Online Appendix for “Debiasing the disposition effect with noninvasive brain stimulation: The role of cognitive control”

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Content:

A. Transcranial Direct Current Stimulation (tDCS)

tDCS is a popular noninvasive brain stimulation method. It applies a weak tonic direct current (typically 1–2 mA) between electrodes mounted on the head. This current de- or hyper-polarizes neuronal resting membrane potentials (i.e., anodal stimulation or cathodal stimulation) and thus alters cortical excitability. The primary effects of tDCS do not include synaptic mechanisms but instead involve voltage-dependent ion channels. tDCS allows establishing causal relationships between circumscribed regions of the brain via electrodes placed on the scalp and their underlying perceptual, cognitive, or motor functions (for a review, see Nitsche et al., 2008).

Figure A. tDCS used in the experiment.

tDCS experiment often consists of three stimulations: anodal, cathodal, and sham. Anodal and cathodal stimulations are assumed to increase and decrease the resting potential, respectively, and therefore the neural excitability in the targeted regions, whereas sham stimulation mimics the peripheral effects associated with tDCS and does not affect neural processing. Anodal and cathodal tDCS are active stimulations. Anodal stimulation is applied to a target brain area via the anode (an electrode with a positive charge which is red, see Figure A), typically associated with increased cortical excitability. Cathodal stimulation is applied to a target brain area via the cathode (an electrode with a negative charge which is blue, see Figure A), typically associated with decreased cortical excitability. Sham stimulation is a form of stimulation in which the current duration and intensity are substantially smaller than those in active stimulations. Sham stimulation can be thought of as a placebo stimulation. For a single target region in the brain, the second electrode is referred to as the reference. This electrode can be placed over a brain area thought not to be involved in the relevant process(es) or a non-brain region (e.g., the cheek or mastoid). The reference electrode is sometimes referred to as the “return” electrode.

From a cognitive neuroscience standpoint, the effect of applying anodal tDCS during task execution should induce facilitation of task performance, while cathodal tDCS should induce inhibition. In this sense, it is believed that tDCS primes the behavioral system by increasing/decreasing cortical excitability and producing corresponding effects in the cognitive system. While the main framework of a “facilitatory” anodal stimulation and a “worsening” cathodal stimulation is well-grounded, that framework is only valid for the use of tDCS in the motor system (Nitsche et al., 2008). The facilitative behavioral effects of anodal tDCS have been identified as the cause for several functions, but the relationship between facilitation and inhibition is often quite complex. In many cognitive neuroscience experiments, the stimulation of non-motor areas has led to the observation that behavioral effects are often not unequivocal, with anodal stimulation inducing facilitation and cathodal stimulation usually inducing a range of effects (Jacobson et al., 2012).

Moreover, there are many factors that affect tDCS-induced excitability changes caused by experimental, technical, or mechanistic issues, such as current density, stimulation duration, inter-participant variability, intra-participant reliability, sham stimulation and blinding, and motor and cognitive interference (Horvath et al., 2014). Weller at al. (2020) show the non-linear effects of anodal tDCS on cognitive control and propose the fact that the efficacy of tDCS depends on stimulation parameters whose implementations vary widely among studies. Schroeder et al. (2020) report on a small moderating effect of tDCS on inhibitory control in single-session studies and highlight the relevance of technical and behavioral parameters when reporting tDCS results.

B. Cognitive Control and Self-Control

In cognitive neuroscience and neuropsychology, cognitive control is defined as "a system that modulates the operation of other cognitive and emotional systems, in the service of goal-directed behavior, when prepotent modes of responding are not adequate to meet the demands of the current context. Additionally, control processes are engaged in the case of novel contexts, where appropriate responses need to be selected from among competing alternatives." This definition comes from a widely accepted clinical framework (i.e., Research Domain Criteria Initiative, RDoC, https://www.nimh.nih.gov/research/research-funded-by-nimh/rdoc/constructs/cognitive-control). Based on RDoC, the sub-construct of cognitive control includes "response selection; inhibition/suppression", "goal selection; updating, representation, and maintenance", and "performance monitoring". The function of the brain areas related to cognitive control is supposed to ensure that deliberation is accurate and that actions are executed as wanted.

The behavioral economic models view self-control "failures" as simple preference reversals. When individuals choose in ways that conflict with explicitly stated goals, these choices are seen as revealing individuals' true preferences. Models that fit this framework consist of temptation models which indicate that the immediate temptations make actual choices conflict with previously stated goals (Gul and Pesendorfer, 2001), temporal discounting models which include dynamic inconsistencies to drive changing preferences (Laibson, 1997), and dual-self models which propose that individuals possess (at least) two sets of preferences that are in active competition (Thaler and Sherfin, 1981; Fudenberg and Levine, 2006).

In the social psychology literature, self-control is viewed as "the overriding or inhibiting of automatic, habitual, or innate behaviors, urges, emotions, or desires that would otherwise interfere with goal directed behavior" (Muraven et al., 2006 p. 524). An influential theory of self-control in social psychology is ego depletion (Baumeister et al., 1998), which proposes that self-control relies on cognitive resources that are depleted the longer they are used. This theory suggests that the motivational or affective state of an individual affects the availability or functional integrity of these resources. Fatigued or stressed individuals, for example, are often presumed to have more limited cognitive resources for self-control upon which to draw (Muraven et al., 1998). This theory has dominated psychological conceptions of self-control as a form of "willpower" with impulsive or suboptimal choice emerging from a failure or depletion of control resources.

Thus, a common structure of cognitive control and self-control, based on the definitions from different disciplines, entails an ideal action that people would like to take and something (e.g., addiction, temptation, or emotion) that interferes with this action. People exert cognitive control or self-control because they want to follow their goal-directed behaviors (either intentional or incidental). When people exert cognitive control or self-control, they inhibit emotional, impulsive, or automatic behaviors.

Apart from the similar component noted above, there are several different aspects among different disciplines. For example, the dual-self model is popular in behavioral economics and some parts of neuroeconomics (Thaler and Sherfin, 1981; McClure et al., 2004; Fudenberg and Levine, 2006; Brocas and Carrillo, 2021), but it has been met with criticism in decision neuroscience circles, where it has been suggested that this dual process theory does not at all reflect the integrated nature of decision processes in the brain (Kable and Glimcher, 2007).

C. Translated Experimental Instructions

Welcome to our experiment. In this experiment you will be given one unit of stock A, one unit of stock B, one unit of stock C, and 50 experimental currencies. The initial price of each stock is 100 experimental currencies per stock unit.

There are 30 periods in the experiment. In every period one of the three stocks will be chosen randomly and its price will be updated by the computer. From period 1 to 6, you will only see updated stock prices and cannot trade any stock. From period 7 to 30, you have the opportunity to buy or sell the stock that is chosen and whose price is updated in the computer screen.

Each stock changes price according to the exact same rule. Each stock is either in a good state or in a bad state. In the good state, the stock goes up with a probability of 70% and goes down with a probability of 30%. In the bad state, the stock goes up with a probability of 30% and goes down with a probability of 70%. Once it is determined whether the price goes up or down, the size of the price change is always random and is either 5, 10, or 15 experimental currencies. The stock will all randomly start in either the good state or the bad state. After each price update, there is a 20% chance that the stock switches its state.

For example, if stock A is in the good state in a period, its price will go up with 70% chance, and the increasing amount is 5, 10, or 15 with equal chance. At the same time its price will go down with 30% chance, and the decreasing amount is 5, 10, or 15 with equal chance. In the next period, if stock A is chosen, it is still in the good state with 80% chance and switches to the bad state with 20% chance.

Stock price changes

	Good state	Bad state
+	70%	30%
−	30%	70%

State changes

	Good state next period	Bad state next period
Good state this period	80%	20%
Bad state this period	20%	80%

Only one of the three stocks will be chosen randomly, and its price is updated in a period. The prices of the other two stocks in this period do not change. You can see the chosen stock, its current price, the amount of price change, and your available cash. However, the state of the stock is not displayed.

Please note:

(1) At the beginning of the entire experiment, you first need to answer two questions: "How much capital gain does holding a stock bring you when you plan to sell it?" and "How much capital loss does holding a stock bring you when you plan to sell it?" The capital gain and capital loss limits are nonbinding, and you could not adjust limits during the entire experiment.

(2) In each period, you have 15 seconds to make a response by pressing the BUY (SELL) or NOT BUY (NOT SELL) button. Otherwise, the computer will randomly select a response for you.

(3) You are only allowed to hold a maximum one unit of each stock and cannot hold negative units (no short selling). However, you can carry a negative cash balance by buying a stock for more money than you have. Any negative cash balance will be deducted from your final earnings.

Your earnings at the end of the experiment will be equal to the amount of cash you accrue over all the periods from buying and selling stocks, plus the current price of any stocks that you own. **Earnings=cash + price A*(hold A) + price B*(hold B) + price C*(hold C).**

Finally, your earnings will be converted at an exchange rate of 10:1. This means that your experimental currencies earned in the experiment are divided by 10. We also pay you the 10 yuan show-up fee.

Computer Screens and Examples

For example, if stock C is chosen in period 1 (see Panel (a) in Figure C), it has increased by 15; its current price is 115; your purchase price is 100; your available cash is 50. From period 1 to 6, you will see a similar computer screen.

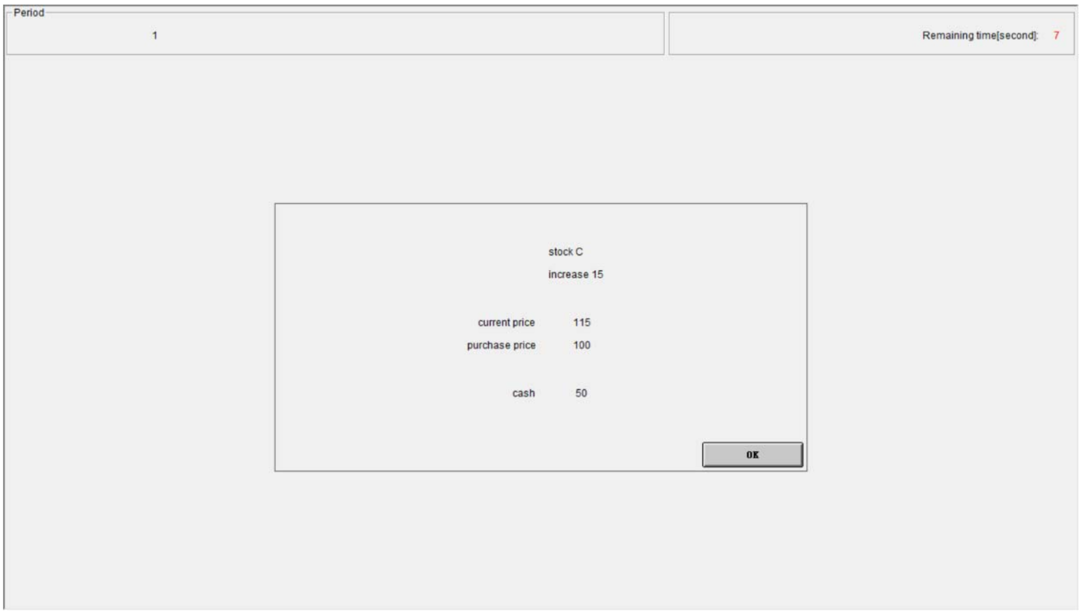
If stock A is chosen in period 13, it has increased by 5; its current price is 105;

your purchase price is 100; your available cash is 130. You need to decide whether to sell the stock by pressing the button of **“Yes”** or **“No”** in 15 seconds (see Panel (b) in Figure C).

If stock A is chosen in period 16, it has decreased by 5; its current price is 110; your available cash is 365. You need to decide whether to buy the stock by pressing the button of **“Yes”** or **“No”** in 15 seconds (see Panel (c) in Figure C).

Figure C. Examples of z-Tree screen in the experiment. For period 1 to 6, you observe a screen like Panel (a) in which a stock price is updated and you are not allowed to trade the stock. After period 6, you can observe a screen like Panel (b) or Panel (c). If you hold the chosen stock in a period, a screen like Panel (b) is displayed, and you decide whether to sell it. If you do not hold the chosen stock, a screen like Panel (c) is displayed, and you decide whether to buy it. In each period you have 15 seconds to make a response. Otherwise, the computer will randomly select a response for you.

Panel (a)



Period 1

Remaining time[second]: 7

stock C

increase 15

current price 115

purchase price 100

cash 50

Panel (b)

Period

13

Remaining time[second]: 13

stock A

increase 5

current price 105

purchase price 100

cash 130

sell?

Panel (c)

Period

16

Remaining time[second]: 13

stock A

increase 5

current price 110

cash 365

buy?

D. Calculation of Net Expected Value

Let $P_i^{t\text{-}1}$ be the price of stock *i* in period *t-1*, after any price update about the stock. S_i^t = *good* indicates stock *i* is in a good state in period *t* and S_i^t = *bad* indicates the opposite. Let $G_i^t = \Pr(S_i^t = good \,|\, P_i^t, P_i^{t\text{-}1}, \ldots, P_i^1)$ be the probability that a Bayesian investor, after observing the price update in period *t*, would consider stock *i* as being in the good state in period *t*. Moreover, let Z_t take the value 1 if the price update in period *t* indicates a price increase for the stock and -1 if the price update indicates a price decrease, $\Pr(Z_t \,|\, S_i^t = good) = 0.5 + 0.2Z_t$. If $G^t = G_i^{t\text{-}1}$, then the price update in period *t* is not about stock *i*. If the price update in period *t* is about stock *i*, then:

$$
\begin{aligned}
G_i^t\left(G_i^{t\text{-}1}, Z_t\right) &= \Pr\left(S_i^t = good \,\middle|\, G_i^{t\text{-}1}, Z_t\right) \\
&= \frac{\Pr(Z_t \,|\, S_i^t = good)\Pr(S_i^t = good \,|\, G_i^{t\text{-}1})}{\Pr(Z_t)} \\
&= \frac{\Pr(Z_t \,|\, S_i^t = good)\Pr(S_i^t = good \,|\, G_i^{t\text{-}1})}{\Pr(Z_t \,|\, S_i^t = good)\Pr(S_i^t = good \,|\, G_i^{t\text{-}1}) + \Pr(Z_t \,|\, S_i^t = bad)\Pr(S_i^t = bad \,|\, G_i^{t\text{-}1})} \\
&= \frac{(0.5 + 0.2Z_t)[0.8G_i^{t\text{-}1} + 0.2(1 - G_i^{t\text{-}1})]}{(0.5 + 0.2Z_t)[0.8G_i^{t\text{-}1} + 0.2(1 - G_i^{t\text{-}1})] + (0.5 - 0.2Z_t)[0.2G_i^{t\text{-}1} + 0.8(1 - G_i^{t\text{-}1})]}
\end{aligned}
$$

At the beginning of the experiment, the state of stock *i* is randomly assigned and stock price is 100, $G_i^0 = 0.5$ and $P_i^0 = 100$. The optimal strategy is to sell (if holding) or not to repurchase (if not holding) stock *i* in period *t* when $G_i^t < 0.5$ and to hold or repurchase it otherwise. The net expected value of holding the stock can be approximated by the stock's expected price change on its next price update:

$$
\begin{aligned}
&\textit{Net Expected Value}_i^t = E_t[P_i^{t+1} \,|\, G_i^t, P_i^{t+1} \neq P_i^t] - P_i^t = E_t[\Delta P_i^{t+1} \,|\, G_i^t, \Delta P_i^{t+1} \neq 0] \\
&\quad = \Pr\left(S_i^{t+1} = good \,\middle|\, G_i^t\right) \times [0.7 \times 10 + 0.3 \times (-10)] + \Pr\left(S_i^{t+1} = bad \,\middle|\, G_i^t\right)[0.3 \times 10 + 0.7 \times (-10)] \\
&\quad = [0.8G_i^t + 0.2(1 - G_i^{t+1})] \times 4 + [0.2G_i^t + 0.8(1 - G_i^t)] \times (-4) \\
&\quad = 4[0.6G_i^t + 0.2 - 0.8 + 0.6G_i^t] \\
&\quad = 2.4[2G_i^t - 1]
\end{aligned}
$$

A risk neutral participant who follows the optimal trading strategy will hold (or repurchase) the stock whenever *Net Expected Value* is positive ($G_i^t > 0.5$) and will sell (or do not repurchase) the stock whenever *Net Expected Value* is negative ($G_i^t < 0.5$). Note that this is only an approximation to the actual decision value because the exact value of holding a stock is the stock's expected cumulative price change until the participant decides to sell it. However, there is little cost in using the above approximation because the value of holding a stock only for its next price change is highly correlated with the value of holding the stock until it is actually optimal to sell it (the latter quantity can be computed by simulation) (Frydman et al., 2014).

E. Additional Figures and Tables

Figure E1. Realized prices used in Experiments 1 and 2. The price of each stock is updated 10 times. Stock A is updated five times for price increase and five times for price decrease. The realized price of Stock A is shown in black. Stock B is updated seven times for price decrease and three times for price increase. The realized price of Stock B is shown in red. Stock C is updated three times for price decrease and seven times for price increase. The realized price of Stock C is shown in green.

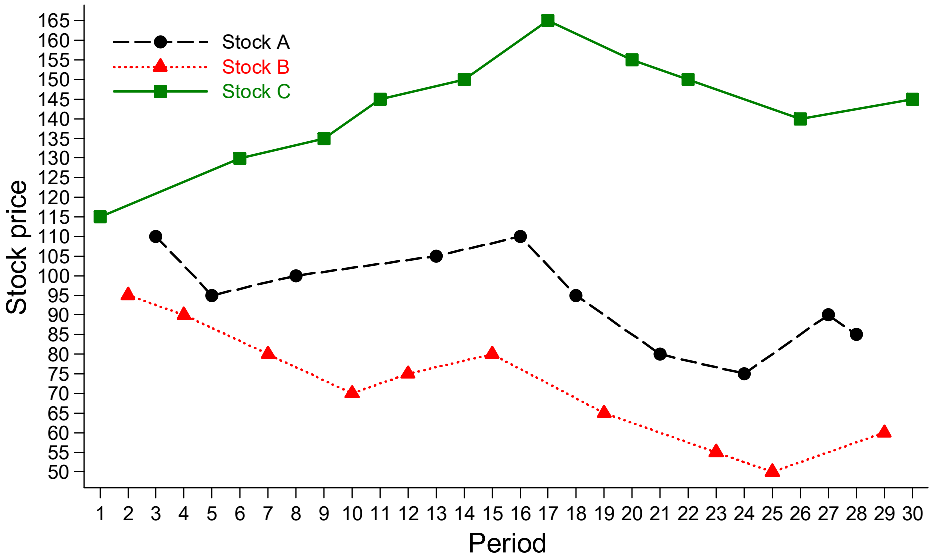


Figure E2. Realized prices used in Experiment 3. The price of each stock is updated 20 times. Stock A is updated eleven times for price increase and nine times for price decrease. The realized price of Stock A is shown in black. Stock B is updated eleven times for price decrease and nine times for price increase. The realized price of Stock B is shown in red. Stock C is updated thirteen times for price increase and seven times for price decrease. The realized price of Stock C is shown in green.

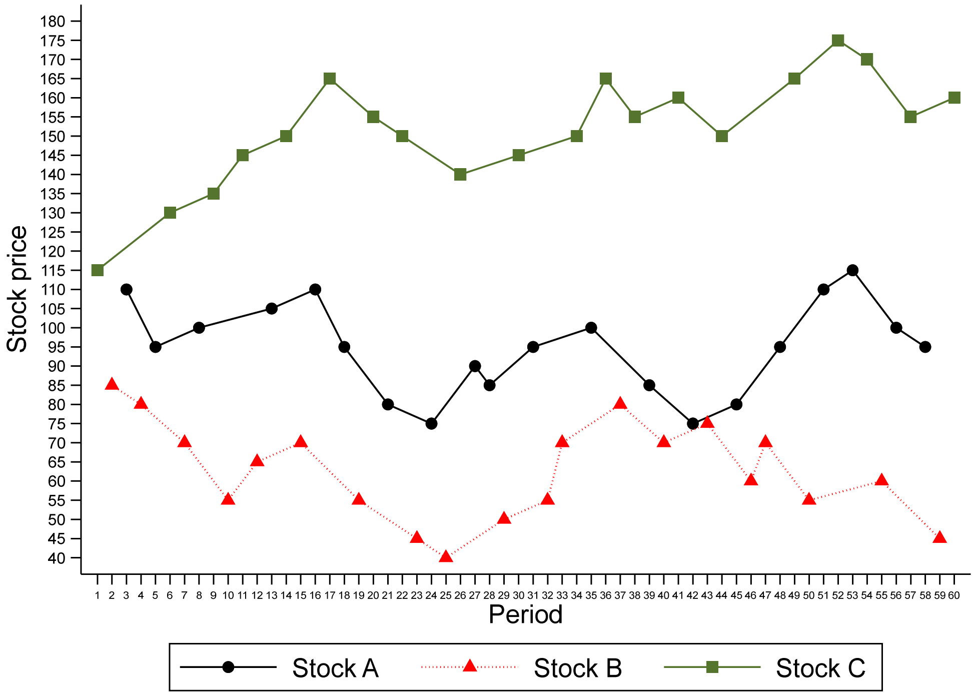


Table E1. Regression analysis of the disposition effect, PGR, and PLR in Experiment 1. OLS regression. rVLPFC_A is a dummy variable that equals one if the stimulation is rVLPFC anodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Disposition effect		PGR		PLR	
	(1)	(2)	(3)	(4)	(5)	(6)
rVLPFC_A	0.036	0.076	0.055	0.068	0.019	−0.009
	(0.101)	(0.101)	(0.070)	(0.074)	(0.064)	(0.062)
rVLPFC_C	-0.349^{***}	-0.286^{***}	-0.079^{*}	−0.058	0.269^{***}	0.228^{***}
	(0.088)	(0.092)	(0.058)	(0.063)	(0.061)	(0.063)
Constant	0.083	−0.818	0.356^{***}	−0.007	0.273^{***}	0.811^{**}
	(0.061)	(0.548)	(0.041)	(0.370)	(0.035)	(0.369)
Demographic controls	No	Yes	No	Yes	No	Yes
N	95	95	95	95	95	95
R^2	0.174	0.220	0.044	0.068	0.186	0.239

Table E2. Regression analysis of optimal trading decisions and cognitive control in Experiment 1. OLS regression. rVLPFC_A is a dummy variable that equals one if the stimulation is rVLPFC anodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Cognitive control is measured with participants' percentage of time-consistent decisions. Optimal trading decision is measured with participants' percentage of optimal trading decisions. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Optimal trading decision		Cognitive control	
	(1)	(2)	(3)	(4)
rVLPFC_A	−0.021	−0.023	0.009	−0.005
	(0.044)	(0.046)	(0.046)	(0.048)
rVLPFC_C	0.107^{***}	0.100^{**}	0.185^{***}	0.161^{***}
	(0.039)	(0.043)	(0.044)	(0.046)
Constant	0.442^{***}	0.811^{***}	0.461^{***}	0.934^{***}
	(0.023)	(0.272)	(0.033)	(0.230)
Demographic controls	No	Yes	No	Yes
N	95	95	95	95
R^2	0.095	0.130	0.192	0.233

Table E3. Descriptive statistics and randomization check for financial professionals in Experiment 3. Sham is rVLPFC sham stimulation. Cathodal is rVLPFC cathodal stimulation. *Age* is the year of age of a professional (30 to 37). *Female* is a binary variable that equals one if a professional is a woman and zero otherwise. *Years in Industry* is the number of years a professional has worked in the finance industry. *Monthly Income* is a professional's monthly income in Chinese yuan. *Trading Frequency* is the number of times a professional trades assets per month. The last column displays *p*-value for the null hypothesis of perfect randomization (Mann-Whitney test).

	Total sample N=37		Sham N=19		Cathodal N=18		*p*-value
	Mean	SE	Mean	SE	Mean	SE	
Age	32.189	0.326	31.894	0.374	32.5	0.544	0.516
Female	0.351	0.079	0.421	0.116	0.278	0.108	0.368
Years in Industry	6.567	0.371	6.473	0.492	6.667	0.404	0.734
Monthly Income	13,702	550.54	13,315	861.97	14,111	685.46	0.237
Trading Frequency	2.432	0.184	2.368	0.244	2.5	0.283	0.753

Table E4. Regression analysis of the disposition effect, PGR, and PLR in Experiment 3. OLS regression. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Disposition effect		PGR		PLR	
	(1)	(2)	(3)	(4)	(5)	(6)
rVLPFC_C	-0.287^{**}	-0.231^{***}	−0.046	−0.033	0.239^{**}	0.198^{***}
	(0.112)	(0.070)	(0.037)	(0.037)	(0.092)	(0.059)
Constant	0.076	0.071	0.302^{***}	0.311	0.226^{***}	0.239
	(0.073)	(0.539)	(0.028)	(0.236)	(0.062)	(0.529)
Demographic controls	No	Yes	No	Yes	No	Yes
N	37	37	37	37	37	37
R^2	0.158	0.723	0.040	0.254	0.162	0.710

Table E5. Regression analysis of optimal trading decisions in Experiment 3. OLS regression. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Optimal trading decision is measured as the percentage of optimal trading decisions. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Optimal trading decision	
	(1)	(2)
rVLPFC_C	0.106^{*}	0.079^{*}
	(0.057)	(0.041)
Constant	0.570^{***}	0.722^{**}
	(0.035)	(0.284)
Demographic controls	No	Yes
N	37	37
R^2	0.089	0.660

Table E6. Regression analysis of present bias and impulsivity in Experiment 2. OLS regression. rTPJ_C is a dummy variable that equals one if the stimulation is rTPJ cathodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Present bias is the difference in the number of impatient choices between "today vs. in 3 months" and "in 3 months vs. in 6 months" (0 to 10). Impulsivity is the average number of impatient choices chosen in the three delay-discounting scenarios (0 to 10). Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Present bias		Impulsivity	
	(1)	(2)	(3)	(4)
rTPJ_C	−0.033	0.042	0.036	0.046
	(0.344)	(0.035)	(0.178)	(0.188)
rVLPFC_C	-0.617^{**}	-0.527^{*}	-0.700^{***}	-0.667^{***}
	(0.269)	(0.293)	(0.177)	(0.179)
Constant	2.2^{***}	−0.720	3.533^{***}	1.588^{*}
	(0.191)	(1.732)	(0.153)	(0.838)
Demographic controls	No	Yes	No	Yes
N	73	73	73	73
R^2	0.063	0.128	0.264	0.323

F. Evolution of Holding Stocks

We shed light on the effect of tDCS on the evolution of held stocks from period 7 to 30 using the data of Experiment 1. The results are reported in Figure F. The benchmark shows the number of held stocks for a risk-neutral Bayesian participant who follows the optimal trading strategy. For the realized price used in Experiment 1 (see Figure E1), a risk-neutral Bayesian participant who follows the optimal trading strategy would sell Stock B in Period 7, buy Stock B in Period 12, sell Stock A in Period 18, sell Stock B in Period 19, sell Stock C in Period 20, buy Stock A in Period 27, sell Stock A in Period 28, and buy Stock B in Period 29. That is, the optimal trading strategy in Experiment 1 involves selling the loser stock (i.e., Stock B) sooner and holding the winner stock (i.e., Stock C) longer.

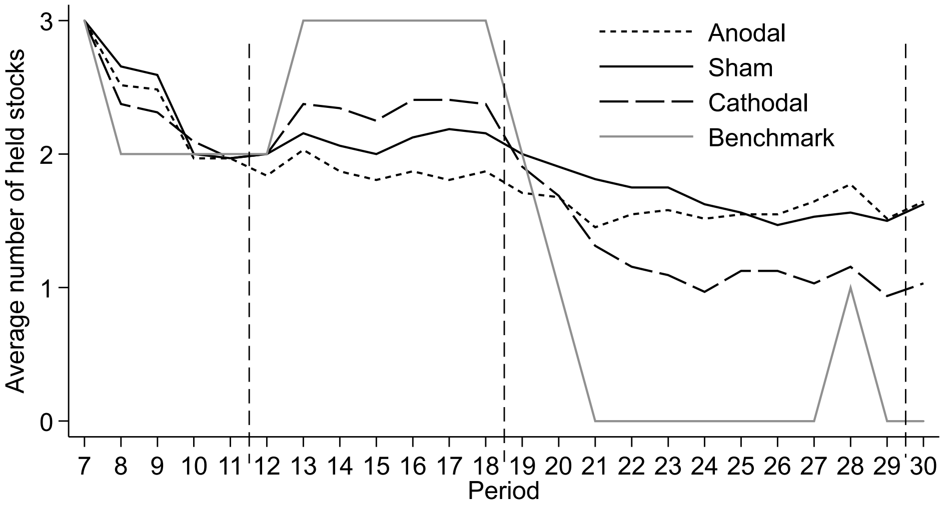
Panel (a) in Figure F shows the average number of held stocks by stimulation. The benchmark (grey solid line) indicates that the optimal trading strategy is to increase the number of held stocks from 2 in Period 12 to 3 in Period 13 and decrease the number of held stocks from 3 in Period 18 to 0 in Period 21. This trading pattern is roughly observed in the cathodal stimulation. Specifically, from Period 7 to 11 the stimulation difference in the number of held stocks is not significant (Kruskal-Wallis test, $p = 0.782$). In Period 11, the number of held stocks is decreased to 1.97 in the three stimulations. This number in the sham and anodal stimulations does not change from Period 12 to 29. However, the participant in the cathodal stimulation increases the number of held stocks from Period 12 to 18 (i.e., average number is 2.31), and then largely decreases this number from 2.375 in Period 18 to 0.937 in Period 29. The Mann-Whitney test shows that the number of held stocks in the cathodal stimulation is significantly different from that of the anodal and sham stimulations from Period 12 to 18 and from Period 19 to 29 (all p values < 0.01).

Panel (b) in Figure F presents the average number of held stocks by stock type in each of the three stimulations. The optimal trading strategy is to sell the loser Stock B sooner and hold the winner Stock C longer. The benchmark in Panel (b4) shows that, for a risk-neutral participant who follows the optimal trading strategy, the number of held Stock B is 0 and the number of held Stock A or C is 1 from Period 8 to 12. The number of held Stock A, B, or C is 1 from Period 13 to 18, and 0 from Period 21 to 27. We find that a participant's trading strategy in the cathodal stimulation is closer to the benchmark relative to the anodal and sham stimulations. That is, participants in the cathodal stimulation are quick to sell the loser Stock B and likely to hold the winner Stock C, whereas participants in the anodal and sham stimulations are quick to sell the winner Stock C and likely to hold the loser Stock B (see Panels (b1), (b2), and (b3)).

Specifically, from Period 8 to 12, the average number of held Stock B in the cathodal stimulation is 0.325 whereas this number is 0.516 in the anodal stimulation and 0.656 in the sham stimulation (Mann-Whitney test, all p values < 0.001), the average number of held Stock C in the cathodal stimulation is 0.875 but this number is about 0.65 in the anodal and sham stimulations (Mann-Whitney test, all p values < 0.01), the average number of held Stock A is basically the same in the three stimulations (i.e., approximately 0.95). From Period 13 to 18, the average number of held Stock C in the cathodal stimulation is 0.745 but this number is only 0.322 in the anodal stimulation and 0.391 in the sham stimulation (Mann-Whitney test, all p values < 0.001), the average number of held Stock A and Stock B is basically the same in the three stimulations (approximately 0.85 and 0.75, respectively). From Period 21 to 27, the average number of held Stock A and Stock B in the cathodal stimulation is 0.371 and 0.491, respectively, but this number is about 0.70 in the anodal and sham stimulations (Mann-Whitney test, all p values < 0.01), the average number of held Stock C is basically the same in the three stimulations (i.e., approximately 0.20).

Figure F. Number of held stocks in Experiment 1. Panel (a) shows the average number of held stocks by stimulation. Panel (b) shows the average number of held stocks by stock type. The benchmark shows the average number of held stocks for a risk-neutral participant who follows the optimal trading strategy. The optimal trading strategy is to hold (or repurchase) the stock whenever NEV is positive and sell (or do not repurchase) the stock whenever NEV is negative. The cathodal stimulation is closer to the benchmark relative to the anodal and sham stimulations.

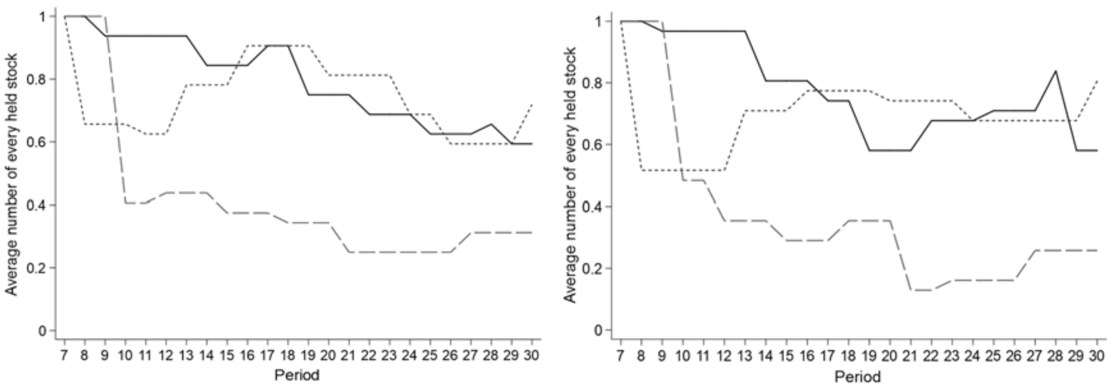
Panel (a): Average number of held stocks by stimulation



Panel (b): Average number of held stocks by stock type

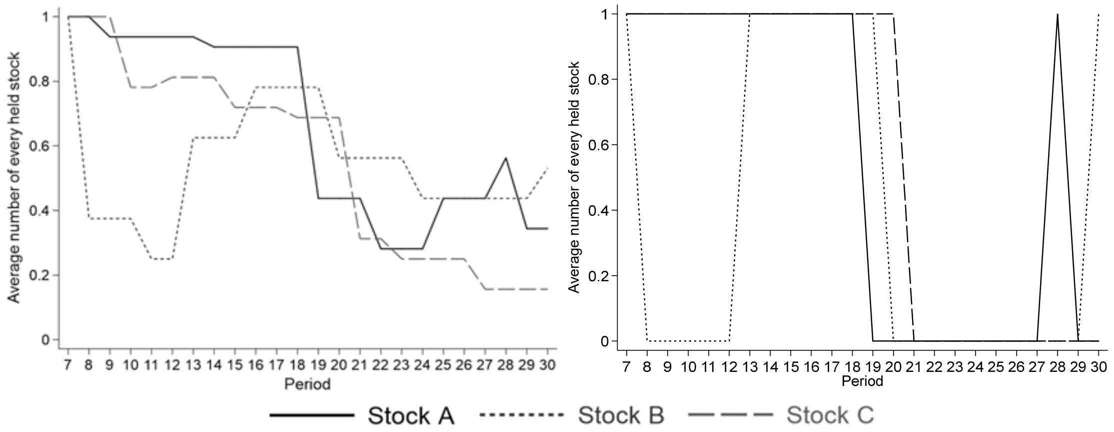
Panel (b1): Sham Stimulation

Panel (b2): Anodal Stimulation



Panel (b3): Cathodal Stimulation

Panel (b4): Benchmark



G. Random Trading

One concern is that the rVLPFC cathodal stimulation may lead to random actions, which may spuriously generate a reduction in the disposition effect, as well as aligning actions with planned actions if these actions are unconditional (not dependent on specifics of history beyond gain/loss limit). Here we test this possibility.

In Panel (a) of Table G1, we report the average frequency of repurchase stocks (i.e., repurchase frequency), the average frequency of selling stocks with capital gains and losses (i.e., total selling frequency), the average frequency of selling stocks with capital gains (i.e., realized gain frequency), and the average frequency of selling stocks with capital losses (i.e., realized loss frequency) by stimulation using data of Experiment 1.

We find that the differences in the repurchase frequency are not significant among the three stimulations (anodal: 1.967, sham: 2.218, cathodal: 2.781; Mann-Whitney test, all p values > 0.20). The total selling frequency in the rVLPFC cathodal stimulation (M = 4.531, SE = 0.277) is significantly higher than that in the sham stimulation (M = 3.687, SE = 0.248; Mann-Whitney test, p = 0.037), and this result is driven by the rVLPFC cathodal stimulation significantly increasing realized loss frequency (sham: 2.093, cathodal: 2.718, Mann-Whitney test, p = 0.019). The differences in the total selling frequency between the anodal and sham stimulations are not significant (3.322 vs. 3.687, Mann-Whitney test, p = 0.246), but the realized loss frequency in the anodal stimulation is significantly lower than that in the sham stimulation (1.645 vs. 2.093, Mann-Whitney test, p = 0.059). The differences in the realized gain frequency are not significant among the three stimulations (anodal: 1.677, sham: 1.593, cathodal: 1.812; Mann-Whitney test, all p values > 0.40).

Thus, the rVLPFC cathodal stimulation only increases the frequency of selling stocks with capital losses, and the rVLPFC anodal stimulation decreases the frequency of selling stocks with capital losses. That is, participants in the cathodal stimulation are more likely to sell losing stocks, whereas participants in the anodal stimulation are less likely to sell losing stocks. This result is in line with the evolutions of holding stocks in the cathodal and anodal stimulations, namely, participants in the cathodal stimulation are closer to the benchmark of optimal trading strategy relative to the anodal stimulation.

Moreover, using the data of Experiment 1, we run a simulation in which the selling decisions are randomly made given each participant's repurchasing decisions in the rVLPFC cathodal stimulation (i.e., simulation_cathodal). The simulation results for the selling frequency and the disposition effect in the cathodal stimulation are reported in the second line from the bottom of Panel (a) of Table G1 and Panel (b) of Table G1, respectively. We also run two simulations using the data of Experiments 2 and 3. The simulation results for Experiment 2 are reported in the second line from the bottom of Panel (a) of Table G2 and Panel (b) of Table G2, respectively. The simulation results for Experiment 3 are reported in the second line from the bottom of Panel (a) of Table G3 and Panel (b) of Table G3, respectively.

Panel (a) of Table G1 shows that random trading not only increases the frequency of selling loser stocks (M = 4.343) but also increases the frequency of selling winner stocks (M = 4.781) relative to the cathodal stimulation (Mann-Whitney test, all p values < 0.01). Similar results are found using the data of Experiments 2 and 3 (see Panel (a) in Tables G2 and G3).

Importantly, Panel (b) of Table G1 shows that random trading leads to basically the same percentage of time-consistent decisions as that of cathodal stimulation (simulation_ cathodal: 0.572, cathodal: 0.550, Mann-Whitney test, $p = 0.722$), but the optimal trading decisions and the disposition effect due to random trading are significantly different from those of cathodal stimulation. The percentage of optimal trading decisions due to random trading is 0.526, which is significantly lower than 0.647 in the cathodal stimulation (Mann-Whitney test, $p = 0.001$). The disposition effect due to random trading is −0.119, which is significantly higher than −0.266 in the cathodal stimulation (Mann-Whitney test, $p = 0.076$).

Panel (b) of Table G2 shows that the optimal trading and percentage of time-consistent decisions due to random trading are significantly lower than those in the cathodal stimulation (optimal trading: 0.568 vs. 0.650, Mann-Whitney test, $p = 0.053$; percentage of time-consistent: 0.513 vs. 0.621, Mann-Whitney test, $p = 0.041$), and the disposition effect due to random trading is significantly higher than that in the cathodal stimulation (−0.103 vs. −0.289, Mann-Whitney test, $p = 0.057$).

Panel (b) of Table G3 shows that the optimal trading decisions due to random trading are significantly lower than those in the cathodal stimulation (0.526 vs. 0.675, Mann-Whitney test, $p = 0.006$), and the disposition effect due to random trading is higher than that in the cathodal stimulation though the difference does not reach the significant level (−0.102 vs. −0.211, Mann-Whitney test, $p = 0.146$).

Taken together, although random trading is not dependent on specifics of history beyond gain/loss limit, the disposition effect due to random trading will not be reduced to the same value as that of cathodal stimulation. Thus, while a portion of the behavioral data we observe in the rVLPFC cathodal stimulation may be driven by random trading, there remains a substantial portion of the data that random actions cannot explain.

Table G1. Test of random trading in Experiment 1. Anodal indicates rVLPFC anodal stimulation. Sham indicates rVLPFC sham stimulation. Cathodal indicates rVLPFC cathodal stimulation. Simulation_Cathodal indicates the simulation in which the selling decisions are randomly made given each participant's repurchase decisions in the rVLPFC cathodal stimulation. Repurchase indicates the average frequency of repurchase stocks. Total selling indicates the average frequency of selling stocks with capital gains and losses. Realized gain indicates the average frequency of selling stocks with capital gains. Realized loss indicates the average frequency of selling stocks with capital losses. Optimal trading decision indicates the percentage of optimal trading decisions. Cognitive control indicates the percentage of time-consistent decisions. Standard error of the mean is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Panel (a): Individual trading decisions

	Repurchase	Total selling	Realized gain	Realized loss
1: Anodal	1.967 (0.268)	3.322 (0.264)	1.677 (0.163)	1.645 (0.199)
2: Sham	2.218 (0.264)	3.687 (0.248)	1.593 (0.134)	2.093 (0.197)
3: Cathodal	2.781 (0.320)	4.531 (0.277)	1.812 (0.212)	2.718 (0.157)
4: Simulation_Cathodal	2.781 (0.320)	9.125 (0.338)	4.781 (0.293)	4.343 (0.218)
Mann-Whitney test	1-2, 2-3, 3-4	1-2, 2-3**, 3-4***	1-2, 2-3, 3-4***	1-2*, 2-3**, 3-4***

Panel (b): The disposition effect, optimal trading decision and cognitive control

	PGR	PLR	Disposition effect	Optimal trading decision	Cognitive control
1: Anodal	0.412 (0.057)	0.292 (0.053)	0.120 (0.080)	0.470 (0.033)	0.421 (0.037)
2: Sham	0.356 (0.041)	0.273 (0.035)	0.083 (0.061)	0.461 (0.032)	0.442 (0.023)
3: Cathodal	0.276 (0.041)	0.542 (0.049)	−0.266 (0.063)	0.647 (0.029)	0.550 (0.032)
4: Simulation_Cathodal	0.647 (0.032)	0.766 (0.033)	−0.119 (0.044)	0.526 (0.019)	0.572 (0.022)
Mann-Whitney test	1-2, 2-3**, 3-4***	1-2, 2-3***, 3-4***	1-2, 2-3***, 3-4*	1-2, 2-3***, 3-4***	1-2, 2-3***, 3-4

Table G2. Test of random trading in Experiment 2. rTPJ_Cathodal indicates rTPJ Cathodal stimulation. Sham indicates sham stimulation. rVLPFC_Cathodal indicates rVLPFC cathodal stimulation. Simulation_Cathodal indicates the simulation in which the selling decisions are randomly made given each participant's repurchase decisions in the rVLPFC cathodal stimulation. Repurchase indicates the average frequency of repurchase stocks. Total selling indicates the average frequency of selling stocks with capital gains and losses. Realized gain indicates the average frequency of selling stocks with capital gains. Realized loss indicates the average frequency of selling stocks with capital losses. Optimal trading decision indicates the percentage of optimal trading decisions. Cognitive control indicates the percentage of time-consistent decisions. Standard error of the mean is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Panel (a): Individual trading decisions

	Repurchase	Total selling	Realized gain	Realized loss
1: rTPJ_Cathodal	2.167 (0.299)	3.458 (0.255)	1.625 (0.117)	1.833 (0.230)
2: Sham	2.24 (0.323)	3.56 (0.265)	1.6 (0.163)	1.96 (0.195)
3: rVLPFC_Cathodal	2.542 (0.288)	4 (0.248)	1.25 (0.150)	2.75 (0.227)
4: Simulation_Cathodal	2.542 (0.288)	8.792 (0.329)	4.083 (0.329)	4.708 (0.279)
Mann-Whitney test	1-2, 2-3, 3-4	1-2, 2-3, 3-4***	1-2, 2-3*, 3-4***	1-2, 2-3**, 3-4***

Panel (b): The disposition effect, optimal trading decision and cognitive control

	PGR	PLR	Disposition effect	Optimal trading decision	Cognitive control
1: rTPJ_Cathodal	0.355 (0.053)	0.311 (0.056)	0.044 (0.089)	0.515 (0.041)	0.510 (0.040)
2: Sham	0.351 (0.054)	0.288 (0.042)	0.063 (0.074)	0.468 (0.038)	0.464 (0.038)
3: rVLPFC_Cathodal	0.203 (0.022)	0.492 (0.064)	−0.289 (0.072)	0.650 (0.038)	0.621 (0.034)
4: Simulation_Cathodal	0.615 (0.037)	0.717 (0.035)	−0.103 (0.059)	0.568 (0.028)	0.513 (0.034)
Mann-Whitney test	1-2, 2-3**, 3-4***	1-2, 2-3***, 3-4***	1-2, 2-3***, 3-4*	1-2, 2-3***, 3-4*	1-2, 2-3***, 3-4**

Table G3. Test of random trading in Experiment 3. Sham indicates sham stimulation. Cathodal indicates rVLPFC cathodal stimulation. Simulation_Cathodal indicates the simulation in which the selling decisions are randomly made given each participant's repurchase decisions in the rVLPFC cathodal stimulation. Repurchase indicates the average frequency of repurchase stocks. Total selling indicates the average frequency of selling stocks with capital gains and losses. Realized gain indicates the average frequency of selling stocks with capital gains. Realized loss indicates the average frequency of selling stocks with capital losses. Optimal trading decision indicates the percentage of optimal trading decisions. Standard error of the mean is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Panel (a): Individual trading decisions

	Repurchase	Total selling	Realized gain	Realized loss
1: Sham	5.158	6.631	3.737	2.895
	(0.832)	(0.908)	(0.411)	(0.625)
2: Cathodal	7.389	8.833	4.056	4.778
	(0.595)	(0.663)	(0.296)	(0.586)
3: Simulation_Cathodal	7.389	19.444	11.167	8.278
	(0.595)	(0.933)	(0.833)	(0.470)
Mann-Whitney test	1-2**, 2-3	1-2*, 2-3***	1-2, 2-3***	1-2**, 2-3***

Panel (b): The disposition effect, optimal trading decision and cognitive control

	PGR	PLR	Disposition effect	Optimal trading decision
1: Sham	0.302	0.226	0.076	0.570
	(0.029)	(0.062)	(0.073)	(0.035)
2: Cathodal	0.255	0.466	−0.211	0.675
	(0.026)	(0.068)	(0.085)	(0.045)
3: Simulation_Cathodal	0.646	0.748	−0.102	0.526
	(0.021)	(0.046)	(0.051)	(0.028)
Mann-Whitney test	1-2, 2-3***	1-2***, 2-3***	1-2**, 2-3	1-2*, 2-3***

H. Detailed Results for Experiment 2

We find that the rTPJ cathodal stimulation does not affect the disposition effect relative to the sham stimulation. The average disposition effect in the rTPJ cathodal stimulation is 0.044 (SE = 0.089), which is not significantly different from 0.063 (SE = 0.074) in the sham stimulation (Mann-Whitney test, $p = 0.711$; Cohen's $d = 0.047$). The PLR in the rTPJ cathodal stimulation is 0.311 (SE = 0.056), which is not significantly different from 0.288 (SE = 0.042) in the sham stimulation (Mann-Whitney test, $p = 0.912$; Cohen's $d = 0.092$). The PGR in the rTPJ cathodal stimulation (M = 0.355, SE = 0.053) is also not significantly different from that of the sham stimulation (M = 0.351, SE = 0.054; Mann-Whitney test, $p = 0.888$; Cohen's $d = 0.013$). Thus, the disposition effect is not reduced by the rTPJ cathodal stimulation. These results also rule out the possibility that the impact of rVLPFC cathodal stimulation on the disposition effect is driven by inducing global excitability changes because the rTPJ cathodal stimulation does not have such an impact.

The rTPJ cathodal stimulation also does not affect the optimal trading and time-consistent decisions. The POTD in the rTPJ cathodal stimulation is 51.47% (SE = 4.15%), which is not significantly different from 46.86% (SE = 3.80%) in the sham stimulation (Mann-Whitney test, $p = 0.447$; Cohen's $d = 0.233$). The PTD in the rTPJ cathodal stimulation is 50.99% (SE = 3.99%), which is not significantly different from 46.37% (SE = 3.83%) in the sham stimulation (Mann-Whitney test, $p = 0.378$; Cohen's $d = 0.238$).[1] The regression results in Tables H1 and H2 show that the rTPJ cathodal stimulation does not significantly influence the disposition effect, PGR, PLR, POTD, and PTD.

We replicate the results of Experiment 1 and find that the disposition effect is significantly reduced in rVLPFC cathodal stimulation. The average disposition effect

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[1] Consistent with Experiment 1, participants prespecify a significantly lower value of capital loss limit (M = 19.397, SE = 1.653) relative to capital gain limit (M = 30.438, SE = 2.019; Wilcoxon signed-rank test, $p < 0.01$). No stimulation differences are found in the capital gain limit (rTPJ cathodal: 27.541, Sham: 29.6, rVLPFC cathodal: 34.208) or the capital loss limit (rTPJ cathodal: 19.208, Sham: 18.48, rVLPFC cathodal: 20.541; Mann-Whitney test, all p values > 0.10). However, significant differences between capital gain and capital loss limits are found in each of the three stimulations (Wilcoxon signed-rank test, all p values < 0.05).

in the rVLPFC cathodal stimulation is −0.289 (SE = 0.072), which is significantly lower than 0.063 (SE = 0.073) in the sham stimulation (Mann-Whitney test, *p* = 0.002; Cohen’s *d* = 0.979) and 0.044 (SE = 0.089) in the rTPJ cathodal stimulation (Mann-Whitney test, *p* = 0.012; Cohen’s *d* = 0.836). The average PGR and PLR in the rVLPFC cathodal stimulation are 0.203 (SE = 0.022) and 0.492 (SE = 0.064) respectively, which are significantly different from those in the sham and rTPJ cathodal stimulations (Mann-Whitney test, all *p* values < 0.05; all Cohen’s *d* values > 0.70).

Table H1. Regression analysis of the disposition effect, PGR, and PLR in Experiment 2. OLS regression. rTPJ_C is a dummy variable that equals one if the stimulation is rTPJ cathodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Disposition effect		PGR		PLR	
	(1)	(2)	(3)	(4)	(5)	(6)
rTPJ_C	−0.019	0.014	0.003	0.011	0.023	−0.003
	(0.116)	(0.109)	(0.076)	(0.077)	(0.070)	(0.067)
rVLPFC_C	-0.352^{***}	-0.331^{***}	-0.148^{**}	-0.134^{**}	0.203^{**}	0.196^{**}
	(0.102)	(0.111)	(0.059)	(0.061)	(0.077)	(0.083)
Constant	0.063	−0.316	0.351^{***}	−0.125	0.288^{***}	0.190
	(0.073)	(0.729)	(0.054)	(0.421)	(0.042)	(0.438)
Demographic controls	No	Yes	No	Yes	No	Yes
N	73	73	73	73	73	73
R^2	0.152	0.183	0.091	0.139	0.104	0.127

Table H2. Regression analysis of optimal trading decisions and cognitive control in Experiment 2. OLS regression. rTPJ_C is a dummy variable that equals one if the stimulation is rTPJ cathodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Cognitive control is measured as the percentage of time-consistent decisions. Optimal trading decision is measured as the percentage of optimal trading decisions. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Optimal trading decision		Cognitive control	
	(1)	(2)	(3)	(4)
rTPJ_C	0.046	0.039	0.046	0.033
	(0.055)	(0.059)	(0.056)	(0.054)
rVLPFC_C	0.158^{***}	0.158^{***}	0.181^{***}	0.170^{***}
	(0.052)	(0.052)	(0.054)	(0.057)
Constant	0.463^{***}	0.311	0.468^{***}	0.721^{**}
	(0.038)	(0.262)	(0.038)	(0.348)
Demographic controls	No	Yes	No	Yes
N	73	73	73	73
R^2	0.117	0.124	0.141	0.195

Moreover, participants in the rVLPFC cathodal stimulation exhibit more optimal trading and time-consistent decisions. The POTD in the rVLPFC cathodal stimulation is 65.01% (SE = 3.80%), which is significantly higher than that in the sham stimulation (M = 46.86%, SE = 3.82%; Mann-Whitney test, $p = 0.003$; Cohen's $d = 0.961$) and that in the rTPJ cathodal stimulation (M = 51.47%, SE = 4.15%; Mann-Whitney test, $p = 0.029$; Cohen's $d = 0.694$). The PTD in the rVLPFC cathodal stimulation is 62.15% (SE = 3.45%), which is significantly higher than that in the sham stimulation (M = 46.37%, SE = 3.83%; Mann-Whitney test, $p = 0.004$; Cohen's $d = 0.873$) and that in the rTPJ cathodal stimulation (M = 50.99%, SE = 3.99%; Mann-Whitney test, $p = 0.052$; Cohen's $d = 0.609$). The regression results of Tables H1 and H2 show that the rVLPFC cathodal stimulation significantly influences the disposition effect, PGR, PLR, POTD, and PTD. Thus, the rVLPFC cathodal stimulation effect is replicated in a different participant pool.

I. Discussions of Different Mechanisms

I1. Cognitive Control Mechanism

We run two mediation analyses and test whether cognitive control mediates the relationship between the rVLPFC cathodal stimulation and the disposition effect. The results are reported in Tables I1 and I2, which use the data of Experiment 1 and Experiment 2, respectively. The dependent variable in columns (1) and (2) is the disposition effect. The dependent variable in columns (3) and (4) is PGR. The dependent variable in columns (5) and (6) is PLR. We always control the demographic variables in the regressions.

Table I1. Mediation analysis of cognitive control in Experiment 1. OLS regression. rVLPFC_A is a dummy variable that equals one if the stimulation is rVLPFC anodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Cognitive control is measured as the percentage of time-consistent decisions. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Disposition effect		PGR		PLR	
	(1)	(2)	(3)	(4)	(5)	(6)
rVLPFC_A		0.067		0.065		−0.001
		(0.095)		(0.074)		(0.058)
rVLPFC_C		−0.241**		−0.044		0.196***
		(0.100)		(0.063)		(0.069)
Cognitive control	−0.665***	−0.451*	−0.202	−0.135	0.463***	0.315*
	(0.243)	(0.092)	(0.160)	(0.160)	(0.170)	(0.183)
Constant	−0.578	−0.452	0.118	0.103	0.697*	0.555
	(0.547)	(0.530)	(0.346)	(0.374)	(0.396)	(0.382)
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes
N	95	95	95	95	95	95
R^2	0.164	0.253	0.048	0.075	0.182	0.275

We find a strong relationship between cognitive control and the disposition effect, as column (1) of Table I1 indicates. In this column, we report an OLS regression in the spirit of column (2) in Table E1, with the difference that cognitive control replaces the stimulation dummy variables. Column (1) shows that the relationship between cognitive control and the disposition effect is negative and highly significant (p = 0.008), indicating that a higher level of cognitive control predicts a less probability of exhibiting the disposition effect. Columns (3) and (4) in Table E2 show that rVLPFC cathodal stimulation has a positive influence on cognitive control. Thus, we have shown that the rVLPFC cathodal stimulation significantly increases cognitive control, and cognitive control is negatively associated with the disposition effect.

To study the extent to which the rVLPFC cathodal stimulation effect is mediated by cognitive control, we estimate a model where we simultaneously control for the stimulation dummy variables and cognitive control, which is shown in column (2) of Table I1. The result of this regression shows that the impact of the rVLPFC cathodal stimulation on the disposition effect is reduced relative to regression (2) in Table E1 in which we do not control for cognitive control. Yet, the effect of the rVLPFC cathodal stimulation is still significant and negative. Thus, cognitive control partly mediates the impact of the rVLPFC cathodal stimulation on the disposition effect. We also find that cognitive control partly mediates the relationship between the rVLPFC cathodal stimulation and PLR (see columns (5) and (6)); however, the effect of rVLPFC cathodal stimulation on PLR is not mediated by cognitive control (see columns (3) and (4)). The regression results of the mediation analysis using the data of Experiment 2 are basically the same as those using the data of Experiment 1 (see Table I2, Table H1, and Table H2).

Table I2. Mediation analysis of cognitive control in Experiment 2. OLS regression. rTPJ_C is a dummy variable that equals one if the stimulation is rTPJ cathodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Cognitive control is measured with participants' percentage of time-consistent decisions. Robust standard error is displayed in parentheses. Significance levels: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

Dependent variable	Disposition effect		PGR		PLR	
	(1)	(2)	(3)	(4)	(5)	(6)
rTPJ_C		0.043		0.016		−0.029
		(0.106)		(0.079)		(0.055)
rVLPFC_C		-0.216^{*}		−0.114		0.101
		(0.116)		(0.068)		(0.082)
Cognitive control	-0.911^{***}	-0.726^{***}	−0.222	−0.126	0.689^{***}	0.601^{***}
	(0.216)	(0.243)	(0.139)	(0.156)	(0.151)	(0.160)
Constant	−0.247	−0.089	−0.168	−0.086	0.078	0.003
	(0.789)	(0.732)	(0.445)	(0.426)	(0.445)	(0.422)
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes
N	73	73	73	73	73	73
R^2	0.220	0.285	0.095	0.108	0.244	0.278

One concern of the regressions is that the measure of cognitive control is part of the measure of the disposition effect. At the end of Experiment 3, we measure financial professionals' self-reported cognitive control. Participants reported their subjective feelings of cognitive control while making their stock trading decisions (i.e., self-reported cognitive control): "I pursued short-term investment returns when making stock trading decisions" (reverse-scored), "I could resist the temptation to receive the short-term investment returns when making stock trading decisions", and "I focused on long-term investment returns when making stock trading decisions". Self-reported cognitive control was measured using a 7-point Likert-type scale (1 = strongly disagree, 7 = strongly agree). After reverse-scored when necessary, we averaged all the items into a single measure (1 = low self-reported cognitive control and 7 = high self-reported cognitive control), which demonstrated good reliability (Cronbach's alpha = 0.85). The average self-reported cognitive control in the rVLPFC cathodal stimulation is 4.722 (SE = 0.238), which is significantly higher than 3.842 (SE = 0.290) in the sham stimulation (Mann-Whitney test, $p = 0.016$).

Table I3. Mediation analysis of self-reported cognitive control in Experiment 3. OLS regression. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Robust standard error is displayed in parentheses. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Dependent variable	Disposition effect		PGR		PLR		Self-reported cognitive control	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
rVLPFC_C		-0.185^{**} (0.080)		-0.018 (0.045)		0.167^{**} (0.068)	0.880^{**} (0.375)	0.804^{*} (0.398)
Self-reported cognitive control	-0.087^{***} (0.017)	-0.058^{**} (0.027)	-0.021 (0.015)	-0.018 (0.019)	0.066^{***} (0.017)	0.039^{*} (0.022)		
Constant	0.502 (0.603)	0.258 (0.545)	0.394 (0.251)	0.370 (0.258)	-0.107 (0.584)	0.112 (0.540)	3.842^{***} (0.290)	3.229 (3.187)
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
N	37	37	37	37	37	37	37	37
R^2	0.695	0.749	0.273	0.278	0.664	0.728	0.134	0.285

Table I3 shows the results of mediation analysis. We find a strong relationship between self-reported cognitive control and the disposition effect, as column (1) of Table I3 indicates. In this column, we report an OLS regression in the spirit of column

(2) in Table E4, with the difference that self-reported cognitive control replaces the stimulation dummy variables. Column (1) shows that the relationship between self-reported cognitive control and the disposition effect is negative and highly significant ($p = 0.005$), indicating that a higher level of self-reported cognitive control predicts less probability of exhibiting a disposition effect. Columns (7) and (8) show that rVLPFC cathodal stimulation has a positive influence on self-reported cognitive control. Thus, we have shown that the rVLPFC cathodal stimulation significantly increases self-reported cognitive control, and self-reported cognitive control is negatively associated with the disposition effect.

To study the extent to which the rVLPFC cathodal stimulation effect is mediated by self-reported cognitive control, we estimate a model where we simultaneously control for the stimulation dummy variables and self-reported cognitive control, which is shown in column (2) of Table I3. The result of this regression shows that the impact of the rVLPFC cathodal stimulation on the disposition effect is reduced relative to regression (2) in Table E4 in which we do not control for self-reported cognitive control. Yet, the effect of the rVLPFC cathodal stimulation is still significant and negative. Thus, self-reported cognitive control partly mediates the effect of rVLPFC cathodal stimulation on the disposition effect. We also find that self-reported cognitive control partly mediates the relationship between the rVLPFC cathodal stimulation and PLR (see columns (5) and (6)).

I2. Preference-Based Mechanism

Previous fMRI studies have found that the rVLPFC activity correlates with risk aversion (Christopoulos et al., 2009), cognitive dissonance (Jarcho et al., 2011), and emotion regulation (Wager et al., 2008). The rVLPFC cathodal stimulation may reduce the disposition effect through one (or more) of the above mechanisms. However, if the rVLPFC cathodal stimulation affects the disposition effect through mechanisms alternative to cognitive control, such mechanisms must also explain why participants' decisions become more time-consistent. For instance, changing risk aversion alone does not seem likely to change time consistency, without some additional features being posited. A similar concern is expressed with cognitive dissonance and regret. To formally test these possibilities, we measured participants' risk aversion (Holt and Laury, 2002), loss aversion (Rau, 2014), and self-reported emotions (i.e., regret and rejoice) (Summers and Duxbury, 2012) at the end of Experiment 1, as well as participants' cognitive reflection (Frederick, 2005) at the end of Experiment 3.

I2.1 Risk and Loss Aversion

It has been found that the activity in the rVLPFC is correlated with risk aversion (Christopoulos et al., 2009). tDCS might have changed a participant's tendency for risk or loss aversion, which in turn might have led to a reduction in the disposition effect (Imas, 2016; Rau, 2014).

During tDCS Experiment 1, the participant is asked to choose between Options A and B for each of the 10 paired lottery choices of Holt and Laury (2002). The total number of "safe" A choices is used as an indicator of risk aversion. The participant's loss aversion is determined using the elicitation task of Rau (2014). In this task, 10 different lottery choices exist. The lotteries are framed such that a certain amount of money is lost if a coin landed on "head" whereas the participant wins 10 Chinese yuan if the coin lands on "tail". The loss increases with each lottery from 2 to 11 Chinese yuan, whereas the winning payoff is constant.

For each of the 10 lotteries, the participant states whether they accept it. We record the switching point when the participant stops accepting the lotteries. Based on the switching point, we calculate the loss-aversion coefficient (λ), which follows $\lambda = V(G)/V(L)$, where $V(G)$ and $V(L)$ represent the potential gain/loss of the lottery which is rejected. Lambda is defined between 0.91 and 5. If a participant accepts all the lotteries, then the loss-aversion coefficient is $\lambda = V(10)/V(2) = 10/2 = 5$. If a participant rejects all the lotteries, then the loss aversion coefficient is $\lambda = V(10)/V(11) = 10/11 = 0.91$.

No significant differences in risk and loss aversion are found among the three tDCS stimulations (Kruskal-Wallis test, all *p* values > 0.50). Results of Tables I4 and I5 highlight that adding risk and loss aversion to the regression model does not change the significance of the rVLPFC cathodal tDCS. Thus, risk or loss aversion alone cannot explain the rVLPFC cathodal effects.

Table I4. Role of risk aversion in Experiment 1. OLS regression. rVLPFC_A is a dummy variable that equals one if the stimulation is rVLPFC anodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Risk aversion is measured by the total number of "safe" "A" choices. Demographic controls include participants' age, gender, and stock trading experience. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Disposition effect		PGR		PLR	
	(1)	(2)	(3)	(4)	(5)	(6)
rVLPFC_A	0.025	0.066	0.044	0.058	0.019	−0.008
	(0.101)	(0.101)	(0.070)	(0.073)	(0.064)	(0.063)
rVLPFC_C	−0.361***	−0.296***	−0.092	−0.064	0.269***	0.228***
	(0.086)	(0.090)	(0.055)	(0.067)	(0.062)	(0.016)
Risk aversion	0.029	0.033	0.029*	0.030*	−0.001	−0.002
	(0.023)	(0.025)	(0.015)	(0.015)	(0.015)	(0.062)
Constant	−0.077	−1.059	0.196**	−0.230	0.274***	0.829**
	(0.146)	(0.644)	(0.096)	(0.420)	(0.089)	(0.397)
Demographic controls	No	Yes	No	Yes	No	Yes
N	95	95	95	95	95	95
R^2	0.194	0.244	0.091	0.120	0.186	0.239

Table I5. Role of loss aversion in Experiment 1. OLS regression. rVLPFC_A is a dummy variable that equals one if the stimulation is rVLPFC anodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Loss aversion is the loss-aversion coefficient (λ). Demographic controls include participants' age, gender, and stock trading experience. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Disposition effect		PGR		PLR	
	(1)	(2)	(3)	(4)	(5)	(6)
rVLPFC_A	0.040	0.084	0.060	0.076	0.020	−0.008
	(0.101)	(0.100)	(0.068)	(0.072)	(0.065)	(0.063)
rVLPFC_C	−0.346***	−0.280***	−0.076	−0.052	0.270***	0.228***
	(0.087)	(0.092)	(0.057)	(0.063)	(0.061)	(0.064)
Loss aversion	0.076	0.091	0.097*	0.098	0.021	0.007
	(0.082)	(0.077)	(0.058)	(0.060)	(0.073)	(0.092)
Constant	−0.041	−0.966*	0.197**	−0.167	0.238*	0.799**
	(0.147)	(0.579)	(0.095)	(0.390)	(0.127)	(0.369)
Demographic controls	No	Yes	No	Yes	No	Yes
N	95	95	95	95	95	95
R^2	0.182	0.231	0.076	0.100	0.187	0.239

I2.2 Regret and Rejoice

Summers and Duxbury (2012) show that regret and rejoice affect the disposition effect. Cathodal tDCS over rVLPFC might have reduced the disposition effect through the enhancement of emotion regulation.

Table I6. Role of regret in Experiment 1. OLS regression. rVLPFC_A is a dummy variable that equals one if the stimulation is rVLPFC anodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Regret is measured with “How regretful were you about your decision when the stock you purchased had decreased in value compared to the previous period?” on a 1-9 scale (1 = not at all, 9 = very much). Demographic controls include age, gender, and stock trading experience. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Disposition effect		PGR		PLR	
	(1)	(2)	(3)	(4)	(5)	(6)
rVLPFC_A	0.023	0.064	0.055	0.068	0.031	0.003
	(0.101)	(0.104)	(0.071)	(0.076)	(0.065)	(0.064)
rVLPFC_C	−0.340***	−0.282***	−0.079	−0.058	0.260***	0.223***
	(0.089)	(0.093)	(0.058)	(0.063)	(0.062)	(0.063)
Regret	−0.057	−0.046	−0.001	−0.003	0.054*	0.043
	(0.044)	(0.043)	(0.027)	(0.028)	(0.032)	(0.032)
Constant	0.304	−0.629	0.366***	0.004	0.062	0.633
	(0.196)	(0.621)	(0.119)	(0.397)	(0.135)	(0.424)
Demographic controls	No	Yes	No	Yes	No	Yes
N	95	95	95	95	95	95
R^2	0.186	0.227	0.044	0.068	0.210	0.253

Table I7. Role of rejoice in Experiment 1. OLS regression. rVLPFC_A is a dummy variable that equals one if the stimulation is rVLPFC anodal and zero otherwise. rVLPFC_C is a dummy variable that equals one if the stimulation is rVLPFC cathodal and zero otherwise. Rejoice is measured with “How rejoiceful were you about your decision when the stock you purchased had decreased in value compared to the previous period?” on a 1-9 scale (1 = not at all, 9 = very much). Demographic controls include age, gender, and stock trading experience. Robust standard error is displayed in parentheses. Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

Dependent variable	Disposition effect		PGR		PLR	
	(1)	(2)	(3)	(4)	(5)	(6)
rVLPFC_A	0.029	0.070	0.052	0.065	0.022	−0.005
	(0.103)	(0.103)	(0.072)	(0.076)	(0.064)	(0.062)
rVLPFC_C	−0.371***	−0.309***	−0.091	−0.069	0.280***	0.239***
	(0.087)	(0.092)	(0.060)	(0.065)	(0.060)	(0.063)
Rejoice	0.079	0.089	0.041	0.043	−0.038	−0.045
	(0.067)	(0.064)	(0.049)	(0.050)	(0.042)	(0.041)
Constant	−0.287	−1.326	0.164	−0.256	0.452**	1.070**
	(0.317)	(0.592)	(0.225)	(0.457)	(0.203)	(0.412)
Demographic controls	No	Yes	No	Yes	No	Yes
N	95	95	95	95	95	95
R^2	0.188	0.237	0.053	0.078	0.193	0.249

We test this possibility by collecting self-reported levels of regret and rejoice: "How regretful were you about your decision when the stock you purchased had decreased in value compared to the previous period?" and "How rejoiceful were you about your decision when the stock you purchased had increased in value compared to the previous period?" (Summers and Duxbury, 2012). The levels of regret and rejoice are measured with a 1-9 scale (1 = not at all, 9 = very much).

We find that tDCS does not have any influences on rejoice and regret (Kruskal-Wallis test, all *p* values > 0.10). Regression results reported in Tables I6 and I7 indicate that the effect of cathodal tDCS over rVLPFC remains significant for controlling regret and rejoice. Thus, regret or rejoice alone cannot explain the rVLPFC cathodal stimulation effect.

I2.3 Cognitive Dissonance

Chang et al. (2016) demonstrate the role of cognitive dissonance in generating the disposition effect, which is supported by evidence that investors avoid realizing capital losses because they dislike admitting that past purchases are mistakes, whereas delegation reverses the disposition effect by allowing the investor to blame the manager instead. According to the explanation of cognitive dissonance, when facing with capital losses, participants are more willing to sell the endowed stock than the self-purchased stock. This willingness would be decreased if cathodal tDCS over rVLPFC reduces the disposition effect by changing the experience of cognitive dissonance alone.

Panel (b) in Figure F presents the participant's number of held types of stocks in sham (b1), anodal (b2), and cathodal (b3) stimulations. Panels (b1) and (b3) in Figure F show that before Period 17 the average number of held Stock A is all above 0.90, indicating that participants almost do not sell the initially endowed Stock A. The average number of held Stock B in the rVLPFC cathodal stimulation is largely decreased to 0.25 in Period 11 and increased to 0.781 in Period 17. The average number of held Stock B in the sham stimulation is also decreased to 0.625 in Period 11 and increased to 0.906 in Period 17. Thus, compared with Stock B, Stock A can be considered as the endowed stock. Figure E1 shows that both Stock A and Stock B are updated by a decrease in price from Period 18 to Period 25.

We find that from Period 18 to 25 the difference in the average selling number between the mostly endowed Stock A and mostly purchased Stock B is 0.124 (0.468−0.344) in the rVLPFC cathodal stimulation. This difference is 0.062 (0.281−0.219) in the sham stimulation. This result indicates that participants in the rVLPFC cathodal stimulation are still more likely to sell the endowed stock (i.e., Stock A). Thus, cognitive dissonance alone cannot explain the rVLPFC cathodal stimulation effect.

I2.4 Cognitive Reflection

The evidence from the behavioral finance literature shows that individuals with better cognitive reflection have more cognitive control (Da Silva et al., 2018). It is possible that the rVLPFC cathodal stimulation may increase cognitive reflection, thereby exhibiting a reduction in the disposition effect.

In Experiment 3, after the experimental task we measured financial professionals' cognitive skills with the 3-item Cognitive Reflection Test (Frederick, 2005). We find that the average score of the Cognitive Reflection Test in the rVLPFC cathodal stimulation is 1.111 (SE = 0.212), which is not significantly different from that of the sham stimulation (M = 1.053, SE= 0.223; Mann-Whitney test, $p = 0.835$). This result indicates that cognitive reflection alone cannot explain the rVLPFC cathodal stimulation effect.

I3. Belief-Based Mechanism

Several studies have shown that investors who irrationally believe prices exhibit mean reversion will sell recent winner stocks or purchase recent loser stocks. For example, Brooks et al. (2012) provide neural evidence that the disposition effect is driven by the belief that the stock will eventually return to the purchase price. Thus, if the cathodal tDCS over rVLPFC reverses a participant's belief in mean-reversion, the participant would likely hold the recent winner stock, thereby exhibiting a reduction in the disposition effect.

However, if rVLPFC cathodal stimulation affects the disposition effect through the belief channel, it must explain why participants make more time-consistent decisions. A simple belief in mean-reversion neither predicts that any time inconsistency should exist, nor does it explain why changing the extent of this belief would result in time-consistent decisions. We also test this possibility using the data collected from Experiment 1.

Specifically, we test this possibility by analyzing the participant's purchase behaviors (Weber and Camerer, 1998). The initial purchase price of Stock A, Stock B, or Stock C in our experiment is 100, which would be naturally regarded as the reference price for the purchase of a stock. If the rVLPFC cathodal stimulation reverses the belief in mean reversion, we would observe a decrease in purchasing the loser stock whose price is below 100 (i.e., Stock B) and an increase in holding the winner stock whose price is above 100 (i.e., stock C).

However, in the 24 trading periods, the average number of held winner Stock C in the three stimulations shows a downward trend (see Panel (a) in Figure F) in Experiment 1. Panel (b1) in Figure F shows that in the sham stimulation the average number of held Stock B increases from 0.625 in Period 11 to 0.906 in Period 16. Panel (b2) in Figure F depicts that in the anodal stimulation the average number of held Stock B increases from 0.516 in Period 11 to 0.774 in Period 16. Panel (b3) in Figure F illustrates that in the cathodal stimulation the average number of held Stock B increases from 0.25 in Period 11 to 0.781 in Period 16. Participants in the cathodal stimulation are more likely to purchase the loser Stock B. These results show that the rVLPFC cathodal stimulation does not largely reverse the participant's belief in mean reversion.

I4. Summary

Taken together, we show that cognitive control is a mechanism that underlies the rVLPFC cathodal stimulation effect. Risk aversion, loss aversion, self-reported emotions (i.e., regret and rejoice), cognitive dissonance, or cognitive reflection alone cannot explain the effect of rVLPFC cathodal stimulation. Moreover, this effect is not due to the change of belief in mean-reversion.

Note that we do not argue that preference-based mechanisms do not occur. Instead, we seek to demonstrate that the preference-based explanations for the disposition effect are not sufficient to explain the rVLPFC cathodal stimulation effect without considering time consistency. In fact, Barberis's (2012) model of casino gambling explicitly shows how a time-inconsistent investor with prospect theory preferences displays the disposition effect.[2] When time inconsistency is combined with preferences such as prospect theory (Barberis and Xiong, 2009; Barberis, 2012), realization utility (Barberis and Xiong, 2012; Frydman et al., 2014), or cognitive dissonance (Chang et al., 2016), investors exhibit the disposition effect. As time inconsistency underlies the rationales based on these preferences, the disposition effect becomes a matter of cognitive control.

Thus, we conjecture that cognitive control is an extension of preference-based explanations of the disposition effect rather than an alternative explanation. We speculate that when a state of better cognitive control is induced by the rVLPFC cathodal stimulation, loss aversion and cognitive dissonance may decrease due to attenuated emotional responses. This may weaken the negative utility bursts from realizing losses relative to the utility bursts from realizing gains, making realizing losses less aversive and accelerating the sale of stocks with capital losses (i.e., a reduction in the disposition effect).

Regarding the discussions about whether the disposition effect is driven by preferences or beliefs (Ben-David and Hirshleifer, 2012), we argue that preference may be a more convincing explanation. As noted above, the main channel through which the rVLPFC cathodal stimulation affects the disposition effect is not obviously consistent with a belief channel, such as the belief in mean-reversion.

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[2] Compared with time inconsistency that stems from hyperbolic discounting, Barberis (2012) studies a different time inconsistency, one that is generated by probability weighting embedded in prospect theory.

J. Asymmetrical Responses

Weber and Welfens (2008) investigate both account level field data as well as data from a controlled laboratory experiment and find that investors' reactions towards the proportion of gains realized (PGR) and proportion of losses realized (PLR) are not only uncorrelated but also stable at the individual level, indicating that the two sides of the disposition effect are asymmetric. Frydman and Camerer (2016) also find that PGR and PLR are not correlated and suggest that the two components are likely governed by different psychological mechanisms.

Several studies give some possible explanations for the asymmetrical responses to PGR vs. PLR. Feng and Seasholes (2005) link these asymmetric responses to investor experience. Heimer (2016) find that social interaction can contribute to some traders' disposition effect and that financial peer effects asymmetrically relate to PGR versus PLR. In a controlled laboratory experiment, Goulart et al. (2015) show that the disposition effect is significantly increased when the trader's stock trading performance is made public. This result is mainly due to a spike in the realization of gains, and it is speculated that participants sell stocks with capital gains in a strategic attempt to avoid the embarrassment of finishing the trading session at the bottom of the performance ranking. Frydman et al. (2014) use neural data to test the realization utility explanation for the disposition effect and find evidence that investors experience a positive burst of utility from realizing capital gains but do not experience a negative burst of utility from realizing capital losses. Chang et al. (2016) suggest that investors avoid realizing capital losses because they dislike admitting that past purchases are mistakes; they demonstrate the role of cognitive dissonance in generating the disposition effect, particularly in the side of realizing capital losses. Rau (2014) shows that women have higher disposition effects than men and behave more loss averse, and the disposition effect is exclusively driven by women's reluctance to sell stocks with capital losses.

Consistent with the above studies, we find that the correlation between PGR and PLR is insignificant in each of the three stimulations using the data collected from Experiment 1 (anodal: Spearman's rho = -0.217, $p = 0.241$; sham: Spearman's rho = -0.283, $p = 0.116$; cathodal: Spearman's rho = -0.087, $p = 0.634$). Similar results are found using the data collected from Experiments 2 and 3. We also provide evidence that cognitive control mediates the relationship between the rVLPFC cathodal stimulation and PLR. However, the effect of rVLPFC cathodal stimulation on PGR is not mediated by cognitive control. In addition, the impacts of rVLPFC cathodal stimulation on cognitive control and the disposition effect are not moderated by gender in all the three tDCS experiments.

Given that we posit that cognitive control is an extension of the preference-based explanations of the disposition effect, we speculate that when a state of better cognitive control is induced by the rVLPFC cathodal stimulation, cognitive dissonance may decrease. This may weaken the negative utility bursts from realizing losses relative to the utility bursts from realizing gains, making realizing losses less aversive and accelerating the sale of stocks with capital losses. Thus, cognitive control mainly mediates the relationship between the rVLPFC cathodal stimulation and PLR.

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