NeuroImage 152 (2017) 467–475

Contents lists available at ScienceDirect

NeuroImage

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

Functional changes in the reward circuit in response to gaming-related cues after training with a commercial video game

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ARTICLE INFO

Keywords:
fMRI
video gaming
cue reactivity
training
reward

ABSTRACT

In the present longitudinal study, we aimed to investigate video game training associated neuronal changes in reward processing using functional magnetic resonance imaging (fMRI). We recruited 48 healthy young participants which were assigned to one of 2 groups: A group in which participants were instructed to play a commercial video game ("Super Mario 64 DS") on a portable Nintendo DS handheld console at least 30 minutes a day over a period of two months (video gaming group; VG) or to a matched passive control group (CG). Before and after the training phase, in both groups, fMRI imaging was conducted during passively viewing reward and punishment-related videos sequences recorded from the trained video game. The results show that video game training may lead to reward related decrease in neuronal activation in the dorsolateral prefrontal cortex (DLPFC) and increase in the hippocampus. Additionally, the decrease in DLPFC activation was associated with gaming related parameters experienced during playing. Specifically, we found that in the VG, gaming related parameters like performance, experienced fun and frustration (assessed during the training period) were correlated to decrease in reward related DLPFC activity. Thus, neuronal changes in terms of video game training seem to be highly related to the appetitive character and reinforcement schedule of the game. Those neuronal changes may also be related to the often reported video game associated improvements in cognitive functions.

Background

A survey conducted in the United States (US) reported that more than 185 million people play and enjoy video games in the US (about 54% of the population) (Ipsos MediaCT, 2015). Along with the growing interest in society, video games have also received attention by psychological and neuroscientific research. For instance, in our recent study, we demonstrated that video gaming can lead to gray matter increase in the dorsolateral prefrontal cortex (DLPFC) and hippocampus. Further, many studies reported improvements in cognitive functioning in association with video gaming. Those findings were summarized in a recently published meta-analysis (Powers et al., 2013).

In purely psychological terms, video game associated training effects may be based on the highly consistent and prompt experience of rewards for beneficial and punishment for maladaptive actions (Sutton and Barto, 1999). In this context, the most prominent features of video games in terms of learning may be that they maximize motivation and learning by highly elaborate reward schedules. This distinguishes video games from conventional cognitive training regimes where reward schedules are often absent or less prominent (Green and Bavelier, 2012). Although previous studies have focused on the importance of reinforcement mechanisms in learning in the context of video gaming (Mathiak et al., 2011), the associated neural mechanisms are not exactly known. However, in non-gaming contexts, neural activation in the prefrontal cortex (PFC) and the ventral striatum (VS) was often associated with reward processing (see meta study by Liu et al., 2011). For instance, the PFC and the VS were activated in the classical "monetary incentive delay" task utilized by Knutson et al. (Knutson et al., 2001). Further, it was shown that VS response was increased in association with higher rewards (Knutson et al., 2001). More recent studies also showed that the VS seems to be specifically involved during actively receiving rewards in comparison to passively receiving rewards (Kätsyri et al., 2013). With regard to video games, after 30 hours of video game training with a non-commercial, 2-dimensional video game ("Space Fortress"), decreased activation of

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http://dx.doi.org/10.1016/j.neuroimage.2017.03.032
Received 9 August 2016; Accepted 16 March 2017
Available online 18 March 2017

the DLPFC was observed (during actually playing in an MR scanner) compared to pretest (Lee et al., 2012). Lee and colleagues showed in addition, that increases in performance during the training session from pre- to posttest were associated with the amount of decrease in brain activation in the DLPFC. In another training study utilizing the Space Fortress game, neuronal response in the striatum was identified as an important factor in prediction of learning success (Vo et al., 2011). Further, 10 hours of training with a commercial video game (over 5 consecutive days), led to increased reactivity to game related cues in the right ventrolateral prefrontal cortex (VLPFC) (Ahn et al., 2015). However, even though potentially rewarding cues were included and presented in the above discussed studies (among other cues), reactivity to reward was not specifically investigated.

A additional link between video gaming and the reward system has been provided by a positron emission tomography (PET) study revealing increased dopamine release in the VS while participants were engaged in playing a video game (Koepp et al., 1998). In particular, dopamine is known to be a crucial neurotransmitter in reward-based learning (Schultz et al., 1997). Beyond its role in reward learning, dopamine has been suggested as a driving force in reshaping neural connections and therewith to modulate neural plasticity (Di Filippo et al., 2009; Lovinger, 2010; Schultz et al., 1997; Surmeier et al., 2007). Thus, neurofunctional changes due to training with video games may be mediated via changes in dopamine-associated plasticity therewith affecting brain regions as the VS and DLPFC. In further support for this view, a cross-sectional study on adolescents comparing frequent to infrequent video gamers observed increased gray matter volume in the VS (Kühn et al., 2011) and a positive association between time spent playing video games and cortical thickness in the DLPFC (Kühn et al., 2014b). Additionally, in our longitudinal study investigating the causal effect of video game training on structural brain plasticity, gray matter volume in the dorsolateral prefrontal cortex (DLPFC, among other regions) was increased in association with video game training (Kühn et al. 2013). Further, it was observed, that video game training associated changes in regional synaptic plasticity may be related to performance improvements after training in non-trained tasks, which are functionally associated with the same areas regions (Nikolaidis et al., 2014).

Based on the findings discussed above, we hypothesized that the elaborate reward schedule in video games may play an important role in eliciting training-related functional changes in reward-related brain structures. Importantly, a recent longitudinal video game training study that presented gaming cues to investigate training-related changes in brain activity did not include stimuli with reward and punishment feedback during scanning (Lee et al., 2012). Thus, it is not clear how gaming-related reward processing may be altered over the course of video game training. The present study therefore aimed to investigate the neural changes of reward and punishment processing in response to training with a video game more directly. For that purpose, we recruited a group of young adults that were instructed to play a commercial video game over a period of two months and a matched passive control group. Before and after the training phase, fMRI imaging was conducted during passive viewing of reward and punishment-related videos sequences taken from the trained video game. We expected that participants in the training group would report more extreme ratings of valence for game related “winning” and "losing” after training with the video game. Further we hypothesized that video game training leads to changes in reward-related functional brain activity after training in the video gaming group compared to the control group. Additionally, those changes in brain response may be associated with gaming related factors like performance, experienced fun, and frustration during the training period.

Method and materials

Participants

We recruited 50 healthy participants via internet platforms as well as via advertisement in local newspapers. Initially, during recruitment, participants underwent a standardized interview regarding video game experience, which assessed the approximate time participants played video games in the last twelve months. Preferably, only participants that played little or no video games in the last 6 months were included. During this interview, none of the participants reported playing video games more than 1 hour per week in the last 6 months. Further, participants were excluded if they played “Super Mario 64” on any device before. Further, participants were screened for mental disorders (Mini International Neuropsychiatric Interview, (MINI) (Sheehan et al., 1998) and standardized questions regarding history of mental disease were collected. According to the MINI and self-report questions, participants were free of mental health problems. Additional exclusion criteria were medical disorders and neurological disease, as well as a history of brain surgery and only participants without MRI contraindications were included (e.g. no non-removable ferromagnetic objects). Four participants were excluded due to excessive head movement (> 3° rotation/pitch/translation or more than 3 mm movement in any direction) and two participants were excluded due to technical issues in data recording. Weekly questionnaires of six participants were lost due to technical issues and excluded from correlation analyses. Twenty-four participants in the training group completed the training. Participants received financial compensation for their participation in the MRI part of the study, but not for the training intervention itself. The local ethics committee of the Charité- University Clinic Berlin, Germany, approved of the study.

Questionnaires

During the training period, once a week we collected a standardized questionnaire (via E-mail) which was provided to the participants prior to the start of the study in digital form. This questionnaire assessed daily hours of gaming and the amount of game-related reward participants received (stars) (see Table 2). Additionally, participants rated how much fun, frustration and desire to play they experienced each week (on a seven-point scale) during the two months training period (see Table 1). In addition, the amount of “total collected stars” was validated via the in-game rating system of the Super Mario 64

Table 1
Descriptive data for valence ratings during pre-and posttest in the video game and control group.

		Pretest						Posttest					
		Loss		Neutral		Win		Loss		Neutral		Win	
	N	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
VG	24	37.84	16.42	50.46	10.14	67.91	14.50	26.84	12.01	52.61	8.18	79.24	15.25
CG	20	33.00	11.29	54.81	10.21	64.35	21.08	35.18	18.52	57.15	12.37	67.63	19.15

VG: Video game group; CG: control group; N: Number of participants; M: Mean; SD: Standard deviation. Valence was assessed using a scale from 0 to 100 (see “valence rating” section).