

# High-definition transcranial direct current stimulation over the right dorsolateral prefrontal cortex reduces risk-taking

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Taking risks is essential for daily life,<sup>1</sup> as it reflects an individual's inclination towards activities that may have positive outcomes despite the possibility of negative results, such as losses or harm.<sup>2</sup> Insufficiency in risk-taking can lead to addictive behaviours and other mental health issues.<sup>2</sup> The Balloon Analogue Risk Task (BART)<sup>3</sup> is a commonly used method to assess risk-taking behaviour.<sup>4</sup>

Previous research had suggested that risk-taking behaviour was linked to the activity of the right dorsolateral prefrontal cortex (DLPFC). To further validate this, a meta-analysis of 82 studies was conducted using Neurosynth (<https://www.neurosynth.org/>) with the search term “risk taking”, showing that the right DLPFC was strongly activated during risk-taking behaviour (figure 1A–C). However, due to the correlational nature of functional magnetic resonance imaging (MRI), a causal relationship between the right DLPFC and risk-taking could not be established. To address this, two independent studies were conducted, and high-definition transcranial direct current stimulation (HD-tDCS) was applied over the right DLPFC. The results showed that anodal stimulation reduced risk-taking behaviour, as measured by the BART, whereas sham or cathodal stimulation had no such effect.

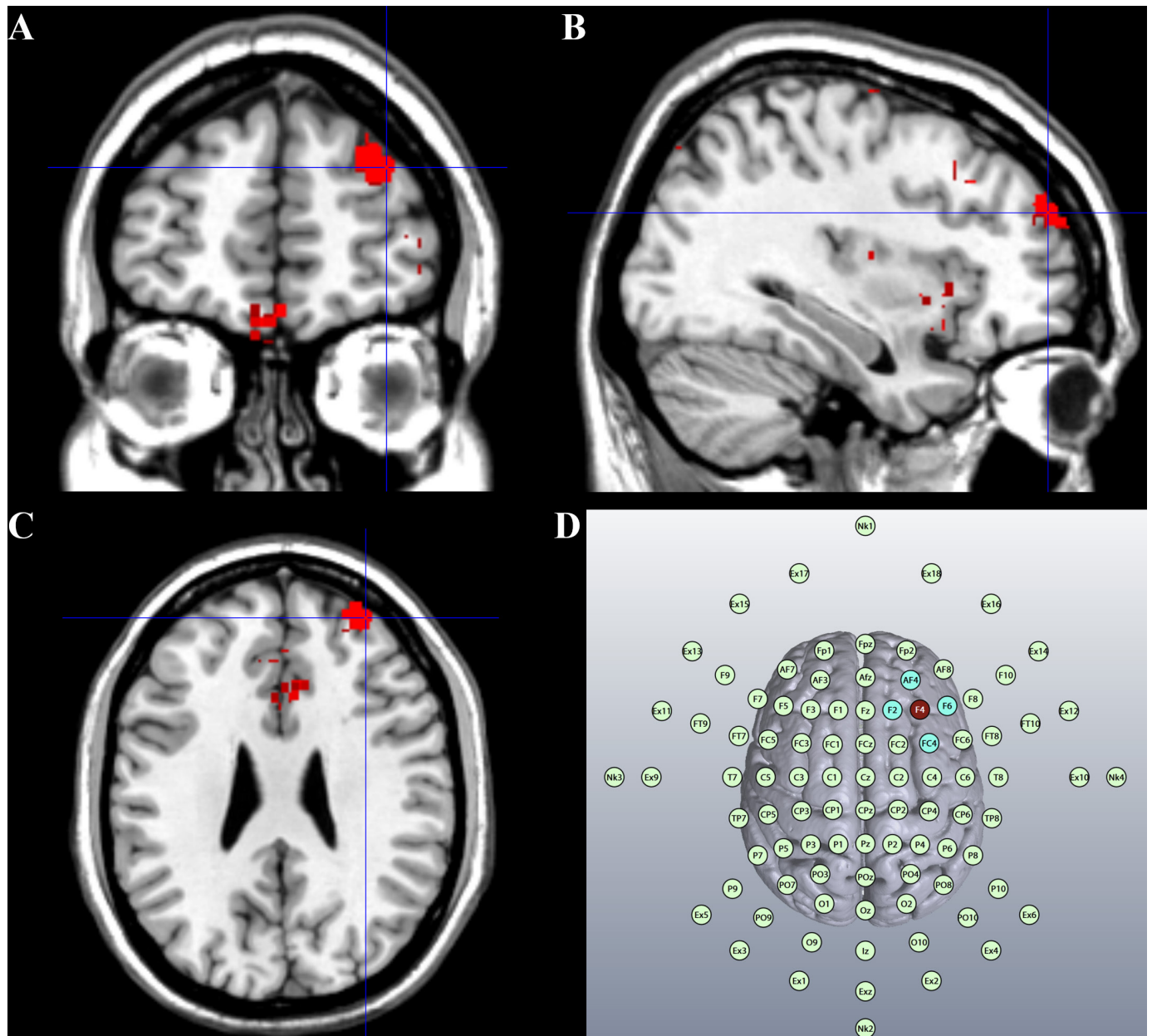
The first study in this research included 45 undergraduate students, and the second included 160 undergraduate students. All participants were right-handed and had no prior experience with HD-tDCS. They were also free of any neurological or psychiatric diseases and provided written informed consent approved by the local institutional review board. Both studies employed a between-subject, random assignment, single-blind design. The first study had two conditions (anodal and sham stimulation), and

the second had three conditions (anodal, cathodal and sham stimulation). The questionnaire survey that followed both studies revealed that the participants were unable to accurately guess their stimulus type, and no adverse side effects were reported.

Stimulation of the right DLPFC was conducted with an anodal (cathodal) electrode placed over F4 and four return electrodes at F6, AF4, FC4 and F2 (figure 1D), following the international 10–20 electroencephalogram system. For sham stimulation, the same montage was used, yet the stimulation was ramped up for 30 s and then shut off.

The BART was used to measure risky behaviour. Participants completed two sessions of BART on a computer before and after stimulation. The task was run on Inquisit (<https://www.millisecond.com/>), a tool for designing and administering psychological tests. Participants saw 30 balloons on the screen, each with the option to pump it up for a reward of ¥0.05 or to collect the money they had accumulated. The number of pumps for a balloon to pop was unknown, ranging from 1 to 128 pumps. After collecting winnings or popping a balloon, a new balloon appeared until the task was completed. Adjusted average pumps (pumps in figure 2) were used as a measure of risk-taking behaviour, calculated as the total pumps divided by the number of unexploded balloons.<sup>3</sup> This indicates that the higher the number of pumps and the lower the number of safe bets, the more likely the person is to take risks.

The first study employed 45 participants with a median age of 20.32 (IQR 1.0) years, with 22 (12 females) in the anodal stimulation condition and 23 (17 females) in the sham stimulation condition. A mixed measure analysis of variance (ANOVA) with sex as a covariable—due to the unequal

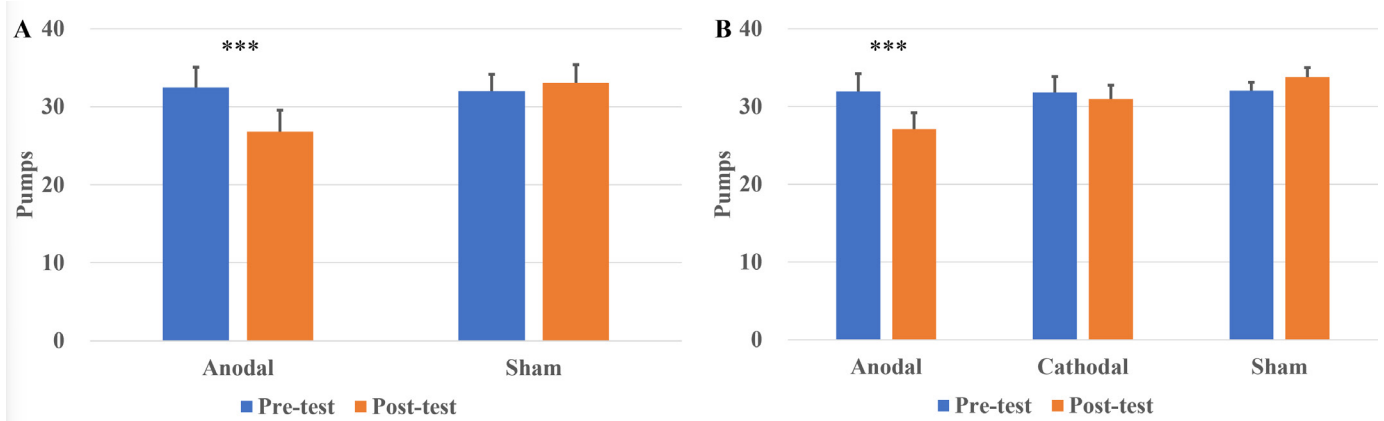


**Figure 1** The meta-analysis of Neurosynth indicated that a substantial cluster in the right dorsolateral prefrontal cortex was activated during risk-taking behaviour, which was presented in coronal (A), sagittal (B) and axial (C) views. (D) The F4 electrode was employed as the stimulation location, while the other electrodes (F6, AF4, FC4 and F2) were used as return electrodes.

distribution of sexes—revealed a significant effect of stimulation by time interaction ( $F(1, 42)=5.618, p=0.022, \eta_p^2=0.118$ ). Simple effect analysis further showed that the adjusted average pumps taken by participants decreased after anodal stimulation (pretest: 32.51 (12.11); post-test: 26.82 (10.02); paired sample  $t(21)=3.861, p=0.001$ ; [figure 2A](#)). In contrast, no such effect was observed in the sham condition (pretest: 32.01 (13.07); post-test: 33.08 (11.17); paired sample  $t(22)=-0.501, p=0.621$ ). These results suggested that anodal stimulation of the right DLPFC decreased risk-taking behaviour.

The second study aimed to replicate and extend the findings of the first study. It included 160 participants with a median age of 20.57 (IQR 1.0) years, with 40 (26 females)

in the anodal stimulation condition, 40 (23 females) in the cathodal stimulation condition and 80 (49 females) in the sham condition. A mixed measure ANOVA was conducted with sex as a covariable due to the unequal distribution of sexes. Results indicated a significant effect of stimulation by time interaction ( $F(2, 156)=6.733, p=0.002, \eta_p^2=0.080$ ). Simple effect analysis revealed that the adjusted average pumps were significantly reduced in the anodal stimulation condition, suggesting that participants took less risk after anodal stimulation of their right DLPFC (pretest: 31.96 (14.42); post-test: 27.12 (13.28); paired sample  $t(39)=3.743, p=0.001$ ; [figure 2B](#)). This effect was not observed in the cathodal stimulation condition (pretest: 31.81 (12.96); post-test: 30.98 (11.30);



**Figure 2** Results from both studies showed that anodal stimulation of the right dorsolateral prefrontal cortex could reduce risk-taking behaviour. (A) the first study. (B) the second study. The SEs were depicted by error bars. \*\*\*  $p < 0.001$ . SE, standard error.

paired sample  $t(39) = 0.513$ ,  $p = 0.611$ ) or sham condition (pretest: 32.03 (9.72); post-test: 33.81 (10.77); paired sample  $t(79) = -1.725$ ,  $p = 0.088$ ). This replicated the first study's results, demonstrating that anodal stimulation of the right DLPFC decreased risk-taking behaviour.

These results suggest that anodal HD-tDCS administered to the right DLPFC reduced risk-taking behaviour, as assessed by the BART, whereas cathodal and sham stimulation were not successful in creating the same effect. To ensure reliability and reproducibility, two separate samples were used. This suggests that the right DLPFC is vital in making risky decisions and could potentially be used to help individuals with psychiatric disorders, such as substance and behavioural addictions, who usually have an impaired ability to take risks. As a potential target for brain-based interventions, the right DLPFC may be useful in treating such disorders.

**Contributors** WL, SZ and QH designed the study. XH, JH and JS conducted the study. WL, SZ and QH analysed the data. WL and SZ prepared the first draft, and all authors approved the final version of the paper.

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**Competing interests** None declared.

**Patient consent for publication** Obtained.

**Ethics approval** This study involves human participants and was approved by the Research Ethics Committee of the Southwest University (SWU210378). All participants provided written consent to participate in this study.

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