015), http://dx.doi.org/10.1016/j.neuroimage.2015.05.024

more strongly when a choice (decision between two options) is followed by a reward or punishment in comparison to the situation when no choice (only one button press possible) is followed by the same reinforcement. In this experiment, participants were instructed that their decision has an influence on reward probability. Indeed, an increased activation was observed in a risk taking task during active choice (again a decision between two options) compared to a passive no-choice condition (again, only one option available) within the striatum and the PFC (Rao et al., 2008). Leotti and Delgado (2011) demonstrated that the anticipation of having a choice (compared to having no choice) followed by a reward, revealed a stronger striatal response. The authors concluded that having a choice between options has an inherently rewarding value itself (Leotti and Delgado, 2011). Taken together, an active choice that increases the perception of control seems to be associated with an increased neural response within a cortico-striatal network during decision making or reward anticipation. However, all reported studies used within-group designs investigating one sample in different conditions including active control and a no-choice condition and manipulated the perception of control objectively. To our best knowledge, no study so far investigated the subjective feeling of control in an uncertain situation. Thus, the aim of the present study is to investigate how reward anticipation is modulated by the subjective false belief of the illusion of control.

Overestimation of control in gambling situations can lead to risk taking behavior, which has been associated with problem gambling (Goodie, 2005). Increased risk taking behavior is observed in particular during adolescence—a period in life, which is characterized by elevated drug and alcohol use, as well as to behavior endangering self- and others in traffic and sexual interactions (Steinberg, 2008). Interestingly, higher rates of problem gambling and pathological gambling are observed in adolescents in comparison to adults (Chambers and Potenza, 2003; Dell'Osso et al., 2006). A possible neurobiological explanation for this increased risk taking behavior is provided by a neurobiological concept of brain development. In particular, during adolescence, striatal and prefrontal development is characterized by an asymmetry. While the striatum develops very early, the prefrontal cortex develops more slowly. This protracted development of the frontal cortex is probably accompanied by a not yet efficient top-down regulation (Casey et al., 2008; Galvan, 2010). Indeed, functional neuroimaging studies show that the striatal activation during reward processing is elevated in adolescence compared to adulthood (Galvan et al., 2006, 2007; Lorenz et al., 2014; Van Leijenhorst et al., 2010).

Taken together, adolescence is a vulnerable period in life characterized by increased risk taking behavior and increased rates of problem gambling. These vulnerabilities are probably related to an asymmetry in striatal-cortical brain development. Therefore in the current study, we investigated a sample of adolescents, because this population might be more prone to phenomena like overestimation of control in uncertain situation. Thus, we believe that the number of adolescents showing an illusion of control in gambling situations is relatively high. We therefore hypothesized that adolescents show an elevated response within the cortico-striatal network in an uncertain situation such as a gambling task when experiencing an illusion of control compared to adolescents who show no such illusion of control in the same task. We further explored the relationship of such activation differences with impulsive personality trait.

Material and methods

Participants

Eighty-six physically and mentally healthy adolescents were recruited in schools in the provinces Brandenburg, Germany. Seven participants had to be excluded: Five due to excessive head movements (more than 3 mm translation or 3° rotation), one due to neurological abnormalities and one due to psycho-pharmacological medication. The remaining 79 participants (mean age = 15.1 years, SD = 0.51, age range: 13–16 years, 42 female) were included in the analysis. Three out of 79 participants were left-handed (Edinburgh Handedness Inventory Score, Oldfield, 1971: M = −79.6; SD = 18.6), while the remaining were all right-handed (Edinburgh Handedness Inventory Score, Oldfield, 1971: M = 79.8; SD = 16.8). All data has also been analyzed without left-handed participants, but equivalent results were obtained when left handed participants were included (data not shown). Therefore, we report results including left-handed participants. Functional imaging data of 34 of the 79 participants has been published before in an article about age-related changes in reward processing (Lorenz et al., 2014).

Before the beginning of the study, participants were screened for MRI exclusion criteria (e.g. non-removable ferromagnetic material) and participants themselves as well as one parent of the participants or a person who has care and custody of the child gave written informed consent. The study was approved by the Ethics Committee of the German Psychological Society, Münster, Germany.

Slot machine paradigm

A virtual slot machine (Lorenz et al., 2014) was programmed using Presentation software (Version 14.9, Neurobehavioral Systems Inc., Albany, CA, USA). The slot machine consisted of three wheels displaying two different types of fruits (alternating cherries (C) and lemons (L)). Above and below the slot machine were two horizontal color bars indicating the commands for start (blue color) and stop (green color) of the machine.

The structure of a trial was realized in the following way: At the beginning of each trial the wheels did not move and the bars were colored gray. When these bars turned blue (indicating the start of a trial), the participant was able to start the machine by pressing a button with the right hand. After the button press, the bars turned gray again (inactive state) and the three wheels started to rotate vertically with different accelerations (exponentially increasing from left to right wheel, respectively). When the wheels reached their maximum velocity (1.66 s after button press) the color of the bars turned green. This color change indicated that the participant could stop the machine by pressing the button again. After the button press the three wheels successively stopped to rotate from the left to the right side. The left wheel stopped after a variable delay of 0.48 and 0.62 s after the button press, while the middle and right wheel were still rotating. The second wheel stopped after an additional variable delay of 0.73 and 1.18 s. The right wheel stopped rotating after the middle wheel with a variable delay of 2.64 and 3.25 s. The stop of the third wheel terminated the trial and a feedback about the current win and the total amount was displayed above the slot machine. After a variable delay the button changed from gray to blue again and the next trial started. The delay between the end of a trial and the start of a new trial ranged between 4.0 and 7.68 s and was characterized by an exponentially decreasing function (see Fig. 1).

Participants gained 10 cents, in the case that all wheels displayed the same fruit (LLL or CCC) and did not win in any other case (LLC, CCL, LCL, CLC, LCC, CLL). The experiment contained 60 trials in total. In order to guarantee a sufficient amount of win trials the slot machine was determined. Thus, the trial sequence was determined with 20 win trials (CCC or LLL) and a pseudo-randomized distribution of loss (LLC or CCL) or early loss (LCL, CLC, LCC or CLL) trials. In other words, the course of win and loss was fixed before the experiment and participants had no influence on winning or losing. Each participant won the amount of 200 cents at the end of the task.

Scanning procedure

Magnetic resonance imaging (MRI) was conducted at the Berlin Center for Advanced Neuroimaging at the Charité — Universitätsmedizin