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Cognitive dissonance theory suggests that our preferences are modulated by the mere act of choosing. According to the cognitive dissonance theory, a choice between two similarly valued alternatives creates a psychological tension (cognitive dissonance) that is reduced by a post-decisional re-evaluation of the alternatives – the post-decisional spreading-of-alternatives effect – the chosen item being later evaluated more positively and the rejected item more negatively. Previous neuroimaging studies indicated a central role of the medial prefrontal cortex in cognitive dissonance. In this work, we used electroencephalography to investigate a similarity of neural mechanisms underlying postdecisional preference change and general performance monitoring mechanisms. Our study demonstrates that decisions, associated with stronger cognitive dissonance, trigger a stronger negative fronto-central evoked response similar to the error-related negativity (ERN). Furthermore, the amplitude of ERN correlated with the post-decisional spreading-of-alternatives effect. ERN has been previously associated with incorrect responses and a general performance monitoring mechanism. Thus, our results suggest that cognitive dissonance can be reflected in the activity of the medial prefrontal cortex as a part of the general performance-monitoring circuitry.

JEL Classification: Z

Key words: cognitive dissonance, ERN, brain, spread of alternatives, Eriksen Flanker task

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Introduction

Normative economic theory suggests that our actions reflect our preferences, whereas a psychological theory of “cognitive dissonance” (CD) postulates that our actions shape our preference. Indeed, previous psychological studies showed that when a person has to select between two items that are equally attractive, the mere act of choosing one item induces a preference change. The decrease in ratings for rejected items (or the increase in ratings for chosen items) has been repeatedly demonstrated under the “free-choice paradigm” (Brehm, 1956; Coppin, Delplanque, Cayeux, Porcherot, & Sander, 2010; Gerard & White, 1983; Shultz, Leveille, & Lepper, 1999): firstly, participants are instructed to (i) rate their preference for a set of items, (ii) choose between two of the items, and (iii) rate them again. Overall, after making a difficult choice between two equally preferred items, individuals tend to like the rejected item less than before – *Spread of Alternatives* (SoA) phenomenon. According to CD theory (Festinger, 1957), coinciding contradictory cognitions (e.g., “I like the item” and “I rejected it”) cause a psychological discomfort called CD and individuals are motivated to reduce this discomfort by changing their original preferences. Thus, decisions can cause CD leading to the changes in opinion, attitude and behavior.

The *Action-based model* (see Harmon-Jones & Harmon-Jones, 2008, for a review), suggested that CD and subsequent behavioral adjustments reflect a cognitive and behavioral conflict that forces people to engage mechanisms of conflict reduction. Importantly, in the Action-based model the activity of the posterior medial frontal cortex (pmMFC) underlies detection of the cognitive conflicts and reduction of CD (Amodio et al., 2004; C. S. Carter, 1998; K. Izuma et al., 2010).

Recent neuroimaging studies investigated neural correlates of CD and demonstrated that it is accompanied by the pmMFC activity (van Veen et al., 2009; Izuma et al., 2010 & 2013; Kitayama et al., 2013). A transcranial magnetic stimulation (TMS) study demonstrated a causal role for pmMFC in choice-induced preference change: repetitive TMS of the pmMFC significantly reduces choice-induced preference change compared with control stimulation over a different brain region (Izuma et al 2015). Izuma (2013) suggested that the activity of the pmMFC reflects the internal consistency of one’s opinions or behaviors, associating CD with the processes underlying the change of opinion/behavior. Additional studies have shown that other brain

regions are involved in CD. For instance, Harmon-Jones and colleagues (2008) manipulated the left dorsolateral prefrontal cortex (DLPFC) activity via EEG biofeedback training, showing a significant reduction in the postdecisional preference change. Mengarelli and colleagues (2013) reduced the postdecisional preference change in free-choice paradigm by delivering cathodal transcranial direct stimulation (tDCS) over the left DLPFC, demonstrating a causal role in choice-induced preference change. Although these studies suggested the role of DLPFC in cognitive dissonance, an EEG study (Eddie Harmon-Jones, Harmon-Jones, Serra, & Gable, 2011) found that a high commitment to behavior induces a greater activation of left dorsolateral frontal cortex both in counter attitudinal and proattitudinal actions. As DLPFC has been shown to be involved in cognitive control (Miller & Cohen, 2001), it was suggested that DLPFC is not directly involved in cognitive inconsistency reduction but its activity is related to a more general cognitive control process (Keise Izuma et al., 2015). Overall, previous neuroimaging studies suggest a key role of the pMFC in behavioral effects of CD (see Keise Izuma, 2013, for a review). Interestingly, the pMFC has been also implicated in the generation of a so-called “reward prediction error” signal when the outcome of an action differs from the expected one (Holroyd & Coles, 2002; Nieuwenhuis et al., 2004; Rushworth et al., 2007; Cohen & Ranganath, 2007; but see also Botvinick, 2007). This signal presumably guides future action selection by updating predictions of action values (Niv, 2009). An involvement of the pMFC in CD and general performance monitoring may suggest that CD and SoA phenomenon can be related to general action-monitoring and reinforcement-learning mechanisms.

In this paper, we hypothesize that dissonance-induced behavioral change shares similar neural structures with reinforcement learning mechanisms. In particular, we investigate neural correlates of SoA in the free-choice paradigm. Here we aim to explore whether choice-induced preference changes after difficult decisions (i.e. *I also like item A but I chose item B*) can be driven by a neural mechanism similar to the general mechanism of performance monitoring and behavioral adjustments.

In order to clarify the mechanism of CD, we used an electrophysiological signature of error detection – a so-called Error-related negativity response (ERN). Previously, ERN was robustly recorded as a response-locked negative event-related potential (ERP) that occurs within 100 ms after erroneous performance in a large number of speeded response tasks (Gehring, Liu, Orr, &

Carp, 2011; Holroyd & Coles, 2002 ; Falkenstein, Hohnsbein, & Hoormann, 1995). For example, ERN has been associated with processing errors (Holroyd Nieuwenhuis, S., Yeung N. and Cohen, J.D., 2003), monitoring action outcomes (Luu, Tucker, & Makeig, 2004), realizing the need for cognitive control and behavioral adjustments (Gehring et al., 2011). Several studies have shown that the main source of ERN generation is the pMFC (Debener, 2005; C B Holroyd & Coles, 2002; Holroyd, C. B., Nieuwenhuis, S., Mars, R. B., & Coles, 2004; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). The Eriksen Flanker Task (Eriksen & Eriksen, 1974). is one of the most frequently used task to obtain ERN response to conflict and can be used as an reward-prediction error localizer (Larson et al., 2014). In the current study, we tested the hypothesis that choice-induced preference changes are associated with changes in a response-locked negative response evoked potential similar to ERN: a larger ERN-like activity is generated after difficult decisions than after the easy ones. Furthermore, we aim to investigate a relationship between individual electrophysiological correlates of CD and individual choice-induced preference changes. To test our hypothesis we recorded ERPs during the free-choice paradigm and during the task, which has been broadly used in studies of the pMFC activity and ERN (Alexander & Brown, 2011; Matthew M Botvinick, Cohen, & Carter, 2004; C S Carter et al., 1998). Overall, our approach allowed us to investigate similarity of neural mechanisms of choice-induced preference with the more general reinforcement learning mechanisms.

Methods

Participants

Twenty-two right-handed healthy participants (9 males, mean age of 21.40 ± 3.15) were recruited for a small compensation (equivalent of 12-15 US dollars). Participants were instructed to fast at least three hours before the study. All participants had normal or corrected-to-normal vision and received no regular medications. None of the subjects had a history of neurological or psychiatric illness. The study protocol was approved by the HSE ethics committee.

Stimuli

A set of 445 digital photos of *snack foods* item on a white background (chocolate, chips, small fruit or vegetable, cheese) were used as stimuli. The items were selected from a larger dataset during a pre-study in order to use the most familiar food items available on the local market. The price of items was below 8 US dollars (500 rubles). The photos were projected onto a screen with a visual angle of 12.68° vertically and 8.18° horizontally.

Experimental Tasks and Procedures

Free Choice Paradigm

The main Free Choice *paradigm* consisted of four parts (Fig.1): (i) Preference task I, (ii) Choice task, (iii) Preference task II, and (iv) Post-Experimental Choice task (see Izuma et al., 2010, for details).

During the *Preference task I*, participants had to rate a set of 445 food items using 8-point Likert scale (1 = “I don’t like it at all” and 8 = “I like it a lot”). Each item appeared at the center of the screen for 3 seconds. During the *Choice task* two foods were presented on the screen at the same time. In *Self trials* participants were instructed to choose one food that they prefer. In order to increase the participants’ motivation, they were informed that they will obtain one of the selected foods along with a monetary compensation. Unknown to participants, the pairs were created using a computational algorithm based of participants’ ratings during the Preference task I: 50 percent of pairs included two highly preferred foods (rated between 6 and 8 – these trials are defined as *Self-Difficult trials*) and 50 percent of pairs included a highly preferred item and an unpreferred foods (rated below 3) – *Self-Easy trials*. In control *Computer trials* participants were instructed to press the button corresponding to the food randomly chosen by the computer (highlighted by a red square). Importantly, in the *Computer trials* items were programmed and selected similarly to *Self-Difficult trials*. Overall, each food appeared in only one pair. At the beginnings of each trial participants were informed about the trial type (*Self trial* or *Computer Trial*). Participants had 5 seconds to make their choice or to confirm computer’s choice. In case of no answer, a written message ‘Please, respond faster’ appeared at the center of the screen.

During the *Preference task II*, participants had to rate again the same set of foods. Unlike the *Preference task II*, an additional text indicated subjects’ or computer’s decision during the

Choice task (e.g. ‘you chose it’/ ‘you rejected it’ or ‘computer chose it’ / ‘computer rejected it’). Finally, participants attended an additional control condition – a *Post-ex* choice task (see Izuma et al., 2010, for details). Subjects were instructed to choose from the same pairs of foods that had appeared during the *Computer trials* of the *Choice task*.

At the end of the experiment, one of the items that participant selected during *Self-Difficult* or *Post-ex choice* trials was randomly selected as an additional reward for the participant.

Eriksen Flanker task

In the Eriksen Flanker task (Fig.2) which constituted the final part of the study performed by each participant, a string of 7 elements appeared on the monitor for 150 ms followed by a black screen (600-1000 ms). Each string consisted of a central element (the target) and three flankers. The elements were combined as *congruent* (<<<<<<<< or >>>>>>>) or *incongruent* (<<<<<<< or >>><>>>). Participants were instructed to react as quickly and as accurately as possible by pressing the correct button according to the orientation (left or right) of the target element regardless the orientation of flankers. If participants responded too late (slower than 800 ms) a message “you are too late” prompted them to respond faster. The task consisted of 7 blocks (60 trials per block). Each string type appeared with probability of 0.25.

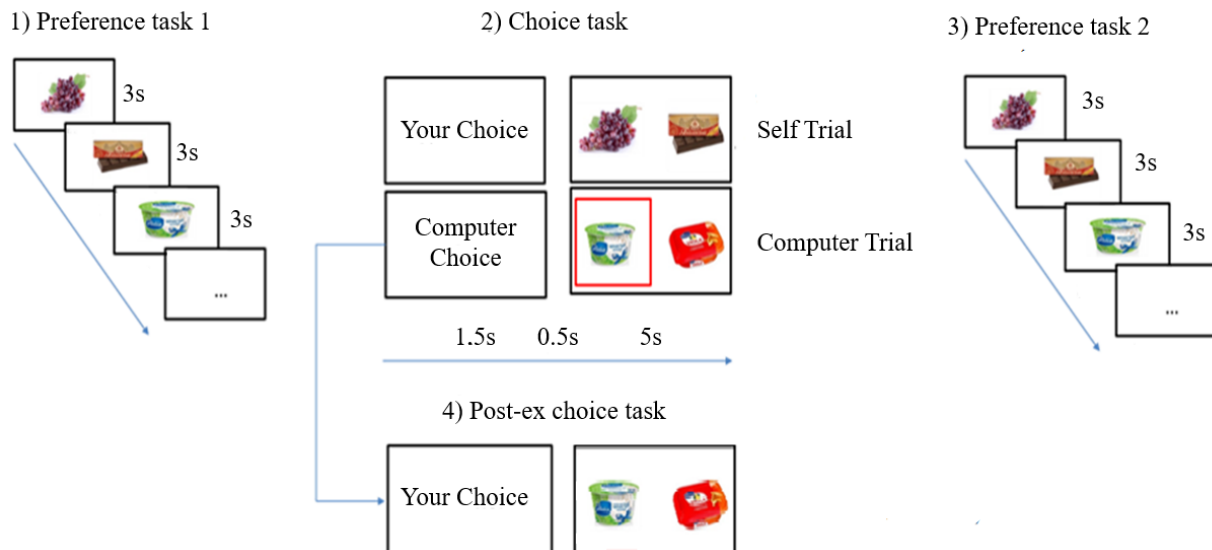


Figure 1. Free choice paradigm. (1) During *Preference task I* participants rated food items presented for 3 s on the screen. (2) During *Choice task* in *Self trials*, subjects freely selected one of two foods (*Self-Difficult trials* evoked strong CD, *Self-Easy trials* evoked weak CD), while in *Computer trials*, subjects had to select the item that has been selected by the computational algorithm (highlighted by a red square). (3) In *Preference task II* participants rated the same foods again. Additionally, participants were reminded about their choices (if any) during the *Choice task*, e.g., “You rejected it”. 4) During *Post-ex choice* task participants choose items from the pairs that had been presented during *Computer trials*.

Behavioral measure and analysis

To assess the effect of cognitive dissonance on behavioral preference change, we calculated the preference change by subtracting the averaged rating made during *Preference Task II* minus the averaged rating made during *Preference Task I* separately for the selected and rejected items and four experimental conditions (Self-Difficult, Self-Easy choice, Computer Choice and Post-ex choice). A positive preference change indicated an increased postdecisional preference of the food item (more liking) whereas a negative preference change suggested a decreased postdecisional preference of the food (less liking). Postdecisional preference change analysis was performed by entering both accepted and rejected item ranks (Preference Task II-minus-Preference task I) for each of experimental conditions into paired t-tests (see Izuma et al., 2010, for a similar analysis).

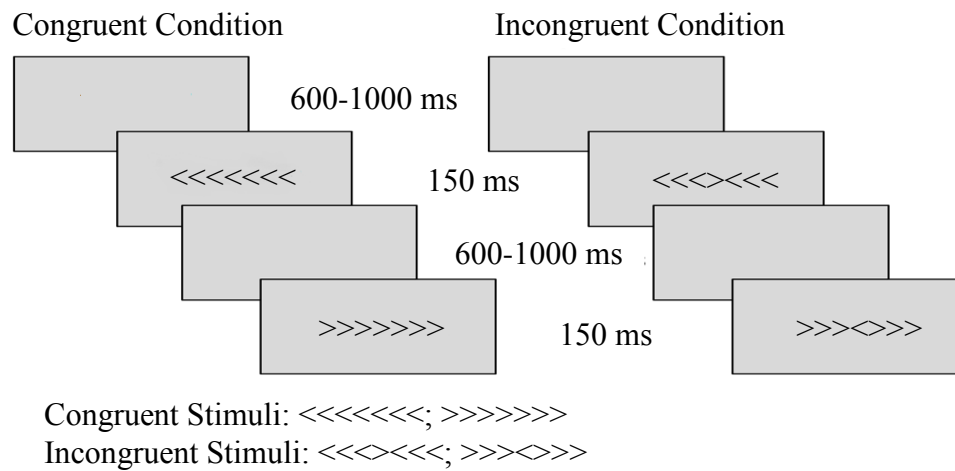


Figure 2. The sequence of events in Congruent and Incongruent conditions of the Eriksen Flanker task.

ERP recording and analysis

EEG was recorded at the 500 Hz sampling rate from 62 high-impedance ActiCap active scalp electrodes (Brain Products, Gilching, Germany) placed according to the 10% system and impedances were kept below 10 k Ω . Eye movements were recorded from electrodes placed at both lateral canthi and below the left eye with Ag/AgCl electrodes). EEG signal was referenced to arithmetically linked mastoids. Offline, a DC-obtained EEG was band pass filtered between 0.1 and 30 Hz. Data were screened for artifacts (amplitudes exceeding $\pm 100 \mu\text{V}$), and less than 10% of all trials in each condition and in each participant were rejected. Next, after a short training, participants performed the *Free-Choice Paradigm* design. Finally, participants performed the Eriksen Flanker task. At the end of the experiment participants received food and a monetary reward.

The ERP responses elicited during *Self-Difficult choices* (ERP_{Self-Difficult}) and *Self-Easy choices* (ERP_{Self-Easy}) were subjected to the analysis of the effect of the *CD* factor.

In the Eriksen Flanker task, ERN was calculated by computing the difference curve between the average waveform on trials with correct responses and that on trials with incorrect responses.

Paired t-test was performed by comparing ERPs generated by correct responses against correct responses in. The trials were classified and averaged as errors-related or correct regardless of the trials type (congruent and incongruent trials).

Across various conditions and tasks, statistical analyses were performed using paired t-tests comparing mean amplitudes and latencies of FCz obtained from the individually averaged ERP responses at the latency window between 0 and 90 ms from the response onset and a 35-ms integration window (Fig. 4).

Results

Behavioral correlates of post-decisional preference change

We found the significant postdecisional spreading-of-alternatives effect (Fig.3): participants' preference for items that were rejected during *Self-Difficult* trials significantly decreased as compared to the rejected items in *Self-Easy trials* [$t(20) = -6.78, p < 0.001$], as well as compared to accepted items in *Self-Difficult* trials [$t(20) = -7.64, p < 0.001$]. Importantly, postdecisional spreading-of-alternatives for items that were rejected during *Self-Difficult* trials was significantly stronger than for items rejected in the control conditions: *post-Ex choice* [$t(20) = -2.115, p = 0.047$], *Computer trials* [$t(20) = -4.941, p < 0.001$]. Postdecisional preference change for rejected items in *post-Ex choice* trials was significantly lower as compared to both rejected and accepted items in *Self-Easy* ([$t(20) = -5.683, p < 0.001$] and [$t(20) = -5.527, p < 0.001$], respectively) and *Computer trials* (rejected items in *Computer trials* [$t(20) = -7.023, p < 0.001$] and selected items in *Computer trials* [$t(20) = -5.987, p < 0.001$], respectively) and against selected items in *Post-ex choice* trials [$t(20) = -8.278, p < 0.001$]. No significant difference was observed for postdecisional preference change of chosen items.

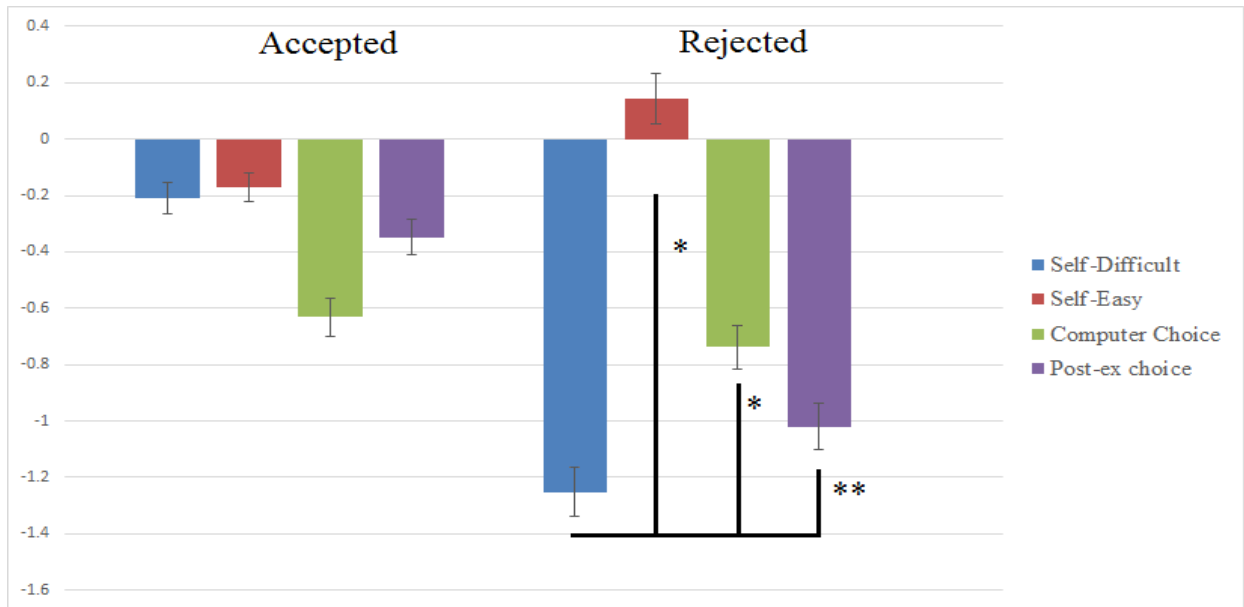


Figure 3. Behavioral result for post-decisional preference change. Bars indicate the change in preference for foods from Preference Task I to Preference task II (preference ratings in Preference task II minus those in Preference task I) . Solid lines bars indicate the statistically significant postdecisional preference change between Preference task I and Preference Task II. * $p < 0.001$; ** $p < 0.05$. Error bars indicate the standard error of the mean.

ERP correlates of Cognitive Dissonance

Figure 4A shows the grand average ERPs at channel FCz and topographical maps of a voltage distribution for ERPs to *Self-difficult* and *Self-easy* choices. A t-test ($ERP_{Self-Difficult}$ vs $ERP_{Self-Easy}$, FCz) led to a significant effect of the factor *CD*: $t(20) = -2.131$, $p = 0.046$, $d = 0.465$. The *Self-difficult* choices were associated with a significantly more negative fronto-central deflection at a latency of 46 ms than *Self-easy* choices.

The analysis of ERP's peak latency, showed no significant difference between *Self-difficult* ERN and *Self-easy* trials ($p = 0.78$).

ERN responses in Eriksen Flanker task

Fig. 4B shows the grand average ERP data at channel FCz and topographical map of a voltage distribution. Approximately 60 ms after the button press, error responses were followed by a larger ERN negativity than ERN to correct responses. A paired t-test (Error response / Correct

response, FCz) showed a significant difference $t(20) = -5.570$, $P = 0.001$, $d = 1.2$. Importantly, fronto-central distribution of FRN (Fig. 4B) was similar to the fronto-central distribution of the ERP in CD paradigm (Fig. 4A).

Behavioral and Electrophysiological correlation

To examine the relation between the magnitude of the ERP correlates of CD and following postdecisional preference changes, we investigated the relationship of individual difference-waves magnitudes (subtracting ERPs in *Self-difficult* trials ERN from ERPs in *Self-easy* trials) and individual preference changes for accepted and rejected items (separately for individual preference following *Self-difficult* and *Self-Easy* trials). The correlation analysis showed a moderate positive correlation between difference-waves' magnitude at FCz electrode and post-decisional preference change for rejected items in *Self-difficult* trials ($r = +0.416$, $p = 0.03$), and a weak positive correlation for selected items in the same condition ($r = +0.380$, $P = 0.45$). No other correlations were significant.

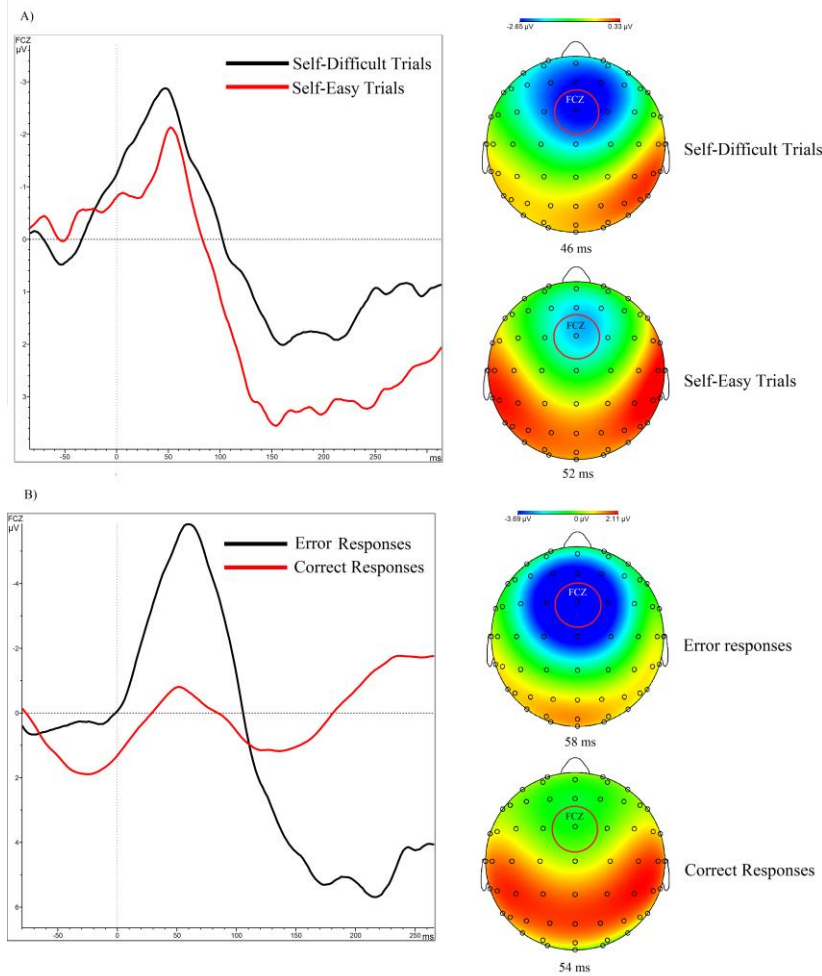


Figure 4. A) Grand-averaged ERP associated with CD recorded during Free-choice paradigm. A topographical map of a voltage distribution for *Self-difficult* and *Self-easy* trials. FCz electrode is indicated by the red circle. B) Grand-averaged ERN records during Flanker task at FCz. Topographical map of a voltage distribution of ERP after Errors and Correct responses. FCz site is in red circle.

Discussion

Similar to the previous studies (Brehm, 1956; K. Izuma et al., 2010; Kitayama, Snibbe, Markus, & Suzuki, 2004; Mengarelli, Spoglianti, Avenanti, & di Pellegrino, 2015) our behavioral results demonstrated that our decisions induce preference changes: individuals were more likely to downgrade their preference for rejected items to align their preferences with own choices.

Previous neuroimaging study (K. Izuma et al., 2010) has shown the neural signature of choice-induced preference change during the re-rating of options – the paradigm which was also utilized in our study. The activity of the pMFC reflected the degree of CD and predicted the strength of choice-induced preference changes. Although CD had been traditionally investigated using free choice paradigm (Brehm, 1956; Eddie Harmon-Jones & Harmon-Jones, 2007), little is known about the cognitive and neural processes occurring during decisional stage and their role in the follow-up postdecisional changes of preferences. To the best of our knowledge, the present study is the first that directly, investigated neural correlate of CD during the decisional process. Our ERP data suggests that choices associated with CD trigger a frontocentral negative ERN-like deflection with the maximum at 60 ms (after the choice) that had often been implicated in performance monitoring and signaling of negative reward prediction error (Miltner et al., 1997; Gehring and Willoughby, 2002; Holroyd et al., 2002; Nieuwenhuis et al., 2004; Nieuwenhuis et al., 2007). Furthermore, ERN's amplitude predicted individual differences in postdecisional change of preferences: larger ERN-like potential was associated with larger changes of preferences.

In the control condition we recorded ERN during the Flanker task (Gehring, Liu, Orr, & Carp, 2011; Holroyd & Coles, 2002; Falkenstein, Hohnsbein, & Hoormann, 1995), in order to test spatial and temporal similarity of the ERN-like potential generated during free-choice paradigm with standard ERN. Our results show a strong similarity of spatial and temporal characteristics of both evoked responses. A difference in the amplitudes of the Eriksen Flanker task and ERN-like potential in the Free-choice paradigm can be due a difference in the tasks. The former task could be simpler to perform than the free-choice paradigm: stimuli are presented faster and reaction time is shorter. An ERN-like potential in free-choice paradigm could reflect a more complex and slower processes associated with relatively complex decisions. Previous studies demonstrated that ERN indeed is susceptible to changes in error salience or attention (Endrass et al., 2010, Hajcak et al., 2005 and Riesel et al., 2012).

Recent neuroimaging studies provided insights into neural mechanism of postdecisional preference changes. For example, Izuma and colleagues (2010) investigated neural correlates of CD and found a significant correlation between the activity of the pMFC (cingulate cortex) during the second rating with the degree of CD. The recent transcranial magnetic stimulation

study demonstrated a causal role of pMFC in post decisional preference changes (Izuma et al., 2015). Down-regulation of the right pMFC induced a reduction of spread of alternatives effect. Importantly, our ERP study suggests that an earlier neural processes might be involved in CD that contribute to the subsequent preference changes for rejected items. Our results suggest that during the choices associated with CD the pMFC generates a neural error-signal reflecting a necessity for behavioural adjustments similar to ERN. Thus, our results can indicate that CD is associated with a general performance-monitoring mechanism of behavioural adjustment (Holroyd and Coles, 2002; Ridderinkhof et al., 2004; Matsumoto et al., 2007).

Taken together, our data extend the knowledge of neural mechanisms of CD suggesting a role of a general performance-monitoring mechanism in postdecisional adjustments of preferences. Overall, our results support the hypothesis suggesting that choice-induced preference change is underlined by a motivational process of conflict resolution and further support an important role of the pMFC in behavioral adjustments.

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