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1 **A Causal Role for Posterior Medial Prefrontal Cortex in Choice-Induced**
2 **Preference Change**

3
4 **Abbreviated Title:** Reducing cognitive dissonance

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6

1 **ABSTRACT**

2 After a person chooses between two items, preference for the chosen item will increase and
3 preference for the unchosen item will decrease because of the choice made. In other words,
4 we tend to justify or rationalize our past behavior by changing our attitude. This
5 phenomenon of choice-induced preference change has been traditionally explained by
6 cognitive dissonance theory. Choosing something that is disliked or not choosing
7 something that is liked are both cognitively inconsistent, and in order to reduce this
8 inconsistency, people tend to change their subsequently stated preference in accordance
9 with their past choices. Previously, neuroimaging studies identified posterior medial frontal
10 cortex (pmMFC) as a key brain region involved in cognitive dissonance. However, it still
11 remains unknown whether the pmMFC plays a causal role in inducing preference change
12 following cognitive dissonance. Here, we demonstrate that 25-min 1-Hz repetitive
13 transcranial magnetic stimulation (TMS) applied over the pmMFC significantly reduces
14 choice-induced preference change compared to sham stimulation, or control stimulation
15 over a different brain region, demonstrating a causal role for the pmMFC.

1 INTRODUCTION

2 Contrary to a basic economic view that our behavior is driven by our preferences,
3 psychological studies have demonstrated that past behaviors (e.g., making a choice) can
4 also affect our preferences. The phenomenon of choice-induced preference change has been
5 traditionally demonstrated by the "free-choice paradigm" (e.g., Brehm, 1956) in which
6 individuals are first asked to rate several items for their preference, and then make choices
7 between pairs of equally attractive items (e.g., posters, CDs, etc.) so that they inevitably
8 have to reject items they may like. When asked to rate the same items a second time they
9 typically report increased preference for the items they chose and decreased preference for
10 the items they rejected. This phenomenon is usually explained as an effect of cognitive
11 dissonance. According to cognitive dissonance theory (Festinger, 1957), any inconsistency
12 between beliefs, preferences, or choices (e.g. not choosing a preferred item) results in an
13 aversive feeling (cognitive dissonance), that in turn motivates people to reconcile the
14 inconsistency (e.g., to justify their past behavior by changing their preference).

15 More recently, social cognitive neuroscientists have started to investigate the neural
16 mechanisms underlying cognitive dissonance and subsequent preference change, and found
17 that a posterior part of medial frontal cortex (pmMFC) activates when individuals detect
18 inconsistency between their attitude and behavior (e.g., van Veen et al., 2009; Izuma et al.,
19 2010). However, these neuroimaging results still left it unknown whether the pmMFC
20 activity merely reflects an epiphenomenon of cognitive dissonance such as passive
21 emotional reactions to inconsistency, or whether it plays a more active role in inducing
22 preference change to resolve inconsistency.

23 In the present study, we attempted to answer this question of causality by using 1-Hz
24 25-min repetitive TMS (rTMS) to temporarily downregulate neuronal activity within
25 pmMFC to test whether this reduces the cognitive dissonance effect. In order to measure
26 choice-induced preference change, we employed a modified free-choice paradigm using a
27 "choice-blindness" procedure (Johansson et al., 2008; Hall et al., 2012; Hall et al., 2013);
28 see Methods for details). This procedure controls for an important artifact inherent in the

1 original free-choice paradigm (Chen and Risen, 2010; for a review, Izuma and Murayama,
2 2013), thus allowing for a methodologically rigorous test of the hypothesis.

3

1 MATERIALS and METHODS

2

3 *Participants*

4 A total of 61 individuals participated in the study. One participant decided to withdraw
5 from the study after the TMS procedure was explained. Another participant was also
6 withdrawn from the study because the participant reported feeling dizzy during the motor
7 thresholding procedure (see below for more details). Seven additional participants were
8 also excluded from the analyses: four detected our critical switch manipulation during the
9 Choice task (see below for details); two were excluded due to technical problems with TMS,
10 and one other participant showed a significantly negative correlation between two
11 preference ratings (First and Second Rating tasks described below; $r_{(49)} = -0.23$, which is
12 more than 3 SDs below the group average of $r = 0.48$ [SD = 0.21]), suggesting very poor
13 compliance with the task instructions. Accordingly, the final analyses were based on 52
14 participants. Participants were randomly assigned to one of three TMS groups
15 (between-subject design); 1) pMFC group (n = 17, 8 female, mean age = 22.4), 2)
16 sham-pMFC group (n = 17, 7 female, mean age = 22.5), or 3) posterior parietal cortex
17 (PPC) group (n = 18, 8 female, mean age = 21.6). There was no significant difference in
18 age across the three TMS groups ($p = 0.84$). The participants were all right-handed with no
19 history of neurological or psychiatric illness. All participants gave written informed consent
20 for participation, and the study was approved by the Institutional Review Board of the
21 California Institute of Technology.

22

23 *Stimuli*

24 The experimental stimuli chosen for this experiment were abstract computer desktop
25 images freely available on the Internet (see Figure 1). There were 50 images used in the
26 study, paired up in 25 pairs of similar but distinct images (the pairs were fixed among all
27 participants). This was done to allow the switch manipulation used in the Choice Task to be
28 undetected by participants, but still provide stimuli that could be differentially preferred.

1

2 *Experimental tasks*

3 In the present study, we used a modified free-choice paradigm using a
4 "choice-blindness" procedure (Johansson et al., 2008; Hall et al., 2012; Hall et al., 2013)
5 during the choice task. The procedure (detailed below) allowed us to address an important
6 methodological flaw in the original paradigm (Chen and Risen, 2010; Izuma and
7 Murayama, 2013). Ratings are not perfect measures of true preference (i.e. there is some
8 "noise" in ratings). During the choice task of the paradigm, an individual's choice reveals
9 additional information about their true preference. Because items chosen are more likely to
10 have higher true preferences than rejected items, when measured a second time, chosen
11 items are more likely to be rated higher than rejected items (i.e., regression toward true
12 preference). Because the effects of true preference and choice are confounded in such a
13 manner, the original "free-choice" paradigm could inadvertently measure preference
14 change without the effect of choice on true preference. To deal with this methodological
15 issue, we employed a modified choice task in our experimental paradigm in which
16 individuals were occasionally led to believe that they had chosen the item they actually
17 preferred less than the alternative. Thus, although preference and choice often go together,
18 our paradigm allows us to dissociate one from the another, which made it possible to
19 dissociate the effects of choice from the effect of true preference. Before the current TMS
20 study, we ran a behavioral pilot study (without TMS; n = 26) to verify that we can measure
21 choice-induced preference change over and above the confound (data not shown). We also
22 verified that the detection rate of our critical switch manipulation (see below) was
23 sufficiently low (3 out of 26 participants).

24 In the present study, participants performed the four following tasks in fixed order; 1)
25 First Rating task, 2) Choice task, 3) Second Rating task, and 4) Memory task. Because our
26 prior fMRI study demonstrated pMFC activation in response to the discrepancy between
27 behavior and attitude during the Second Rating task (Izuma et al., 2010), the rTMS
28 treatment was administered right before participants performed the Second Rating tasks (an
29 off-line rTMS approach). After completing the Second Rating task, all the participants took

1 a 35-40 min break before the Memory task, to ensure that the effects of TMS had subsided
2 before continuing.

3 In the First Rating Task, participants were presented with images serially and were
4 instructed to rate how much they liked each image by using an 8-point scale (1 = not at all,
5 8 = very much) labeled on the keyboard. There was no time limit, but participants were
6 encouraged to give their first impression. The inter-trial interval was 1 second.

7 In the Choice task, images were presented in pairs, and participants were asked to
8 indicate the image they preferred in each trial by using a computer mouse with their right
9 hand. Thus, participants made 25 binary choices in total (50 images). There were 4
10 experimental conditions during the Choice task; 1) Switch trials (5 trials), 2) No-switch
11 trials (5 trials), 3) Computer trials (5 trials), and 4) Other trials (10 trials; not included in
12 preference change analysis).

13 While the 25 pairs were fixed among all participants, which pairs were used in each of
14 the four conditions (Switch, No-Switch, Computer and Other) in the Choice task was
15 determined based on each participant's rating during the First Rating task. Before the
16 Choice task, 15 image-pairs (30 images) used in the Switch, No-Switch and Computer trials
17 were automatically matched by a Matlab program in terms of the difference in the first
18 ratings between two images in each pair. As discussed previously (Chen and Risen, 2010;
19 Izuma and Murayama, 2013), the strength of the artifact in the traditional free choice
20 paradigm depends on the rating difference between two images in a choice pair (i.e., the
21 smaller the within-pair rating difference, the bigger the preference change by the artifact).
22 Moreover, pairs with larger difference in the first ratings were preferentially allocated to the
23 three conditions used in analysis. This was done to induce stronger cognitive dissonance
24 (i.e., larger discrepancy between preference and choice) in the Switch condition. That is,
25 assuming that participants choose the image from a pair with the higher first rating most of
26 the time, when their choice is reversed by the switch manipulation, they would believe that
27 they chose the image they disliked and did not choose the image they liked. The remaining
28 20 images were assigned to the Other condition and excluded from preference change
29 analysis because items in the Other trials were not matched on within-pair rating difference.

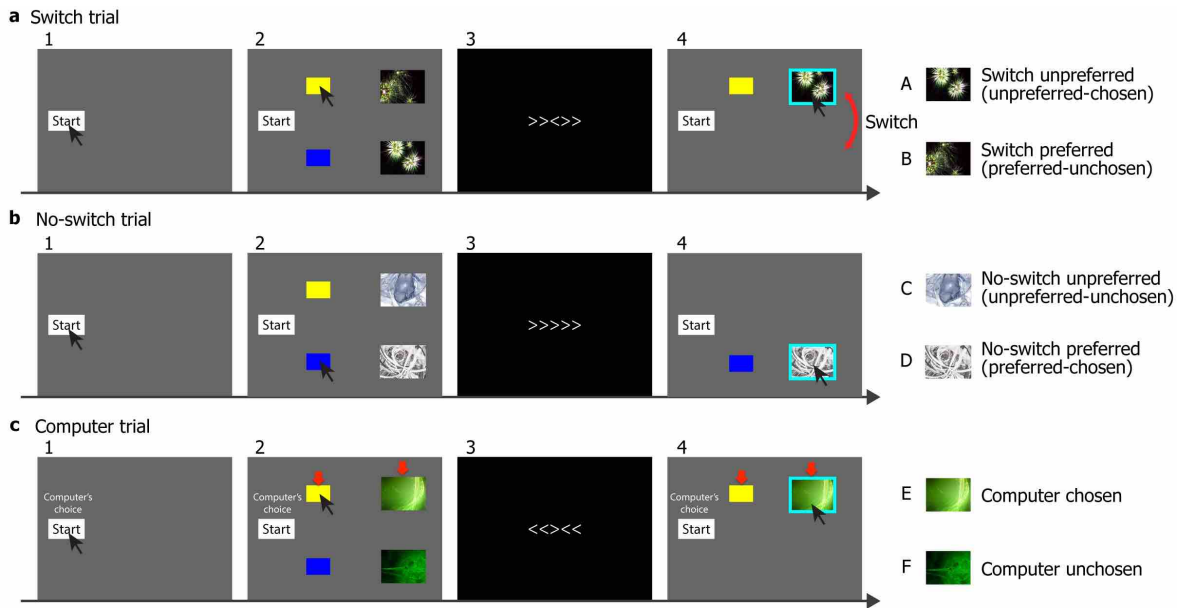
1 Thus the comparisons between the Other vs. the three critical conditions would not be
2 informative. Although not used in the analyses, these additional 20 images were necessary
3 in order to have more options from which we chose 15 pairs for the three critical conditions
4 that were sufficiently matched on the within-pair difference.

5 In each trial of the Switch condition, participants were first asked to click the "Start"
6 button located on the left side of the screen (Figure 1a, stage 1). As soon as they clicked the
7 button, two images and two boxes (a yellow box on the top and a blue box on the bottom,
8 both of which were aligned with each of two images) appeared on the screen (Figure 1a,
9 stage 2). Participants were asked to look at each of the two images carefully and to move
10 the mouse cursor to the box corresponding to the image they preferred. For example, if they
11 preferred the image on the top, they moved the cursor to the yellow box. The two images
12 remained on the screen until a preference was indicated, or for a maximum of 3 seconds. If
13 the participants did not decide after 3 seconds, the two images disappeared, and participants
14 then had to make their choice from memory.

15 As soon as the cursor touched one of the two boxes, the screen automatically changed,
16 and participants performed 4 trials of a flanker task (Figure 1a, stage 3), which was
17 intended to distract participants' memory for the locations of the two images. During
18 instructions, the Choice task was referred to as the "choice and attention" task, and each
19 participant was told that the task was intended to test decision-making and attention at the
20 same time, providing an explanation for the flanker task. During the four trials of the
21 flanker task, there were always 2 congruent (">>>>>" or "<<<<<") and 2 incongruent
22 ("<<<<<" or ">>>>>") trials, and participants were asked to answer the direction of a
23 central target arrow (left or right). Participants responded by pressing one of two keys
24 labeled on the keyboard with their left hand (index and middle fingers), and were told that
25 they would get one point every time they responded accurately within 1 second. They were
26 encouraged to try to get at least 60 points (out of 100) in total and aim for 80 points if
27 possible. There was no monetary incentive for the task. Stimuli were presented once every
28 second (0.5 seconds for stimulus presentation plus 0.5 seconds for inter-stimulus interval).

1 After 4 trials (4 sec), the total points accumulated were displayed on the screen for 1
2 second.

3



4

5 **Figure 1:** The illustration of a Switch trial (a), a No-switch trial (b) and a Computer trial (c) during the
6 Choice task. During Switch and No-switch trials, participants were first instructed to move the mouse cursor
7 to the box corresponding to the image they preferred (e.g., a yellow box if they preferred the image on the
8 top). After performing 4 trials of the Flanker task that serves as a distractor (stage 3), they were asked to click
9 the image on the screen (stage 4; presumably the one they preferred at stage 2). Note that the locations of two
10 images were switched between stages 2 and 4 only during a Switch trial so that the participants were led to
11 believe that they had chosen the image they actually preferred less than the alternative. Each image of Switch
12 and No-switch trials was categorized into one of the 4 conditions (images A-D) depending on the condition
13 (Switch or No-switch) and participant's action during stage 2 (preferred or unpreferred). During a computer
14 trial, participants were asked to simply pick the image selected by a computer (indicated by red arrows). Each
15 image of Computer trials was categorized into either Computer-chosen or Computer unchosen conditions
16 (images E & F).

17

18 After the flanker task (5 seconds in total), the screen showed only one image, which
19 was presumably the one they had preferred before the flanker task, along with the start
20 button and the box touched by the participants (Figure 1a, stage 4). Finally, participants
21 were instructed to click the image on the screen (presumably the one they had preferred),

1 and the image was highlighted by a light blue square for 1.5 seconds. Unknown to the
2 participants, during the Switch trials, the locations of two images were switched after the
3 flanker task so that they were led to believe that they had chosen the image they actually
4 preferred less than the alternative (i.e., the image that was not preferred at the stage 2 of the
5 Choice task) The switch manipulation always occurred on 5th, 10th, 16th, 20th, and 24th
6 trials. No participant reported the switches during the task, but 4 of them reported it during
7 the post-experimental interview (see below).

8 In the No-switch trials (and Other trials), the task proceeded in the same way except
9 that no switch was made (Figure 1b, stage 4). In the Computer trials, the words
10 "Computer's choice" were displayed above the start button at the beginning of the trial
11 (Figure 1c, stage 1). After clicking the start button, two images and two boxes were
12 displayed on the screen just like other trials. However, the participants were asked to wait
13 for a computer to choose one of two images. After 1 second, the computer's choice (red
14 arrows) was displayed on the screen (see Figure 1c, stage 2), and the participants were
15 asked to simply move the cursor to the box (thus the wallpaper) selected by a computer.
16 The rest of the task proceeded in the same way as No-switch and Other trials, and no switch
17 manipulation was introduced during the Computer trials.

18 Importantly, unknown to the participants, each computer trial occurred shortly after
19 each of the Switch trials (specifically, the Computer trials always occurred on 6th, 12th,
20 17th, 22nd, and 25th trials), and by doing so, the Computer's choice automatically
21 mimicked the participant's choice made in a previous Switch trial in terms of consistency
22 between their first preference rating and choice (note that more specifically, "choice" here
23 refers to participant's preference revealed at the stage 2 of the Choice task). That is, suppose
24 a participant was presented with two images that were rated 5 and 7 on the 8-point scale
25 during the First Preference Rating task. Typically, they prefer the image with a higher first
26 rating (i.e., the one rated 7) during the stage 2 of the Choice task. However, since behavior
27 is noisy, occasionally they would prefer the image with a lower rating (i.e., the one rated 5)
28 during the stage 2 of the Choice task. Because this behavior is known to contribute to an
29 important artifact (Chen and Risen, 2010; Izuma and Murayama, 2013), the computer trials

1 were programmed to select the image with a lower first rating whenever the participant
2 preferred (i.e., based on their action in the stage 2 of Figure 1) the image with a lower first
3 rating in a previous Switch trial. Similarly, the computer selected the image with a higher
4 first rating when the participant preferred the image with a higher first rating in a previous
5 Switch trial. The order of No-switch and Other trials was randomly determined.

6 At the end of the Choice task, each of the 30 images used in the Switch, No-switch and
7 Computer trials was categorized into the 6 conditions (5 images each) depicted in Figure 1
8 (images A-F). Based on participant's action during the stage 2 of the Switch and No-switch
9 trials, each image was categorized as either "preferred" or "unpreferred." Similarly, based
10 on participant's final choice during the stage 4, each image was categorized as either
11 "chosen" or "unchosen." Because of the switch manipulation, preference and choice are
12 inconsistent in the Switch condition (e.g., preferred-unchosen or unpreferred-chosen). Thus,
13 the choice-blindness paradigm makes it possible to dissociate the effect of choice from the
14 effect of preference.

15 After the completion of the Choice task, the participants were escorted to the TMS
16 room where rTMS was administered as described below. Immediately after rTMS, the
17 participants were asked to perform the Second Rating task in the TMS room. All
18 participants started the task within 2 min of the TMS completion.

19 The Second Rating task was similar to the first one, with the exception that the images
20 were now accompanied with information from the choices the participants had previously
21 made (as similarly done in the previous fMRI study; Izuma et al., 2010). Below each
22 image, they were presented with the information about whether they (or a computer) had
23 chosen or unchosen the image during the Choice task (e.g., "You chose this picture,"
24 "Computer rejected this picture," etc.). For items in the Switch condition, this information
25 was based on what participants believed to have chosen at the stage 4 of the Choice task
26 (Figure 1). More specifically, those images clicked on after the Flanker task in the stage 4
27 were accompanied with "You chose this picture," whereas alternative images were
28 accompanied with "You rejected this picture." This information was intended to make the
29 effect of cognitive dissonance stronger by making the discrepancy between attitude and

1 past behavior salient. It should be noted that because of the explicit information, preference
2 change found in the present study should if anything be inflated. However, the aim of the
3 present study is not to find a minimum condition for choice-induced preference change to
4 occur, but to test the effect of TMS on pmFC when it does occur (see the paper by (Salti et
5 al., 2014) that formally tests the effect of this explicit information). The participants were
6 told that this information about their past choices was related to a task they were going to
7 perform afterwards, but not related to the rating task, and they were asked to focus on
8 reporting their preference for each image one more time. As was in the First Rating task,
9 they rated the same 50 images using the 8-point scale.

10 After the Second Rating task, the participants were also asked to answer the Positive
11 and Negative Affect Schedule (PANAS) questionnaire (10 items each for positive and
12 negative moods) (Watson et al., 1988) by using an 8-point scale to measure if different
13 rTMS conditions had differential effect on their mood. All the participants finished the
14 Second Rating task and the PANAS questionnaire within 8 min after the TMS, thus
15 presumably well under the influence of the 25-min rTMS (e.g., see Bruckner et al., 2013).
16 After completing the questionnaire, they took a 35-40 min break in the original
17 experimental room to ensure the effects of the TMS had subsided before continuing.

18 After the break, the participants completed the Memory task. Importantly, the Memory
19 task was completely unanticipated by the participants, and they did not know that memory
20 about their past choices would be tested later on. During the task, they were presented
21 images serially (as in the first and second rating tasks) and were instructed to answer
22 whether they “chose” or “rejected” (i.e., unchosen) the item during the Choice task by
23 pressing one of two keys on the keyboard. They were instructed that images presented in
24 the Computer trials of the Choice task would not be presented. Consequently, a total of 40
25 images were presented during the task. They were also asked to make best guess if they
26 were not certain.

27 The Memory task was intended to test whether the rTMS had any differential effect on
28 the participants’ ability to retrieve memory about their past choices. Although during the
29 Second Rating task, the participants' past choice for each presented image was explicitly

1 displayed, if the participants were able to remember their (correct) indicated preferences in
2 the Switch trials, then the intended effect of cognitive dissonance induced by discrepancy
3 between behavior and attitude would have been likely to be reduced. It should be noted that
4 during the Memory task, the correct response was defined based on participants' action at
5 the stage 2 of the Choice task. Accordingly, if the switch manipulation was successful, and
6 participants believed the explicit information about their past choice during the Second
7 Rating task, memory performance for the Switch condition should be lower than that for
8 the Non-switch condition (e.g., they mistakenly remember that they chose the item which
9 they actually did not prefer at the stage 2 due to the switch manipulation).

10 After finishing the Memory task, participants were asked to complete the Preference for
11 Consistency Scale (Cialdini et al., 1995) using an 8-point scale. This 18-item scale was
12 intended to measure individuals' disposition to perceive themselves as predictable, stable
13 and thus consistent (e.g., "It is important to me that my actions are consistent with my
14 beliefs").

15 Finally, as similarly done in the original choice-blindness study (Johansson et al., 2008),
16 the participants were asked the three following questions during the post-experimental
17 interview to ensure that they did not detect our critical switch manipulation; "Do you have
18 any comments on the experiment?", "Do you find anything strange with the wallpaper
19 stimuli during the tasks?", "Some participants mentioned that during some trials of the
20 Choice task, the locations of two images changed. Do you think it happened to you?" The
21 three questions were asked always in this order of increasing specificity. Four participants
22 reported in response to the last question that the switch happened to them also, and thus
23 they were excluded from the analyses. All the remaining participants showed no sign of
24 detection.

25

26 *TMS procedures*

27 In order to downregulate the activity in pmFC, we employed 1-Hz repetitive TMS
28 (rTMS). rTMS is a non-invasive technique that can produce after-effects on cortical

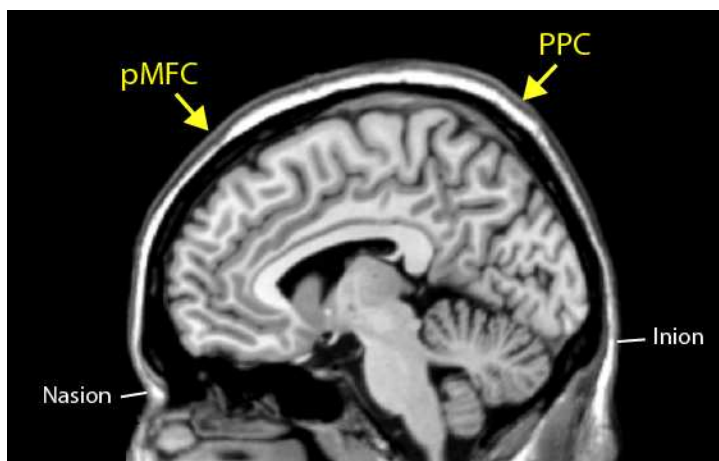
1 excitability, and a low frequency (e.g., 1-Hz) rTMS is known to decrease cortical
2 excitability in stimulated areas (Ridding and Rothwell, 2007). Each participant received
3 1-Hz rTMS for 25 minutes. According to previous reports (e.g. Bruckner et al., 2013), the
4 after effect of the 25-min 1-Hz rTMS is considered to last 20 min or more. A Magstim
5 Super Rapid with a 70mm air-cooled figure-8 coil was used.

6 The experimenter administering TMS was blind to the task and study design except for
7 knowledge of the three stimulation conditions, and was in the same room as the participants
8 only during the TMS phase and an initial portion of the Second Rating task. The
9 experimenter administering the participants' tasks was absent during TMS positioning and
10 delivery, and not informed of the TMS condition until after the completion of the
11 experiment. Participants were blind to the study's intent, but were aware of the possibility
12 that they could be receiving either real or sham stimulation, and that real stimulation would
13 be expected to lower the level of brain activity in the area under the coil for up to 30
14 minutes after the end of stimulation.

15 The intensity of the TMS was set for each participant at 80% of the participant's active
16 motor threshold. To determine threshold, we first adjusted the TMS coil location and
17 orientation to maximize the EMG magnitude in tibialis anterior from single pulse
18 stimulation. The participant was then asked to steadily contract the muscle with moderate
19 intensity. Starting from 50% output, the stimulator was adjusted in 5% steps to find the
20 minimum intensity at which single-pulse TMS elicited a liminal EMG for 3 out of 4 stimuli.
21 The main rTMS treatment was conducted at 80% of this value.

22 Participants were randomly assigned to one of three TMS groups; 1) pMFC, 2)
23 sham-pMFC, and 3) PPC. Based on previous fMRI studies (Izuma et al., 2010; Izuma and
24 Adolphs, 2013), the pMFC target region was determined as one-third of the distance from
25 nasion toinion (i.e., the region roughly corresponding to the areas commonly activated in
26 our two previous fMRI studies) and the control (PPC) region was determined as two-thirds
27 of the same distance (Harmer et al., 2001) (see Figure 2). Because activations found in the
28 previous fMRI studies were slightly stronger in the right hemisphere (Izuma et al., 2010;

1 Izuma and Adolphs, 2013), both stimulation sites were offset to the right of the
2 nasion-Cz-inion midline by 1 cm. The TMS coil was positioned with handle pointing in the
3 superior direction. During the 25-min rTMS, participants in the pMFC and sham-pMFC
4 group were supine, while those in the PPC group were prone. Sham-TMS was administered
5 by tilting the coil 90 degrees off the scalp so that no stimulation actually reached the cortex.



6

7 **Figure 2:** The location of rTMS target sites. The pMFC target region was determined as one-third of the
8 distance from nasion to inion, and the PPC region was determined as two-thirds of the same distance. Our two
9 simulated regions roughly correspond to the MNI coordinates of $x = 10, y = 48, z = 70$ (pMFC) and $x = 10, y$
10 $= -76, z = 85$.

11

12 Coil orientation: TMS effects are maximized when the induced field is perpendicular to
13 the gyral pattern, as this aligns the field with cortical columns in the walls of the sulcus
14 (Brasil-Neto et al., 1992; Mills et al., 1992; Fox et al., 2004). Based on the gyral pattern in
15 the area of interest, we chose to orient the field parallel to the midline. Stimulation polarity
16 with respect to this line can modulate the effectiveness of stimulation, but there is no
17 preceding research that would indicate the optimal polarity for this area or function. Also,
18 the stimulator is biphasic, which makes polarity less critical (Brasil-Neto et al., 1992). Thus,
19 we positioned the handle in the superior direction to minimize the equipment's
20 obtrusiveness to the participant. It is possible that the opposite orientation of the coil would
21 have induced a stronger effect.

1 Adverse Effects: TMS was well-tolerated by most participants, who generally fell
2 asleep during the main treatment. One participant, however, experienced dizziness after
3 receiving 3 sham and 5 real single-pulse stimuli during the search for the site for
4 stimulating tibialis anterior. Dizziness declined, resolving after approximately 2 minutes.
5 The participant was examined by emergency medical technicians and released. Dizziness
6 was attributed to a combination of stress/anxiety of the experiment, and pre-existing
7 conditions of sleep deprivation and dehydration.

8 9 *Data analyses*

10 Our main analysis is based on the 2 (Preference; preferred or unpreferred) X 2 (Switch;
11 switch or no switch) X 3 (TMS group; pMFC, sham-pMFC, or PPC) mixed design with
12 preference change (second preference ratings minus first preference ratings) as a dependent
13 variable. It should be noted that in our choice-blindness paradigm, a choice-induced
14 preference change is indicated by a significant 2 (Preference; preferred or unpreferred) X 2
15 (Switch; switch or no switch) interaction. This 2 X 2 interaction indicates that preference
16 change depends on what the participants believed about past choices they had made
17 previously. Regardless of their initial relative preferences of two images as revealed in the
18 stage 2 of the Choice task (Figure 1) (preferred or unpreferred), preferences for the images
19 should increase when participants believed that they had chosen the image (i.e., the
20 preferred-No-switch condition and the unpreferred-Switch condition), while preferences for
21 images should decrease when images were thought to have been unchosen (i.e., the
22 preferred-Switch condition and the unpreferred-No-switch condition).

23 Furthermore, in order to 1) compute the size of the TMS effect on choice-induced
24 preference change and 2) investigate the correlation between individual difference in
25 choice-induced preference change and participant's tendency to prefer consistency as
26 measured by the Preference for Consistency scale, we computed a single preference change
27 score for each participant as following: We computed the 2-way (Preference X Switch)
28 interaction term, divided it by 2 in order to take an average of preference change observed

1 in the Preferred and Unpreferred conditions, and subtracted preference change observed in
2 the computer condition. This score represents the magnitude of preference change caused
3 by choices participants themselves made. More specifically, a preference change (PC) score
4 was computed as

5

$$6 \quad [(PC_{\text{Preferred-No_switch}} - PC_{\text{Preferred-Switch}}) + (PC_{\text{Unpreferred-Switch}} - PC_{\text{Unpreferred-No_Switch}})]/2 -$$
$$7 \quad (PC_{\text{Computer_Chosen}} - PC_{\text{Computer_unchosen}})$$

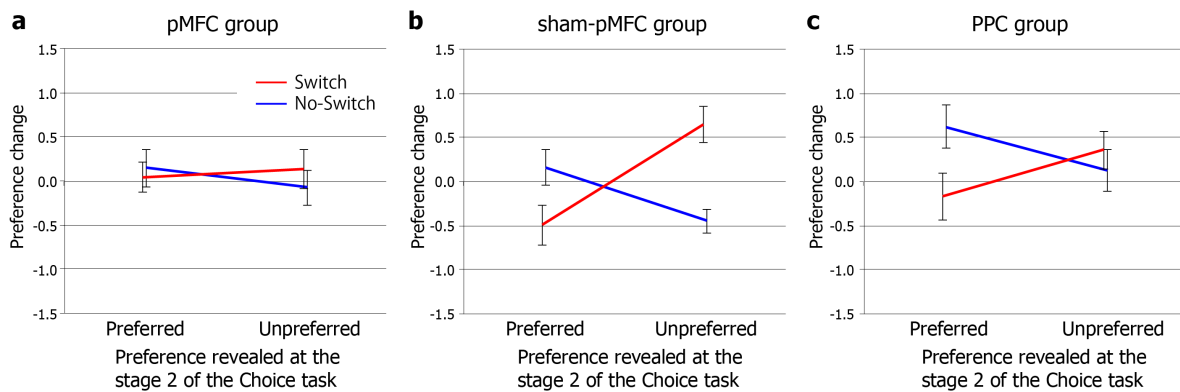
8

1 RESULTS

2 *Preference Change*

3 A 2 (Preference; preferred or unpreferred) X 2 (Switch; switch or no switch) X 3 (TMS
4 group; pMFC, sham-pMFC, or PPC) mixed ANOVA revealed a significant 2-way
5 Preference X Switch interaction ($F_{(1,49)} = 23.19, p < 0.001$). Importantly, it also revealed a
6 critical 3-way Preference X Switch X TMS group interaction ($F_{(2,49)} = 3.34, p = 0.044$)
7 (Figure 3). No other significant main effect or interaction was found in the ANOVA (all p s
8 > 0.082).

9



10

11 **Figure 3:** Mean preference changes (2nd preference ratings minus 1st preference ratings) in the Switch and
12 No-switch conditions across the three TMS groups. Note that "Preferred" and "Unpreferred" (x-axis) are
13 based on participant's relative preferences of paired images, which was revealed during the Stage 2 of the
14 Choice task (Figure 1).

15

16 In order to further probe the significant 3-way interaction, 3 separate two-way
17 (Preference X Choice) repeated-measures ANOVAs were conducted for each TMS group.
18 This revealed a significant Preference X Choice interaction in the sham-pMFC group ($F_{(1,16)}$
19 $= 16.36, p < 0.001$; Figure 3b) and in the PPC group ($F_{(1,17)} = 7.73, p = 0.013$; Figure 3c).
20 As stated earlier, this 2-way interaction indicates the existence of choice-induced
21 preference change and indicates that preference change depends on what the participants
22 believed about past choices they had made previously regardless of their initial relative

1 preferences of two images (preferred or unpreferred). We further conducted two-sample
2 t-tests comparing switch vs. no-switch conditions in each of the preferred and unpreferred
3 conditions for the sham-pMFC and PPC groups. The results revealed that the difference
4 between the switch vs. no-switch conditions were all significant ($p < 0.006$) except for the
5 unpreferred condition of the PPC group ($p = 0.21$). In contrast, the same 2-way interaction
6 was not significant for the pMFC group ($F_{(1,16)} = 1.30$, $p = 0.27$, n.s.) (Figure 3a).
7 Two-sample t-tests comparing switch vs. no-switch conditions in each of the preferred and
8 unpreferred conditions for the pMFC group revealed that there was no significant
9 difference in both preferred and unpreferred conditions ($p > 0.45$). Thus, rTMS to the
10 pMFC region significantly reduced choice-induced preference change.

11 In order to test whether TMS had any effect on preference change for the items
12 presented in the Computer condition, we conducted 2 (Computer's choice; chosen or
13 unchosen) X 3 (TMS group) mixed ANOVA. It revealed a significant main effect of
14 Computer's choice ($F_{(1,49)} = 7.65$, $p = 0.008$). However, a main effect of TMS group and a
15 2-way interaction were not significant ($ps > 0.18$), indicating that TMS had no influence on
16 preference change following choices made by the computer. As seen in Figure 4, across all
17 three TMS groups, participants' preference for the items chosen by computer decreased,
18 while their preference for the items unchosen by computer increased. This result seems to
19 suggest the existence of a significant regression-to-the-mean effect. Since the computer's
20 choice was matched with participant's choice made in the Switch condition, the items
21 chosen by the computer were more likely to have higher first preference ratings.
22 Accordingly, participant's preference rating for the items chosen by the computer is more
23 likely to decrease during the second rating task due to the regression-to-the-mean effect
24 compared to the items unchosen by computer.

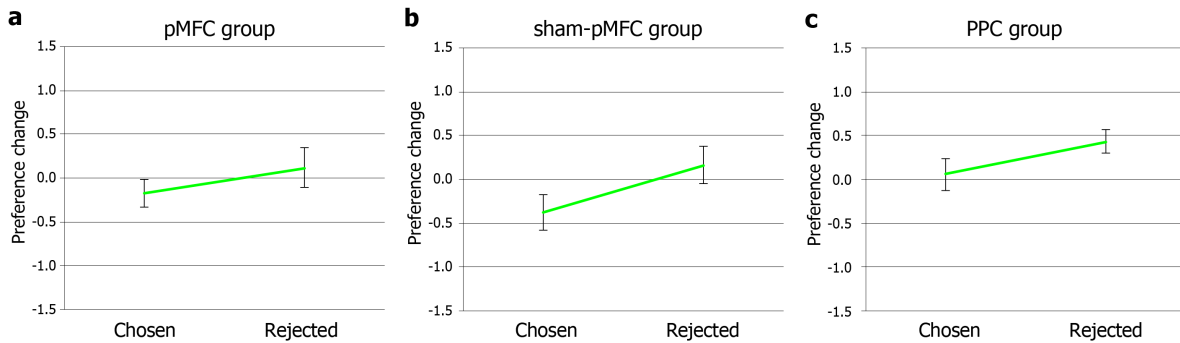


Figure 4: Mean preference changes (2nd preference ratings minus 1st preference ratings) in the Computer condition across the three TMS groups.

Effect Size Analysis

In order to compute the size of the TMS effect on choice-induced preference change, we computed a single preference change score as described in Method. One-way ANOVA on this score comparing across the three TMS groups revealed a marginally significant effect of TMS ($F_{(2, 49)} = 2.56, p = 0.088$). Because there was no significant difference in mean preference change scores between two control conditions (the sham-pMFC and PPC groups, $p = 0.28$), we combined these two control groups in order to calculate Cohen's d . A two-sample t -test comparing the pMFC group with this combined control group revealed a significant difference ($t_{(50)} = 1.93, p = 0.03$), and the calculation of Cohen's d revealed a moderate effect size of the TMS ($d = 0.59$).

Control Analyses

We tested whether the rTMS had any effect on 1) participants' general attention level as indexed by reaction times (RTs) during the First and Second Rating tasks, 2) mood as measured by PANAS, and 3) memory about past choices.

A 2 (Rating task; first or second) X 3 (TMS group) mixed ANOVA on RTs revealed no significant main effects or interaction ($ps > 0.15$), suggesting that the rTMS did not affect participants' attention level during the Second Rating task, which they performed

1 immediately after the rTMS. Regardless of the TMS groups, average RT (including all 50
2 trials) during the First Rating task was 2.17 sec (SD = 0.80), while average RT during the
3 Second Rating task was 2.07 sec (SD = 0.70).

4 Two 1 X 3 (TMS group) ANOVAs on positive and negative mood of the PANAS score
5 revealed no significant effect of the rTMS ($p > 0.34$), indicating that the rTMS did not
6 alter participants' mood.

7 A 2 (Switch; switch or no-switch) X 3 (TMS group) mixed ANOVA on memory about
8 past choices revealed a significant main effect of the switch manipulation ($F_{(1,49)} = 4.14$, $p =$
9 0.047). Because, in the Switch condition, the participants were led to believe that they
10 chose the image they preferred less than the alternatives, their memory performances were
11 significantly lower than those in the No-switch condition. Regardless of the TMS group,
12 average memory performance of the Non-switch condition was 58.5 % (SD = 13.6), which
13 was significantly higher than the chance level (50 %; $t_{(51)} = 4.48$, $p < 0.001$), whereas
14 average memory performance of the Switch condition was 47.9 % (SD = 16.4), which did
15 not differ significantly from the chance level ($p = 0.36$). This result suggests that our switch
16 manipulation was successful, and participants continued to believe that they had chosen the
17 images they actually preferred less than alternatives and had not chosen the images they
18 preferred more than alternatives. A main effect of the TMS group and a 2-way interaction
19 were not significant ($p > 0.77$), suggesting that our main results reported above cannot be
20 explained by differential memory about past choices across the three TMS groups.

21 Finally, we also checked whether 1) within-pair rating difference and 2) the
22 preference-choice consistency were successfully matched across the three experimental
23 conditions (Switch, No-switch and Computer) during the Choice task as we intended.

24 First, average within-pair rating differences (all TMS group combined, $n = 52$) in the
25 No-Switch and Switch conditions were both 1.98, and it was 2.01 in the Computer
26 condition. A 3 (experimental conditions; Switch, No-switch, or Computer) X 3 (TMS
27 group; pMFC, sham-pMFC, or PPC) mixed ANOVA revealed no significant main effects
28 or interaction ($p > 0.19$).

1 Second, participants generally chose images that had higher first preference rating when
2 they had a chance to make a choice themselves (i.e., the Switch and No-switch conditions).
3 The mean preference-choice consistency (all TMS group combined, $n = 52$) in the
4 No-switch condition was 62.9%, and it was 65.0% in the Switch condition and the
5 Computer condition (as previously described, the preference-choice consistency was
6 matched between these two conditions by the task program). A 3 (experimental conditions;
7 Switch, No-switch, or Computer) X 3 (TMS group; pMFC, sham-pMFC, or PPC) mixed
8 ANOVA revealed no significant main effect or interaction ($ps > 0.66$).

9 Taken together, these results indicate that the main findings reported above is highly
10 unlikely to be explained by the different level of the artifact (Chen and Risen, 2010) across
11 three TMS groups.

12

13 *Preference for Consistency Scale*

14 Finally, we conducted 1 X 3 (TMS group) between-participant ANOVA on the
15 preference for consistency scale. It revealed no significant effect ($p = 0.54$), suggesting that
16 individual difference in the tendency to prefer consistency was no different across the three
17 TMS groups.

18 We also investigated, as exploratory analyses, whether participants' preference for
19 consistency scores were related to their level of choice-induced preference change,
20 separately for each TMS group. We used the same single preference change score described
21 above to index an individual's tendency to justify choices they made. Although correlations
22 in all 3 groups did not reach statistical significance largely due to our limited sample size,
23 sham-pMFC and PPC groups tended to show positive correlation (sham-pMFC $r_{(15)} = 0.27$,
24 $p = 0.15$; PPC $r_{(16)} = 0.32$, $p = 0.10$). In contrast, correlation in the pMFC group was
25 virtually zero ($r_{(15)} = 0.03$, $p = 0.46$).

26

27

1 **DISCUSSION**

2 The present study demonstrated that choice-induced preference change was
3 significantly reduced by TMS over the pMFC region compared to the control conditions
4 (TMS to the PPC region and sham-TMS to the pMFC region), providing the evidence that
5 the pMFC plays a causal role in inducing preference change following inconsistency
6 between choice and preference. It is important to note that we used a modified
7 choice-blindness paradigm to control for the artifact inherent in the traditional free-choice
8 paradigm (Chen and Risen, 2010). Thus, unlike a number of previous behavioral as well as
9 neuroimaging studies that used the original paradigm (see Izuma and Murayama, 2013), the
10 present study provides unequivocal evidence for the existence of choice-induced preference
11 change and the effect of TMS over different brain regions on the phenomenon.

12 The present findings are consistent with the previous studies showing that the pMFC
13 plays a causal role in inducing behavioral or attitude change following a variety of aversive
14 experiences in both social and non-social contexts. The pMFC is known to be activated by
15 a variety of aversive outcomes (Shackman et al., 2011). Furthermore, some neurons in
16 pMFC do not simply respond to negative outcomes *per se*, rather these neurons respond to
17 negative outcome (e.g., reduced reward) only when the monkey subsequently changed their
18 behavior from the previous trial (Shima and Tanji, 1998). There exist similar neurons in the
19 human dorsal anterior cingulate regions, and ablation of this area significantly impaired
20 participants' performance in a reward-based movement selection task especially when they
21 had to change their movement after reduced reward (Williams et al., 2004). Recently, fMRI
22 studies found that the same region is activated by aversive experiences in social contexts
23 (for a review, Izuma, 2013), such as disagreeing with others (Klucharev et al., 2009; Izuma
24 and Adolphs, 2013), or agreeing with people we dislike (Izuma and Adolphs, 2013).
25 Furthermore, Klucharev and his colleagues demonstrated that TMS to the pMFC region
26 significantly decreased individual's tendency to conform to others' opinion (Klucharev et al.,
27 2011). Therefore, just like its known role for non-social situations (Williams et al., 2004),
28 the pMFC plays a key role not only in detecting a social situation that requires some level

1 of adjustment in behavior or attitude (such as cognitive dissonance, disagreeing with others,
2 etc.), but also in actually inducing that change.

3 It is important to note that preference change following cognitive dissonance requires at
4 least two processes: 1) detection of discrepancy (conflict), and 2) subsequent
5 implementation of conflict resolution. The present study does not allow us to specify the
6 exact role played by pMFC. The pMFC could play a role in either conflict detection,
7 conflict resolution or both. Two past TMS studies on response-level conflict showed that
8 pre-SMA plays a causal role in conflict resolution rather than conflict detection (Mars et al.,
9 2009; Soutschek et al., 2013), and it will be an important future direction to investigate
10 whether the pMFC plays a similar causal role in resolving (rather than simply detecting)
11 cognitive conflict such as cognitive dissonance. Furthermore, two past studies
12 (Harmon-Jones et al., 2008b; Mengarelli et al., 2013) suggested that left dorsolateral
13 prefrontal cortex (DLPFC) plays a causal role in the resolution of cognitive dissonance, part
14 of a larger literature from neuroimaging studies that have found correlational evidence for
15 this brain region's role in cognitive dissonance processes (Harmon-Jones et al., 2008a;
16 Harmon-Jones et al., 2008b; van Veen et al., 2009; Izuma et al., 2010). It was further
17 demonstrated that the DLPFC specifically in left hemisphere plays a causal role in
18 choice-induced preference change (Harmon-Jones et al., 2008b; Mengarelli et al., 2013).
19 An electroencephalography (EEG) study found that when an individual's left dorsal
20 prefrontal cortex (DLPFC) activity was decreased through neurofeedback training,
21 choice-induced preference change was significantly reduced (Harmon-Jones et al., 2008b).
22 Conceptually similar results have been reported by a study using transcranial direct current
23 stimulation (tDCS) (Mengarelli et al., 2013). It showed that choice-induced preference
24 change was significantly reduced after individual's left DLPFC was stimulated by cathodal
25 tDCS, which is known to reduce the excitability of the target areas. However, another EEG
26 study (Harmon-Jones et al., 2011) suggests that the DLPFC is not related to cognitive
27 dissonance *per se*, and the commitment to the chosen course of actions can increase the left
28 DLPFC activity regardless of the existence of inconsistency between attitude and actions.
29 As the DLPFC is known to be involved in cognitive control (Miller and Cohen, 2001), the

1 studies seem to suggest that the actual implementation of choice justification requires
2 general cognitive control processes.

3 Although this neural model of a discrepancy (dissonance) resolution system is similar
4 to the model of response level conflict resolution (Mansouri et al., 2009), it is probably too
5 simplistic to argue that they share the common neural mechanisms. For example, our
6 previous study (Izuma and Adolphs, 2013) showed that the pmFC region activated by
7 cognitive imbalance, which is conceptually similar to cognitive dissonance (Abelson et al.,
8 1968; Gawronski and Strack, 2012), does not overlap with the region activated by response
9 conflict. The region activated by response conflict was located more posteriorly (i.e.,
10 pre-SMA) (Izuma and Adolphs, 2013), consistent with two previous TMS studies (Mars et
11 al., 2009; Soutschek et al., 2013) demonstrating that stimulating pre-SMA disrupts response
12 conflict resolution. Although the lack of anatomical resolution in the present study does not
13 allow us to specify the exact location stimulated by TMS, our pmFC target region roughly
14 corresponds to $x = 10$, $y = 48$, $z = 70$ (Jurcak et al., 2005), which is more anterior than the
15 previous studies: $y = 18$ (Mars et al., 2009) and $y = 21$ (Soutschek et al., 2013). As
16 previously discussed (Izuma and Adolphs, 2013), we believe that the neural mechanism of
17 a discrepancy resolution system may be similar to that of behavioral adjustment following
18 an aversive outcome. Previously, we found that the areas activated by cognitive imbalance
19 largely overlapped with the areas activated by aversive outcome (posterior dmPFC) (Izuma
20 and Adolphs, 2013). This functional distinction within pmFC is consistent with what has
21 been previously suggested (Ridderinkhof et al., 2004; Rushworth et al., 2004; Hikosaka and
22 Isoda, 2010). Furthermore, other additional regions, such as the insula, seem to play a role
23 in processing social types of conflict (Klucharev et al., 2009; van Veen et al., 2009; Izuma
24 et al., 2010; Izuma and Adolphs, 2013). Comparisons between these multiple systems for
25 resolving discrepancies between expectations and outcomes should be investigated further
26 in future research.

27 It should be noted that the preference change observed in the present study could be
28 explained by self-perception theory (Bem, 1967). Self-perception theory posits that just like
29 we came to know another person's preference by observing their behavior, we infer our

1 own preference by observing our own behavior (e.g., I must like it because I chose it). This
2 limitation is inherent in all past studies demonstrating choice-induced preference change,
3 and Greenwald even argued that these two theories cannot be distinguished (Greenwald,
4 1975, 2012). Although not conclusive, our present TMS study along with the previous
5 fMRI study (Izuma et al., 2010) seem to support cognitive dissonance theory. In our
6 previous fMRI study, the degree of cognitive dissonance is quantified as the discrepancy
7 between a participant's past choice and preference for the item, and we found that activity
8 in the pMFC correlated with this parameter. Since this parameter is irrelevant to
9 self-perception theory, being able to reduce choice-induced preference change by
10 stimulating the pMFC with TMS suggests that dissonance reduction processes played a
11 major role in the present study. But, we admit that the fact that our data is consistent with
12 one theory does not necessarily mean that the other theory plays no role (i.e., consistency
13 fallacy). Nonetheless, the present study highlights the potential of cognitive neuroscience
14 methods (fMRI, TMS) in distinguishing two social psychological theories. For example, we
15 can test whether different brain regions are activated by psychological processes assumed
16 in cognitive dissonance theory vs. self-perception theory. If activated regions are reliably
17 different, we can further test whether TMS to those regions could reduce choice-induced
18 preference change.

19 In summary, the present study demonstrated that TMS to the pMFC could reduce
20 choice-induced preference change. Our results inform neural models of the choice
21 justification processes implemented by the pMFC and provide a clear demonstration of the
22 causal role of the pMFC. It will be most important in future studies to sharpen our
23 understanding of this causal role by providing direct comparisons among different types of
24 conflict, and to link the role of the pMFC to that of other brain regions with which it is
25 connected.

26

1 REFERENCES

- 2 Abelson RP, Aronson E, McGuire WJ, Newcomb TM, Rosenberg MJ, Tannenbaum PH
3 (1968) Theories of cognitive consistency: A sourcebook. Chicago: Rand McNally.
- 4 Bem DJ (1967) Self-Perception - an Alternative Interpretation of Cognitive Dissonance
5 Phenomena. *Psychological Review* 74:183-&.
- 6 Brasil-Neto JP, Cohen LG, Panizza M, Nilsson J, Roth BJ, Hallett M (1992) Optimal focal
7 transcranial magnetic activation of the human motor cortex: effects of coil
8 orientation, shape of the induced current pulse, and stimulus intensity. *Journal of*
9 *clinical neurophysiology : official publication of the American*
10 *Electroencephalographic Society* 9:132-136.
- 11 Brehm JW (1956) Post-decision changes in the desirability of choice alternatives. *J*
12 *Abnorm Soc Psychol* 52:384-389.
- 13 Bruckner S, Kiefer M, Kammer T (2013) Comparing the after-effects of continuous theta
14 burst stimulation and conventional 1 Hz rTMS on semantic processing.
15 *Neuroscience* 233:64-71.
- 16 Chen MK, Risen JL (2010) How Choice Affects and Reflects Preferences: Revisiting the
17 Free-Choice Paradigm. *J Pers Soc Psychol* 99:573-594.
- 18 Cialdini RB, Trost MR, Newsom JT (1995) Preference for Consistency - the Development
19 of a Valid Measure and the Discovery of Surprising Behavioral-Implications.
20 *Journal of Personality and Social Psychology* 69:318-328.
- 21 Festinger L (1957) *A Theory of Cognitive Dissonance*. Stanford: Stanford University
22 Press. .
- 23 Fox PT, Narayana S, Tandon N, Sandoval H, Fox SP, Kochunov P, Lancaster JL (2004)
24 Column-based model of electric field excitation of cerebral cortex. *Hum Brain*
25 *Mapp* 22:1-14.
- 26 Gawronski B, Strack F, eds (2012) *Cognitive Consistency: A Fundamental Principle in*
27 *Social Cognition*, 1 Edition. New York: Guilford Press.
- 28 Greenwald AG (1975) Inconclusiveness of Crucial Cognitive Tests of Dissonance Versus
29 Self-Perception Theories. *Journal of Experimental Social Psychology* 11:490-499.
- 30 Greenwald AG (2012) There Is Nothing So Theoretical as a Good Method. *Perspect*

- 1 Psychol Sci 7:99-108.
- 2 Hall L, Johansson P, Strandberg T (2012) Lifting the Veil of Morality: Choice Blindness
3 and Attitude Reversals on a Self-Transforming Survey. Plos One 7.
- 4 Hall L, Strandberg T, Parnaments P, Lind A, Tarning B, Johansson P (2013) How the Polls
5 Can Be Both Spot On and Dead Wrong: Using Choice Blindness to Shift Political
6 Attitudes and Voter Intentions. Plos One 8.
- 7 Harmer CJ, Thilo KV, Rothwell JC, Goodwin GM (2001) Transcranial magnetic
8 stimulation of medial-frontal cortex impairs the processing of angry facial
9 expressions. Nat Neurosci 4:17-18.
- 10 Harmon-Jones E, Gerdjikov T, Harmon-Jones C (2008a) The effect of induced compliance
11 on relative left frontal cortical activity: A test of the action-based model of
12 dissonance. Eur J Soc Psychol 38:35-45.
- 13 Harmon-Jones E, Harmon-Jones C, Serra R, Gable PA (2011) The Effect of Commitment
14 on Relative Left Frontal Cortical Activity: Tests of the Action-Based Model of
15 Dissonance. Personality and Social Psychology Bulletin 37:395-408.
- 16 Harmon-Jones E, Harmon-Jones C, Fearn M, Sigelman JD, Johnson P (2008b) Left frontal
17 cortical activation and spreading of alternatives: tests of the action-based model of
18 dissonance. J Pers Soc Psychol 94:1-15.
- 19 Hikosaka O, Isoda M (2010) Switching from automatic to controlled behavior:
20 cortico-basal ganglia mechanisms. Trends Cogn Sci 14:154-161.
- 21 Izuma K (2013) The neural basis of social influence and attitude change. Curr Opin
22 Neurobiol 23:456-462.
- 23 Izuma K, Adolphs R (2013) Social manipulation of preference in the human brain. Neuron
24 78:563-573.
- 25 Izuma K, Murayama K (2013) Choice-induced preference change in the free-choice
26 paradigm: a critical methodological review. Frontiers in psychology 4:41.
- 27 Izuma K, Matsumoto M, Murayama K, Samejima K, Sadato N, Matsumoto K (2010)
28 Neural correlates of cognitive dissonance and choice-induced preference change.
29 Proc Natl Acad Sci U S A 107:22014-22019.
- 30 Johansson P, Hall L, Sikstrom S (2008) From change blindness to choice blindness.

1 Psychologia 51:142-155.

2 Jurcak V, Okamoto M, Singh A, Dan I (2005) Virtual 10-20 measurement on MR images
3 for inter-modal linking of transcranial and tomographic neuroimaging methods.
4 Neuroimage 26:1184-1192.

5 Klucharev V, Munneke MAM, Smidts A, Fernandez G (2011) Downregulation of the
6 posterior medial frontal cortex prevents social conformity. J Neurosci
7 31:11934-11940.

8 Klucharev V, Hytonen K, Rijpkema M, Smidts A, Fernandez G (2009) Reinforcement
9 learning signal predicts social conformity. Neuron 61:140-151.

10 Mansouri FA, Tanaka K, Buckley MJ (2009) Conflict-induced behavioural adjustment: a
11 clue to the executive functions of the prefrontal cortex. Nat Rev Neurosci
12 10:141-152.

13 Mars RB, Klein MC, Neubert FX, Olivier E, Buch ER, Boorman ED, Rushworth MF
14 (2009) Short-latency influence of medial frontal cortex on primary motor cortex
15 during action selection under conflict. J Neurosci 29:6926-6931.

16 Mengarelli F, Spoglianti S, Avenanti A, di Pellegrino G (2013) Cathodal tDCS Over the
17 Left Prefrontal Cortex Diminishes Choice-Induced Preference Change. Cereb
18 Cortex.

19 Miller EK, Cohen JD (2001) An integrative theory of prefrontal cortex function. Annu Rev
20 Neurosci 24:167-202.

21 Mills KR, Boniface SJ, Schubert M (1992) Magnetic brain stimulation with a double coil:
22 the importance of coil orientation. Electroencephalography and clinical
23 neurophysiology 85:17-21.

24 Ridderinkhof KR, Ullsperger M, Crone EA, Nieuwenhuis S (2004) The role of the medial
25 frontal cortex in cognitive control. Science 306:443-447.

26 Ridding MC, Rothwell JC (2007) Is there a future for therapeutic use of transcranial
27 magnetic stimulation? Nat Rev Neurosci 8:559-567.

28 Rushworth MF, Walton ME, Kennerley SW, Bannerman DM (2004) Action sets and
29 decisions in the medial frontal cortex. Trends Cogn Sci 8:410-417.

30 Salti M, El Karoui I, Maillet M, Naccache L (2014) Cognitive dissonance resolution is

1 related to episodic memory. PLoS One 9:e108579.
2 Shackman AJ, Salomons TV, Slagter HA, Fox AS, Winter JJ, Davidson RJ (2011) The
3 integration of negative affect, pain and cognitive control in the cingulate cortex. Nat
4 Rev Neurosci 12:154-167.
5 Shima K, Tanji J (1998) Role for cingulate motor area cells in voluntary movement
6 selection based on reward. Science 282:1335-1338.
7 Soutschek A, Taylor PC, Muller HJ, Schubert T (2013) Dissociable networks control
8 conflict during perception and response selection: a transcranial magnetic
9 stimulation Study. J Neurosci 33:5647-5654.
10 van Veen V, Krug MK, Schooler JW, Carter CS (2009) Neural activity predicts attitude
11 change in cognitive dissonance. Nat Neurosci 12:1469-1474.
12 Watson D, Clark LA, Tellegen A (1988) Development and Validation of Brief Measures of
13 Positive and Negative Affect - the Panas Scales. Journal of Personality and Social
14 Psychology 54:1063-1070.
15 Williams ZM, Bush G, Rauch SL, Cosgrove GR, Eskandar EN (2004) Human anterior
16 cingulate neurons and the integration of monetary reward with motor responses. Nat
17 Neurosci 7:1370-1375.