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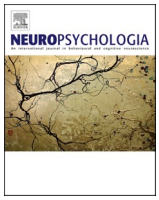

The role of the mPFC in the social influence of majority and expert opinion

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ABSTRACT

Individual attitudes and preferences are easily affected by social information. In a world where information sharing and dissemination are extremely convenient, social influence has played a greater role than in any previous era. Previous studies have suggested that the medial prefrontal cortex (mPFC) participates in mediating the tendency towards social conformity. However, the specific role of this brain area is still unknown, and it is not clear whether various types of external information influences share a mechanism. In this research, we aimed to use transcranial direct current stimulation (tDCS) to further explore the role of the mPFC in human conformity behaviour. In our experiment, the subjects received the majority opinion/expert opinion, and conformity behaviour was measured by the subject's tendency to follow this information after receiving the social information. Our research found that when social information conveys the majority opinion, cathodal stimulation of the mPFC significantly enhances the subject's consistency tendency. When social information conveys an expert opinion, stimulation of the mPFC has no significant effect on the conformity tendency of subjects. The results suggest that the mPFC plays an inhibitory role in regulating the social conformity tendency and that the activated neural circuits may vary with source when dealing with social influences.

1. Introduction

Recent studies have shown that, unlike the assumptions of traditional economic theories, our attitudes and preferences are easily influenced by the outside world (Cialdini and Goldstein, 2004; Mikulincer et al., 2015). According to the theory of social influence, people's attitudes and preferences are influenced by others, and this influence is very common in both animal and human groups (Britton et al., 2002; Lorenz et al., 2011). From the perspective of the recipient, the influences of social information on individual decision-making are driven by a variety of motivations, such as the belief that other people's information is more accurate or the desire to obtain certain social recognition by being consistent with others (Deutsch and Gerard, 1955). In terms of influencers, their power of influence is usually considered to be derived from persuasiveness (Klucharev et al., 2008) or authority obedience (Cialdini and Goldstein, 2004; French et al., 1959; Koslowsky et al., 2001). Social influence is a double-edged sword. On the one hand, it enables the rapid spread of good things and professional knowledge. On the other hand, it may also cause the spread of fanaticism or lead to hidden financial risks. Regardless of whether the result of social influence is good or bad, in today's world, in which information sharing is extremely convenient and fast, social influence has played a greater role in multiple fields (including economics, social sciences, politics, health, etc.) than in any previous era (Cacioppo et al., 2018). Our research focuses on the neural mechanism behind the social influence of majority/expert opinion.

Individuals' behaviour of changing their preferences under the influence of society has received extensive attention in economic, psychological, and neurological research. Experimental research on this topic is generally based on the investigation of attitudes (rating or choosing) toward specific things, including financial products (Cipriani and Marco, 2005), crowdfunding projects (Wang et al., 2019), faces (Huang et al., 2014; Klucharev et al., 2011), dishes (Cai and Fang, 2009), T-shirt designs (Izuma and Adolphs, 2013), and pieces of music (Berns et al., 2010). In these experiments, subjects received two kinds of information (private information and social information) and then made a decision. Private information is generally objective information about the things being rated, such as pictures or introductions; social information is usually expressed as the opinions of the majority or experts (Izuma, 2013). Experimental research has generally found that people tend to follow the majority and expert opinions when making decisions.

Previous neurological studies have shown that the social influence of

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attitudes is associated with the activities of multiple brain regions, of which the mPFC, posterior medial frontal cortex (pMFC), ventral striatum, and insula are the most important brain regions involved (Wu et al., 2016). When external social information comes from the majority opinion, the mPFC is found to be related to the identification of socially labelled activities during the social influence process (Mason et al., 2009) and the tendency to follow the majority (Izuma and Adolphs, 2013). In particular, a tDCS study found that cathodal stimulation of the vmPFC significantly improves informational social conformity (Li et al., 2020). The ventral striatum is related to the conflict between majority opinion and private opinion (Klucharev et al., 2009). The insula and pMFC are related to people's conforming behavioural adjustments after being informed of social information (Berns et al., 2010; Wu et al., 2016). Klucharev et al. (2011) used the transcranial magnetic stimulation method to find that the downregulation of pMFC prevented social conformity. In addition, the anterior cingulate has been found to be related to social information conflicts. When external social information conveys expert opinions, the mPFC also regulates the tendency of individuals to obey expert opinions (Campbell-Meiklejohn et al., 2012), and the ventral striatum and insula are related to the congruency between individual and expert opinions (Biele et al., 2011; Campbell--Meiklejohn et al., 2010; Meshi et al., 2012). Based on these studies, some research has further found that the main relevant brain regions do not seem to act independently; rather, they regulate the tendency towards social consistency in the form of neural circuits (Shamaytsoory et al., 2019). Biele et al. (2011) found that the brain's reward system (especially the amygdala) generates a greater reward signal for outcomes following trustworthy advice. Shamaytsoory et al. (2019) suggested that herd behaviour is not only related to a single brain area but is also regulated by a neural circuit, including an error-monitoring system that reacts to misalignment, an alignment system, and a reward system that is activated when alignment is achieved.

In addition, some of the experimental literature on social influence mainly focuses on persuasive perspective. The external influence in this type of research is mainly public service announcements, and the research topics are mainly health-related attitudes/decisions such as smoking, drinking, and using sunscreen. These studies have found that mPFC (especially vmPFC) activity is related to conformity tendency (Burns et al., 2018; Chua et al., 2011; Doré et al., 2019a,b; Falk et al., 2012; Falk et al., 2010; Falk et al., 2011; Falk et al., 2015; Senecal Cooper et al., 2015; Vezich et al., 2016). Doré et al. (2019b) found that the specific mode of action of the mPFC may be reflected in the mediation of deeper brain regions (amygdala). Aquino et al. (2020) found that the effect of the vmPFC on individual conformity tendencies depends on individual differences in affective and cognitive orientation based on a daily consumer product rating experiment. Although many brain imaging studies have indicated the important role of the mPFC in persuasion, there is still a lack of direct causal evidence. In addition, previous neurological studies have generally focused on the brain regions involved in the social impact of a certain form of external information. Although this type of behaviour involves similar brain areas, there is currently no experimental study on the distinction between and comparison of the effects of various information sources.

The prefrontal cortex has long been considered to be closely related to the social behaviour of individuals (Anderson et al., 1999; Grafman, 1995). Among them, the mPFC has been found to be closely related to affect, social cognition, and self-vs. other-referential judgements (Murray et al., 2012; van der Meer et al., 2010). Further research shows that the mPFC participates in processing one's personality traits, attitudes, values, physical attributes, and other personal semantic information (Brosch et al., 2012; Jenkins and Mitchell, 2011; Zysset et al., 2002). The effects of social influence on individuals are mainly divided into informational and normative influences (Deutsch and Gerard, 1955). Informational influences usually originate from objective facts and seek to accurately describe the state of affairs; normative influences mainly affect judgment issues and seek to make "preferred" or "appropriate" decisions. Most previous studies suggest that the motivation for attitude/preference shifts under social influence results from a combination of normative and informational influences (Cialdini and Goldstein, 2004; Toelch and Dolan, 2015).

Some studies have suggested that in the social influence-related domain, the mPFC may involve an implicit process that guides subsequent behaviour change rather than reflecting a conscious decision; in addition, this region has been considered a candidate for more deliberative types of processing (Lieberman, 2007; Satpute and Lieberman, 2006). This suggests that the mPFC may play multiple roles in social influence and persuasion processes. That is, mPFC activities have multiple moderating effects on individuals' decisions when integrating external social information. On one hand, the mPFC is closely linked to informational social influence as it involves value judgments and integration (Clithero and Rangel, 2014; Kumaran et al., 2015). Some recent studies have found that the adjustment of the mPFC's social impact is adjusted by forming a loop mechanism with deep regions, and have indicated that the mPFC is responsible for integrating incoming information into pre-existing beliefs (Levy and Glimcher, 2012; Preston and Eichenbaum, 2013; Rangel and Hare, 2010; Sescousse et al., 2013; Shamaytsoory et al., 2019). On the other hand, the mPFC guides individual's behaviour and decision making in a socially appropriate manner and thus is associated with normative social influence (Jenkins and Mitchell, 2011; Yin et al., 2017). In conclusion, previous studies have shown that the mPFC can inhibit norm compliance (Yin et al., 2017) while prompting individuals to perform better via value integration (Kumaran et al., 2015). Thus, we hypothesize that the mPFC acts as an inhibitory moderator in terms of the normative aspect of social influence, while in terms of the informational aspect, it mainly acts to help individuals better integrate persuasive information into their self-concept and identity.

Majority opinions and expert opinions are the two of the most concerning sources of social influence. Some studies have suggested that an individual's decision to follow the majority when making preference-related decisions usually depends on his or her subjective identification with the majority (Izuma and Adolphs, 2013). When individuals consider whether to follow expert opinions, they mainly rely on the persuasive power of the experts, and this persuasive power is influenced by value judgements of expert opinions and the trusted reputation of experts (Cialdini and Goldstein, 2004; Priester and Petty, 2003). Although previous psychological and neurological studies have shown that the two have a great deal in common, there are still some differences in the social influences of the majority and experts. Our research hopes to supplement related comparative studies.

Although the mPFC is likely to play an important role in conforming behaviour, its specific regulatory role is still unclear. More importantly, brain imaging methods are inherently related, which can cause causal ambiguity (Cacioppo et al., 2003). To study the causal link between mPFC activities and preference conformity based on the above-mentioned correlation evidence, we used tDCS to adjust the subjects' tendency to conform when faced with majority opinions and expert opinions. To clearly identify the subjects' conformity tendency, the subjects were asked to make two choices in a trial. First, they were asked to independently make a preference choice and then to indicate their final choice after learning the majority/expert opinion; that is, they were asked to decide whether they agreed with the majority/expert opinion. Specifically, in this study, we hoped to examine the following questions. (1) Is the influence of majority opinion/expert opinion on individuals' attitudes adjusted by mPFC? (2) If there is a causal relationship between individual conformity tendency and mPFC activities, what is the direction of influence? (3) Is there a difference in how the mPFC regulates the consistency tendency of individuals under the influence of majority opinion and expert opinion?

2. Method

2.1. Participants

We recruited 130 subjects, who were randomly assigned to participate in Experiment 1 (65 participants) or Experiment 2 (65 participants). The experiment was conducted on December 14–16, 21–23, 2019, and January 1–3, 2020. The laboratory is located at Zhejiang University of Finance and Economics. In Experiment 1, four subjects were excluded because they did not complete the Experiment. We collected data from 61 subjects in Experiment 1 (mean age 20.279 years, 31 females) and 65 subjects in Experiment 2 (mean age 19.969 years, 33 females). Sample sizes were based on the sample sizes used in previous studies on social influence and preference change and the effect sizes of the impacts of tDCS on social compliance in previous studies (Izuma et al., 2015; Klucharev et al., 2011; Zhang et al., 2016). A sensitivity analysis using the G*Power software (Faul et al., 2007) showed that with a sample size of 21 subjects per group, the study had a power of 0.8 to detect a medium-to-large effect at an alpha level of 0.05. All subjects were right-handed, healthy, with normal or corrected-to-normal vision and were not familiar with the contents of the experiment or tDCS.

2.2. Experimental tasks and procedure

Our experimental tasks used both a two-alternative forced-choice task and a Likert scale. The Likert scale (Likert and Rensis, 1932) has long been one of the most widely used self-reporting measures (Brown and Maydeu-Olivares, 2012), but it also faces rating scale errors due to acquisition bias, extreme response style and midpoint response style (Greenleaf, 1992; Kieruj and Moors, 2010; Landy and Farr, 1980). In addition, some studies have indicated that because Likert scale data are in ordinal form, there are unequal values across the range at different levels (Hodge and Gillespie, 2003; Pett, 1997). Forced-choice overcomes the midpoint/extreme response style and other problems and shows a better measurement effect (Bartram and Casimir, 2007; Brown et al., 2016). In our experiment, the subjects first rated the item with a 7-point Likert scale and then made a final choice of two options after knowing the majority/expert opinion, that is, deciding whether to be consistent with the majority/expert opinion. In this way, it is possible to collect the details of the subjects' initial evaluation of the items and to observe the tendency of the subjects' attitudes to shift from the crowd/experts. After the experiment, the subjects would obtain the stationery items they selected in their final choices in the experiment. Stationery is a common necessity for students, and it can effectively motivate participants to express their true preferences.

2.2.1. Experiment 1 influence of majority opinion

Subjects were informed that the main task of the experiment was to compare and evaluate 40 sets of pictures. These pictures were taken from the cover of notebooks with the same style and price. There were two pictures in each set, totalling 80 pictures. At the beginning of the experiment, four participants were randomly assigned to each group, and the group members did not change throughout the experiment. The experiment was conducted for 40 rounds. The complete process for each round of the experiment is as follows (Fig. 1):

Step 1: Two pictures appeared on the participant's screen. Participants were asked to rate the pictures based on how much they liked them (7-point scale: Dislike Extremely, Dislike Very Much, Dislike Somewhat, Neither Like nor Dislike, Like Somewhat, Like, Like Extremely). The ratings of the two pictures could not be the same.

Step 2: The screen of the subjects showed pictures with a higher rating given by the other three members of the group.

Step 3: The subjects choose whether to change their original choice.

The students were told that they would see the preferences of other members of the group, but in fact, the preferences shown were manipulated by the experimental software. Following the design of many similar social influence studies (Huber et al., 2014; Izuma and Adolphs, 2013; Klucharev et al., 2011), we manipulated the congruency conditions of the participants in each round. The initial selection of the participants was consistent with the majority opinion in 20 rounds and was inconsistent with the majority opinion in the other 20 rounds. Following the design of Frydman and Krajbich (2017), we used a variable called Net Public Information (NPI). NPI has four distinct values, which were 3 (all three others in the group had the same initial choices as the participant) and 1 (two in the group had the same initial choices as the participant, and one had a different choice) in the congruent condition and −3 (all three others in the group had different initial choices from the participant) and −1 (two in the group had different initial choices from the participant, and one had the same choice) in the incongruent condition. In 40 rounds of experiments, the above four NPI conditions each appeared in 10 rounds in random order. After the formal experiment, the subjects were asked to complete the questionnaire. After the questionnaire, the subjects were instructed to rate the pictures in the formal experiment again (the pictures appeared in random order).

2.2.2. Experiment 2 influence of expert opinion

Subjects were informed that the main task of the experiment was to compare and evaluate five sets of notebooks and five sets of pens. Each set included two notebooks/pens with the same price. Before the experimental task began, the subjects were first shown some introductory materials about a review website. The review site (www.diaox2.

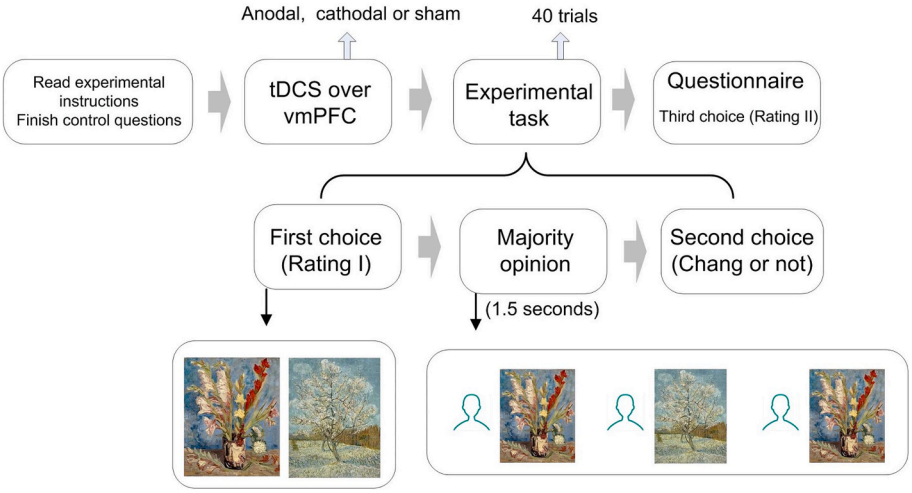

Fig. 1. Design of experiment 1.

com/) contains reviews from a group of professional reviewers and is equipped with professional testing equipment, mainly providing comments and purchase recommendations on daily consumer goods. In this experiment, we used the results of the review report on this website to represent expert opinions. The name of the review website was blocked to avoid external interference with the rate results caused by familiarity. The participants were asked to complete ten rounds of experiments. The complete process for each experimental round is as follows (Fig. 2):

Step 1: Participants were shown pictures and a brief introduction of one set of notebooks (pens). Participants were asked to rate the items based on how much they liked the two items in a notebooks/pens set separately (7-point scale: Dislike Extremely, Dislike Very Much, Dislike Somewhat, Neither Like nor Dislike, Like Somewhat, Like, Like Extremely). The ratings of the two pictures could not be the same.

Step 2: Participants were shown the results of the review website's evaluation of two notebooks/pens.

Step 3: The subjects choose whether to change their original choice.

Similar to Experiment 1, we manipulated the congruency conditions of the participants in each round. The participants' initial selection was congruent with the expert opinion in four rounds and was incongruent with the majority opinion in the other six rounds. After the formal experiment, the subjects were asked to rate the trustworthiness of the review sites and complete the questionnaire. The brief introduction to the item was taken from the purchase interface of the item on the shopping website (www.taobao.com). The presentation of expert opinions was similar to that of review sites. The opinions included multiple categories (such as the paper fluorescence, appearance, etc.), and at the end, the notebook with the highest comprehensive rating was directly indicated.

There was no time limit for either stage of the experiments, but the subjects were encouraged to make choices as soon as possible. To encourage the participants to reveal their true attitude shifting, they were compensated with stationery according to their choices in the experiment. In Experiment 1, each participant received four notebooks with the pictures that appeared in the experiment printed on the cover. The pictures were the real cover images of the notebooks from the online shopping website (www.taobao.com). We randomly selected a part (4/40 round) of the final pictures (second choice) for the participants in each trial and distributed the notebooks (worth 7 US dollars) with the corresponding covers to them. Similarly, after Experiment 2, the subjects received two notebooks and two pens (worth 7 US dollars) based on their final choices in the four rounds of the experiments. In addition, each participant received an appearance fee of 10 RMB yuan (approximately $1).

2.3. tDCS

tDCS is a form of neuromodulation that can be used to regulate the excitability of the cerebral cortex (Kuo et al., 2014; Lefaucheur et al., 2017). Previous studies have found that, in general, anodal (cathodal) stimulation can enhance (reduce) cortical excitability, which in turn affects the brain function of subjects (Nitsche and Paulus, 2000). Specifically, in our experiment, we used a tDCS device (NeuroConn, Ilmenau, Germany) to apply a very weak direct current to the scalp through two saline-soaked surface sponge electrodes (5 cm × 7 cm; 35 cm^2).

The participants were randomly assigned to one of the three stimulation treatments and were unaware of the stimulation group to which they were assigned. In Experiment 1, 20 participants were in the anodal stimulation group (10 male and 10 female), 21 were in the sham stimulation group (10 male and 11 female), and 20 were in the cathodal stimulation group (10 male and 10 female). In Experiment 2, 22 participants were in the anodal stimulation group (11 male and 11 female), 22 were in the sham stimulation group (11 male and 11 female), and 21 were in the cathodal stimulation group (10 male and 11 female).

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The target area of stimulation is the mPFC. According to the international 10–20 EEG system, when performing anodal stimulation, we placed the anodal electrode over the Fpz position and the cathodal return electrode over the Oz position (Sellaro et al., 2015) (Fig. 3). For cathodal stimulation, the polarity was reversed. The current stimulation duration was 20 min, the intensity was constant at 1.5 mA, and there was a 30 s fade-in (fade-out) at the beginning (end) of the stimulation. For the sham stimulation, the current lasted for only the first 30 s. The subject was still required to wear the instrument during the remaining stimulation period, but there was no current. Previous studies have shown the safety and effectiveness of these tDCS operations (Gandiga et al., 2006; Nitsche et al., 2008; Nitsche et al., 2003).

3. Data analysis

We define the conformity tendency of preference as the subjects choosing to follow the majority/expert opinions. In Experiment 1, stimulation (anodal vs. sham vs. cathodal) was a between-subject factor, and congruency condition (incongruent vs. congruent) and absolute NPI (3 vs. 1) were within-subject factors. In Experiment 2, stimulation was the between-subject factor, and congruency condition was the within-subject factor. All experimental conditions and possible responses in Experiment 1 and Experiment 2 are shown in Tables 1 and 2.

According to Shapiro-Wilk's test, the conformity probability of the subjects when they were informed of the majority opinion and the expert opinion did not obey a normal distribution ($p < 0.05$). Thus, our data analysis is mainly based on nonparametric testing. In addition, we added

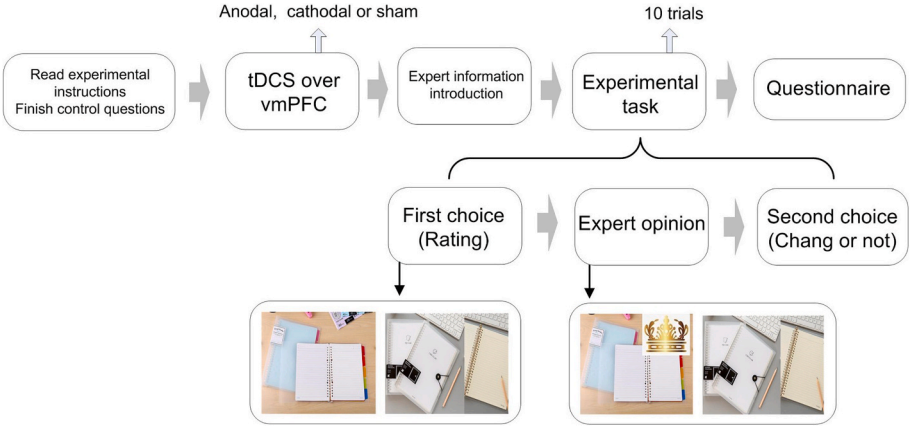

Fig. 2. Design of experiment 2.

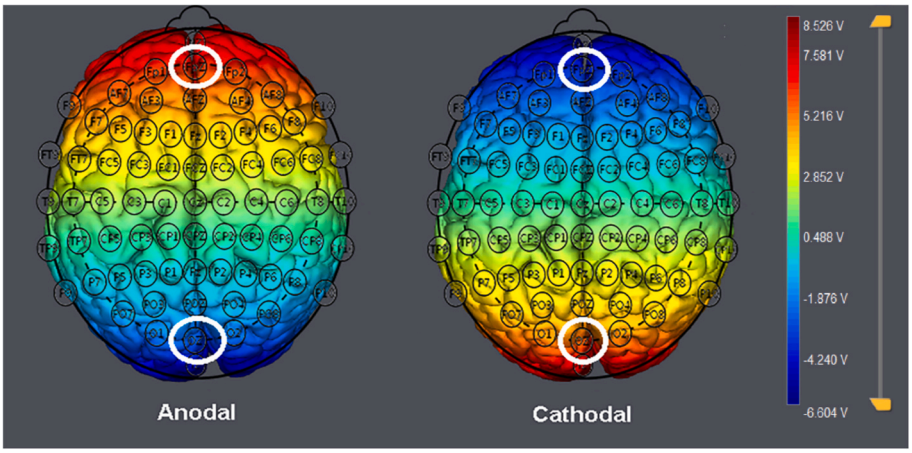

Fig. 3. Locations of the electrodes and stimulation modes in tDCS treatments.The electrode positions are located at Fpz and Oz. The shading represents the range of input voltage from −6.604 to 8.526 V.

Table 1
Participant decision table in Experiment 1.

Condition	NPI	First	Majority opinion	Second	Attitude shift	conformity
Incongruent	NPI = −3 NPI = −1	A	B	B	shift	conformity
Congruent	NPI = 3 NPI = 1	A	A	A	no shift	
Incongruent	NPI = −3 NPI = −1	A	B	A	no shift	no conformity
Congruent	NPI = 3 NPI = 1	A	A	B	shift	

Table 2
Participant decision table in Experiment 2.

Condition	First	Expert Opinion	Second	Attitude shift	conformity
Incongruent	A	B	B	shift	conformity
Congruent	A	A	A	no shift	
Incongruent	A	B	A	no shift	no
Congruent	A	A	B	shift	conformity

a regression analysis. The dependent variable is whether the subjects make consistent choices, and the independent variables are the type of stimulus and some other factors. We used z-tree (version 3.5.1) to collect data and SPSS software (version 22) and Stata statistical software (version 14.0) to analyse the data.

4. Results

4.1. Influence of majority opinion

The experimental results show that there were situations in which the participants followed the majority opinion under both the incongruent conditions (M = 0.09, $p < 0.001$) and the congruent conditions (M = 0.989, $p < 0.001$; all P values of multiple tests in this article are Benjamini and Hochberg FDR corrected p values.). The conformity tendency of the subjects in the incongruent condition was significantly lower than that in the congruent condition ($p < 0.001$, Table 3). Specifically, the conformity tendency of the subjects when NPI = −1 was significantly lower than when NPI = −3 (NPI = −3, 0.141; NPI = −1, 0.039; p = 0.025; Fig. 4). When everyone else in the group had different preferences from the subjects (NPI = −3), there was a significant difference among the three stimulations in the conformity tendency of subjects' preferences (p = 0.046). In particular, the conformity tendency of the subjects in the cathodal stimulation group was significantly higher than that of the subjects in the anodal and sham groups (Fig. 4).

The participants rated their preferences using a 7-point scale, with a mean rating of 4.798 (SD = 1.23), indicating that the subjects gave a relatively positive evaluation to the pictures overall. We then defined the rating difference as the absolute value of the difference in the ratings of the two pictures in one round. The average value of the rating difference is 1.257 (SD = 0.644). There was no difference in the ratings or rating differences of the pictures among the three stimuli.

Furthermore, we ran a logistic regression to model the conformity behaviour as a function of the participants' stimulation types (the baseline group: sham stimulation group), rating difference, NPI value and gender based on incongruent condition data (Table 4). Conformity behaviour was set as a dummy variable. When it equalled 1, it indicated that a participant made a conformity decision, and was set to 0 otherwise. We found that the subjects in the cathodal stimulation group had a higher conformity tendency than those in the sham stimulation group. The subjects under the NPI = −3 condition had a higher conformity tendency than those under the NPI = −1 condition. Females had a higher conformity tendency than males. A further Mann-Whitney U analysis also found that the conformity tendency of females was significantly higher than that of males (0.11 vs. 0.07, p = 0.056), with marginal statistical significance. In addition, we found that subjects' rating differences did not have a significant effect on their conformity behaviour.

In Experiment 1, the total average reaction time of the subjects was

Table 3
Participant conformity tendency and reaction time (RT) under different conditions.

Simulation	Anodal		Sham		Cathodal	
	M	(SE)	M	(SE)	M	(SE)
Conformity Incongruent	0.063	(0.014)	0.064	(0.014)	0.145	(0.033)
RT Incongruent(s)	3.479	(0.229)	3.767	(0.211)	3.740	(0.220)
Conformity Congruent	0.990	(0.008)	0.981	(0.012)	0.995	(0.003)
RT Congruent(s)	2.810	(0.113)	2.725	(0.102)	2.941	(0.093)

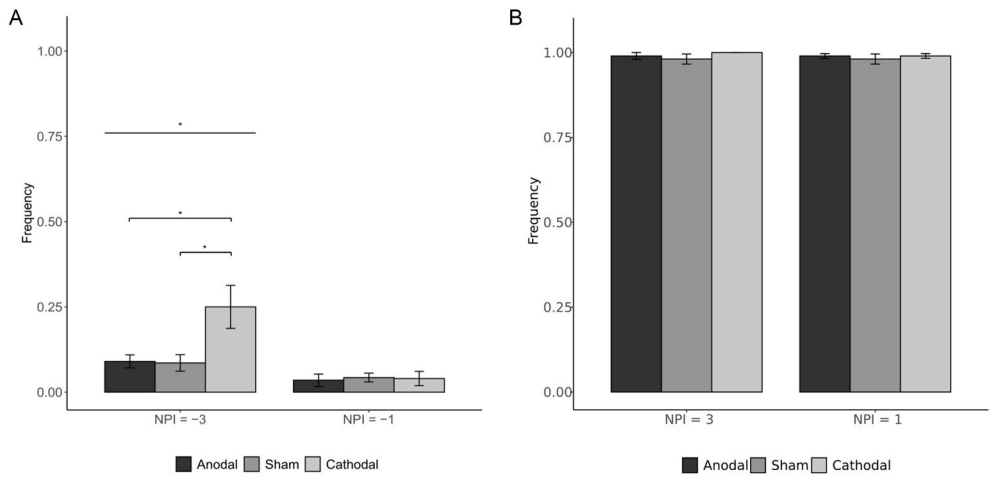

Fig. 4. Impact of stimulation on the tendency to conform to the majority opinion. (A) Incongruent condition: Cathodal stimulation led to a higher percentage following the majority than both sham (*p = 0.05) and anodal stimulation (*p = 0.038) in the incongruent condition. (B) Congruent condition. Error bars indicate ±1 SEM.

Table 4
Conformity behaviour under the incongruent condition in logistic regression.

Conformity	Coef.	Robust Std. Err.	z	P>|z|
Rating difference	−0.085	0.175	−0.490	0.627
Anodal	−0.024	0.295	−0.080	0.936
Cathodal	0.952	0.255	3.730	0.000
NPI = −3	1.426	0.245	5.820	0.000
Female	0.529	0.211	2.500	0.012
Constant	−3.798	0.399	−9.530	0.000

3.243 s. The reaction time of the subjects under incongruent conditions was longer than that under congruent conditions (3.664 s vs. 2.823 s, $p < 0.001$, Fig. 5). Generally, a short reaction time indicates easy decision-making, and a long reaction time indicates difficult decision-making. In our experiments, when private judgements conflict with the majority opinion, comprehensive judgements are more difficult than in nonconflict situations and therefore require more thinking time. The more disagreements the subjects face, the longer the decision-making time they need.

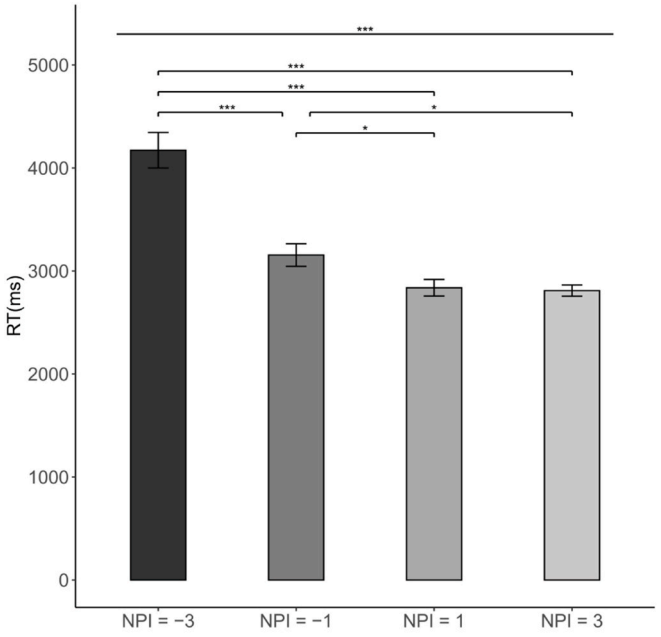

Fig. 5. RT in different NPIs. Error bars indicate ±1 SEM. *P < 0.05; **P < 0.01; ***P < 0.001.

In the previous analysis, we mainly focused on the participants' immediate decision-making after learning the majority opinion. In fact, the retention of the preference shift is also one of the issues that researchers have been concerned about. After all our experiments were completed, we once again surveyed the subjects' preference for pictures through a questionnaire to supplement the observation of subjects' preference retention. This time, the order of the pictures was randomly disrupted. The results showed that there was no significant difference between the final choice of the subjects' formal experiment and the postexperiment survey choice ($p > 0.1$, retention ratio: 86.84%). We also further analysed the retention of preferences if the subjects underwent a conformity change (if the participant chose to change the initial selection to follow the majority opinion) in the formal experiment. The results show that the retention ratio in the postexperiment questionnaire decreased (60.50%), but McNemar's test showed that there was no significant difference between the subjects' preferences in the formal experiments and the postevent investigations. ($p > 0.1$). In summary, after the experiment, the subjects' preferences remained socially influenced, which is consistent with previous research findings (Izuma and Adolphs, 2013).

After the experiment, we asked the participants to report the motivation for preference change in the experiment through a questionnaire. In the questionnaire we provided subjects with three options, which included (1) "the picture chosen by the majority should be better"; (2) "I want to be consistent with the majority"; and (3) "I have not changed my initial choice". The results showed that the proportion of subjects who held the second motivation (seeking to be consistent) differed significantly across stimulus groups (Anodal: 5%; Sham: 9.5%; Cathodal: 40%; $p = 0.05$; Fig. 6).

4.2. Influence of expert opinion

There was a phenomenon in which the participants' preferences followed expert opinion under both incongruent conditions ($M = 0.421$, $p < 0.001$) and congruent conditions ($M = 0.981$, $p < 0.001$). Whether the participants' initial opinions were consistent with the expert opinions had a significant impact on their final decision-making results. The participants were more likely to follow expert opinions when they were in agreement than when they were in disagreement (0.421 vs. 0.98; $p < 0.001$; Anodal: $p < 0.001$; Sham: $p < 0.001$; Cathodal: $p < 0.001$). Under congruent and incongruent conditions, the stimulus had no significant

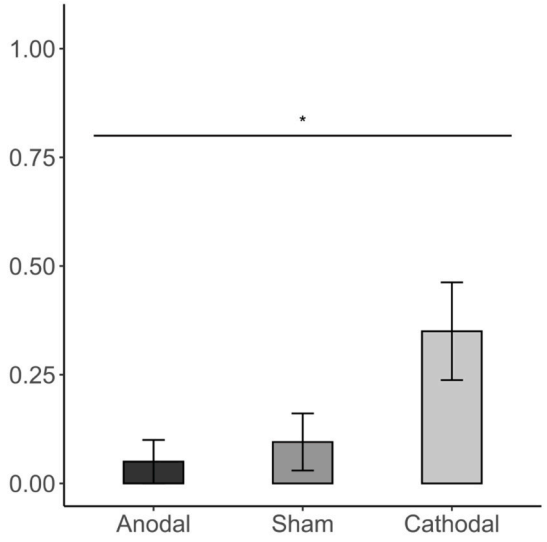

Fig. 6. The proportion of subjects in the different stimulus groups who were motivated by the belief that "I want to be consistent with the majority". Error bars indicate ±1 SEM. *P < 0.05.

effect on the subjects' conformity tendency (Fig. 7).

The participants were asked to rate their trust in experts (7-point scale: Distrust Extremely, Distrust Very Much, Distrust Somewhat, Neither Trust nor Distrust, Trust Somewhat, Trust, Trust Extremely). The subjects had different levels of trust in experts under different stimuli and had higher levels of trust in experts under cathodal stimuli (Fig. 8). It is worth noting that under inconsistent conditions, there is a significant positive correlation between the participants' trust in review sites and the participants' tendency to follow experts (Spearman's r = 0.580, p < 0.001).

The participants' preferences were rated using a 7-point scale, with a mean rating of 5.029 (SD = 1.025). The average value of the rating difference is 1.255 (SD = 0.514). There was no difference in the ratings or rating difference among the three stimulation groups.

We ran a logistic regression model of conformity behaviour as a function of participant stimulation types (the baseline group: sham stimulation group), rating difference and gender based on incongruent condition data (Table 5). The degree of trust had by the subjects in the experts had a significant positive effect on the subjects' tendency to follow the expert opinions. We found that females had a higher conformity tendency than males. The Mann-Whitney *U* test results also

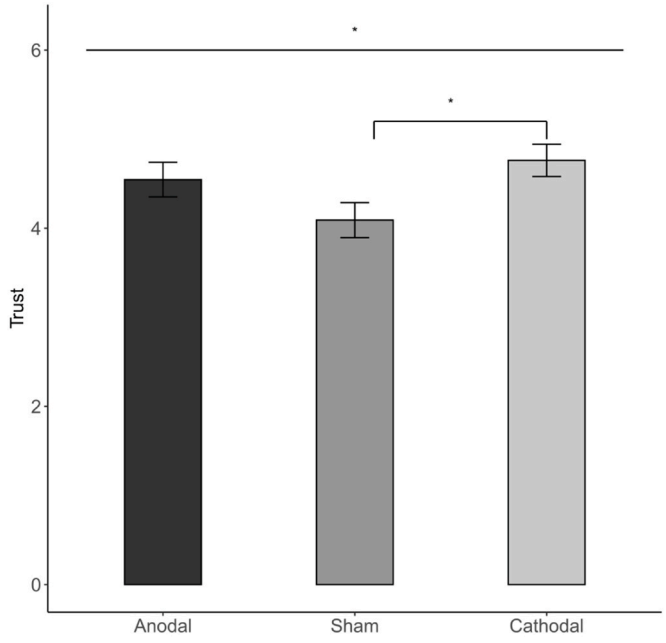

Fig. 8. The level of trust in experts. Error bars indicate ±1 SEM. *P < 0.05.

Table 5
Conformity behaviour under the incongruent condition in logistic regression.

Conformity	Coef.	Robust Std. Err.	z	P>|z|
Rating difference	−0.321	0.238	−1.350	0.176
Anodal	0.237	0.267	0.890	0.374
Cathodal	−0.173	0.283	−0.610	0.541
Female	0.541	0.217	2.490	0.013
Trust	0.605	0.135	4.470	0.000
Constant	−2.954	0.647	−4.570	0.000

supported this result (female vs male: 0.505 vs 0.333, p = 0.005).

After the experiment, we asked the participants to report the motivation for preference transfer in the experiment through a questionnaire. We provided the subjects with three options, including (1) "the items recommended by the review website should be better"; (2) "I want to be consistent with the review website's opinion"; and (3) "I have not changed my initial choice". The results showed that there was a

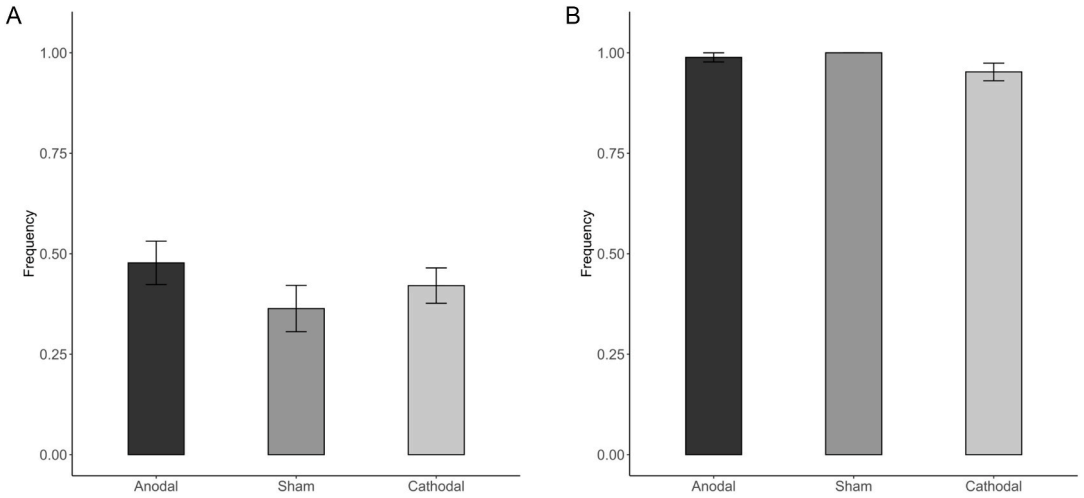

Fig. 7. Impact of stimulation on the tendency to conform to expert opinion. Error bars indicate ±1 SEM.

significant difference in the proportion of subjects with the first motivation (choose the better one) across stimulus groups (Anodal: 90.9%; Sham: 54.5%; Cathodal: 81%; $p = 0.014$), with higher proportions in the anodal stimulus group (Fig. 9).

5. Discussion

When people make social decisions, they are usually influenced by majority opinions and expert advice. Previous studies have shown that the mPFC is closely related to conformity behaviour, but the neural basis behind this association needs to be further explored. To study these issues, we used the tDCS method to stimulate the mPFC and provided participants with majority and expert opinions in a social conformity experiment. The study found that cathodal stimuli to the mPFC significantly enhanced the subjects' consistency tendency when facing majority opinions, while tDCS over the mPFC had no significant effect on the subjects' preference shift when facing expert opinions. Our results indicate that, first, when the social influence is the majority opinion, the mPFC has a moderating effect on the tendency of social conformity. Then, the influence of majority opinion and expert opinion on individual preferences may be based on different neural mechanisms.

When social information comes from the majority, the consistency of the cathodal stimulation group is significantly higher than that of the anodal stimulation group and the sham stimulation group under NPI = −3. That is, in the face of most dissenting opinions, the mPFC suppressed the subjects' tendency to conform. In addition, the results of Experiment 1 showed that the mPFC moderated the proportion of subjects who held the motivation "I want to be consistent with the majority". It has been demonstrated that the mPFC guides socially appropriate behaviour and decision-making (Rushworth et al., 2007; Watson and Platt, 2012; Willis et al., 2010). Yin et al. (2017) showed that disruptions of the mPFC increased subjects' propensity for voluntary norm compliance. Thus, we suggest that the mPFC moderates subjects' tendency to seek consistency, which in turn leads to a change in the tendency to follow the crowd. Previous studies on social conformity found that this behaviour involves both deep brain regions (such as the ventral striatum and insula) and surface brain regions (such as the mPFC) (Wu et al., 2016). Previous cognitive neuroscience research has shown that there is top-down control of the prefrontal cortex to the internal areas involved in reward and emotion in the brain (Banks et al., 2008; Batterink et al., 2010; Somerville et al., 2009; Volkow et al., 2009; Volkow et al., 2008). According to the brain balance model (Heatherton and Wagner, 2010), an important role of the prefrontal cortex is to control the impulses generated by the central part of the brain (such as the amygdala, insula, and nucleus accumbens). In summary, the results of Experiment 1 probably signify that the tendency to follow the majority may be driven by deep brain regions and is inhibited by our target brain area (the mPFC).

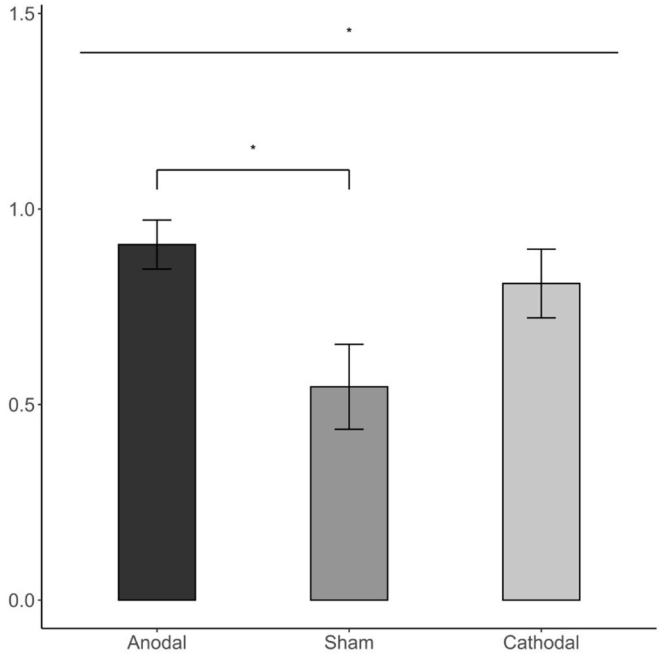

Fig. 9. The proportion of subjects in the different stimulus groups who were motivated by the belief that "the items recommended by the review website should be better". Error bars indicate ±1 SEM. *P < 0.05.

Our results show that subjects' tendency to follow expert opinions does not differ significantly with stimulus changes. We suggest that this phenomenon is mainly due to the dual effect of the stimulation of the mPFC on the subjects' decision-making process. In particular, we propose that subjects are likely to be affected by dual factors when they synthesize expert opinions and their initial evaluations of items. On one hand, stimulation of the mPFC increased the proportion of participants who believed that "the items recommended by the review website should be better". Previous studies have shown that the mPFC regulates the individual's integration of external social information and his or her self-concept and identity. Studies have further shown that damage to the mPFC can cause serious defects in individual value-based decision-making and prompt individuals to make more irrational decisions (Kumaran et al., 2015). Therefore, we speculate that anodal stimulation of the mPFC improves the individual's ability to make value-related decisions, which in turn enhances the participants' ability to rationally judge the comments from the review website that represent "expert opinions". That is, such stimulation promotes the more "rational" behaviour of following the opinions provided by the professional review website. On the other hand, stimulation of the mPFC reduced the participants' trust in experts. Previous studies have pointed out that the result of social influence is significantly affected by the ability or expertise of others (Aronson, 1994), that is, the individual's degree of trust in the source of the opinions. Some studies have shown that the mPFC is associated with trust behaviour (Klucharev et al., 2008), and our results support this correlation. In addition, in our experiments, the tendency to follow the expert's recommendation is positively related to the degree of trust. In conclusion, we suggest that stimulation of the mPFC enhances individuals' ability to make value-based decisions (awareness of the value of the professional review website) on the one hand and inhibits the tendency to blindly follow experts (level of trust in experts) on the other hand, which ultimately leads to no significant directional effect of mPFC stimulation on subjects' tendency to follow experts' opinions.

Based on the experimental results, we suggest that the differential effects of mPFC stimulation on an individual's conformity tendency indicate that the mPFC has different specific effects on the integration of majority and expert opinions when making preference decisions. Since previous studies have shown that stimulation of the mPFC can inhibit compliance with norms (Yin et al., 2017) and prompts individuals to conduct better value integration (Kumaran et al., 2015), we speculate that the mPFC has an inhibitory moderating effect on normative social conformity and a moderating effect on informational social conformity that helps individuals to better integrate persuasive information with their self-concept and identity. Under the influence of majority opinion, the change in an individual's conformity tendency during decision making is mainly manifested by the inhibitory modulation of normative aspects by the mPFC, which in turn leads to a higher tendency to follow the crowd under cathodal stimulation. In comparison, under the influence of expert opinion, the informational aspect of decision making is facilitatively modulated by the mPFC, while trust in the expert opinion is inhibitively modulated by this brain region, which ultimately leads to the stimulation having no significant effect on the subjects' tendency to follow the expert opinion. In addition, we noted that some motivational factors were not modulated by the stimuli, and we speculate that one possible reason for this is that these motivations do not result from value

judgments or normative conformity alone. Specifically, under the influence of majority opinion, stimulation of the mPFC had no clear tendency effect on the proportion of subjects motivated by the belief that "the picture chosen by the majority should be better", possibly because the function of the mPFC in value-related decision making is mainly to promote better value integration, while it had no clear tendency effect on the subjective value judgment of majority opinion (Raafat et al., 2009; Toelch and Dolan, 2015). Under the influence of expert opinion, the "I want to be consistent with the review website's opinion" motivation may be influenced by both value judgments regarding expert opinion in general and trust in the specific review website used in the experiment. Thus, this motivational factor was moderated by both the value integration and trust moderation functions of the mPFC (Biele et al., 2011; Klucharev et al., 2008; Meshi et al., 2012) and therefore did not vary significantly across stimulus groups.

The difference in the tendency of social conformity between males and females has always been the subject of concern in psychological research. Early studies have shown that females are more susceptible to social influences than males, which leads to females' higher consistent tendency (Eagly, 1978, 1983; Eagly and Chrvala, 1986; Wijenayake et al., 2019). Our experimental results show that females tend to be more consistent than males when faced with majority opinions and expert opinions. Past studies have shown that compared with males, females generally have higher empathy ability (Baron-Cohen and Wheelwright, 2004; Cohen and Strayer, 1996; Michalska et al., 2013), which provides an explanation for females' susceptibility to the influence of others. In addition, Mingming et al. (2017) found that when making social decisions related to risk, females usually use both social and nonsocial information, while males rely more on nonsocial information. The article used in our experiment is stationery, and there is no obvious gender difference in the degree of demand for stationery among college students; therefore, it can objectively reflect the difference in consistency tendencies between men and women. Therefore, this article supplements the research on gender differences in social conformity.

6. Limitation

In this study, we used a relatively small sample, although some previous studies on similar topics used similar sample sizes (Izuma et al., 2015; Klucharev et al., 2011). Our results should be considered with caution and require further validation with a larger sample.

7. Conclusion

Our research attempts to confirm the role of the mPFC in regulating social conformity through tDCS. Specifically, we conducted two experiments to provide subjects with majority opinions and expert opinions and tested the subjects' tendency to follow the majority/expert opinions under different stimuli. The experimental results show that when social information is the majority opinion, the cathodal stimulus for the mPFC significantly enhances the consistency tendency of the subjects, and when social information is from experts, the stimulation of the mPFC has no significant effect on the subjects' consistency tendency. These findings lead us to speculate that the subjects' conformity tendency is driven by the deep brain area and is inhibited by the surface area mPFC. We also suggest that the social impact of different sources of external information may be based on different neural mechanisms. Furthermore, we suggest that the different effects of mPFC stimulation on the individual's tendency to conform may be due to the multiple roles that mPFC plays in integrating majority and expert opinions when making preference decisions. In addition, we found that females tend to be more consistent than males. In summary, our findings complement neurological research on the role of the mPFC in the adjustment of individual social conformity.

Credit author statement

Yuzhen Li: Conceptualization, Methodology, Investigation, Writing – original draft, Xinbo Lu: Conceptualization, Methodology, Investigation, Wanjun Zheng: Conceptualization, Methodology, Investigation, Jun Luo: Conceptualization, Methodology, Investigation, Writing – review & editing

Ethics statement

The study conformed to the Declaration of Helsinki. All participants provided their written informed consent to participate in this study.

Declaration of competing interest

The authors declare no competing interests.

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