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Reviews

NEURAL MECHANISMS OF POST-DECISIONAL SPREADING OF ALTERNATIVES

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Abstract

Human choices are not only driven by inner preferences, but also have an impact on behavior. Economists and psychologists have extensively demonstrated that choosing between two attractive options leads to a downgrade of the rejected option and to an upgrade of the chosen one. Preference modulation after the mere act of making a choice has been repeatedly demonstrated over the last 50 years by an experimental paradigm called the 'free-choice paradigm'. In the past decade the phenomenon of choice-induced preference change generated by cognitive dissonance has been explored by neuroscientists. An increasing amount of research has highlighted the central role of the posterior medial frontal cortex (pMFC) in social conformity and cognitive dissonance. This area represents the dissonance between one's currently inconsistent and ideally consistent states. However, other brain areas have been linked to cognitive dissonance and its resolution, but as yet the mechanisms underpinning cognitive dissonance and the functional connection among brain areas found involved in cognitive dissonance are still unknown. Here, we firstly review the neural mechanisms and brain areas involved in post-decisional preference change and cognitive dissonance. Secondly, we suggest an integration of the existing neurocognitive mechanism of cognitive dissonance. Finally, we suggest new research lines to further explore neural principles of cognitive dissonance and subsequent post-decisional preference change.

Keywords: cognitive dissonance, preference change, decision making, medial prefrontal cortex, nucleus accumbens, dorsolateral prefrontal cortex.

Introduction

Every day, people make numerous decisions that include different degrees of complexity. Classical economics decision theory assumed that when people select

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between equally attractive options, the decision-making process reflects individual inner preferences (i.e., hedonic utility). However, many psychological studies have challenged hedonic utilitarianism and demonstrated that human choices are more than a consequence of inner preferences (see Harmon-Jones & Harmon-Jones, 2008, for review); individual preferences are influenced by various endogenous and exogenous factors, including cognitive consistency. A set of theories in social and cognitive psychology (see Hinojosa, Gardner, Walker, Cogliser, & Gullifor, 2016, for a review) argues that people adjust their preferences and values to make them cognitively consistent with an already existing set of cognitions, values, and preferences. Among these theories, the most prominent is the cognitive dissonance theory (CDT) (Festinger, 1957), which states that individuals experience a feeling of discomfort when they hold two or more contradictory cognitions. This negative feeling motivates people to either avoid or at least reduce their discomfort by changing one of the contradictory cognitions, including preferences, to minimize any discrepancies between them. Importantly, per CDT, conflictual decisions trigger cognitive dissonance and subsequently preference changes. In this review, we focus on the neurobiological mechanisms of preference changes that are induced by cognitive dissonance.

Many studies have documented consequences of cognitive dissonance, or "post-decisional preference change," which refers to reevaluating options after either selecting or rejecting one option due to a conflict (Brehm, 1956). Psychologists and neuroscientists have extensively used either the original or the modified version of Brehm's (1956) "free-choice paradigm" to induce cognitive dissonance and measure the magnitude of a post-decisional preference change.

In the original version of the free-choice paradigm, participants 1) rate a set of items (rating I) and then 2) choose between two equally liked alternatives (choice task) before 3) rating the same set of items again (rating II). During the choice task (decisional stage), participants are forced to select only one item of the pair, which causes conflictual decisions. By subtracting the mean second rating (rating II) from the mean initial rating (rating I), it is possible to measure the choice-induced preference change. Because Brehm's (1956) free-choice paradigm studies have repeatedly demonstrated that the mere act of choosing between two equally attractive alternatives induces preference change, preferences for the chosen items increases, while preferences for the rejected items decreases (Brehm, 1956; Colosio, Shestakova, Nikulin, Blagovechtchenski, & Klucharev, 2017; Festinger, 1957; Gerard & White, 1983; Izuma et al., 2010). Thus, contrary to normative economic theory, individuals not only behave in accordance with their preferences but also change their preferences to match their previous choices and behavior.

The Neuronal Mechanism of Cognitive Dissonance

Posterior medial cortices. A growing body of evidence (see Izuma, 2013, for review) has suggested that frontal cortices play a critical role in both detecting dissonance and the reevaluation of options. The key brain region that is involved in cognitive dissonance is the posterior medial frontal cortex (pMFC). This is a medial area that is formed by the supplementary motor area (SMA), the pre-SMA, the dorsal medial frontal cortex, and the dorsal anterior cingulate cortex (ibid.). The pMFC is known to be involved in conflict-induced tasks, such as the Stroop task (Botvinick et al., 2001) and the flanker task. It also reflects performance monitoring and error detection mechanisms (Carter et al., 1998; Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003). The signal generated by the pMFC is often measured using electroencephalography (EEG) as a negative deflection in the event-related potential, which is called error-related negativity (ERN). It is a frontocentral evoked response that appears between 60 and 120ms after an error response (Bellebaum & Colosio, 2014; Debener, 2005; Holroyd et al., 2003; Holroyd & Coles, 2002).

The action-based model of cognitive dissonance proposes that cognitive dissonance could interfere with effective actions; thus, post-decisional reevaluation of options facilitates the execution of effective actions (Harmon-Jones & Harmon-Jones, 2008). This theory suggests that the activity of the pMFC underlies cognitive conflict recognition and contributes to the reduction of cognitive dissonance (Amodio et al., 2004; Carter et al., 1998; Izuma et al., 2010). Pioneering functional magnetic resonance imaging (fMRI) studies have employed different paradigms (Izuma et al., 2010; Jarcho, Berkman, & Lieberman, 2011; Kitayama, Chua, Tompson, & Han, 2013; van Veen, Krug, Schooler, & Carter, 2009) and revealed a strong activation of the pMFC in tasks that are related to cognitive dissonance. Importantly, the magnitude of activity of the pMFC is correlated with the magnitude of the post-decisional preference change following any decisions that are associated with a high degree of cognitive dissonance (Izuma et al., 2010).

Brain stimulation studies have demonstrated the causal role of the pMFC in both the generation and subsequent reduction of cognitive dissonance. Izuma and colleagues (2015) found a significant reduction of choice-induced preference changes following the downregulation of the pMFC using transcranial magnetic stimulation (TMS). No significant behavioral modulation was observed after either sham stimulation over the pMFC region or the downregulation by TMS of the control brain regions (the parietal posterior cortex). Thus, the authors demonstrated the causal relation between the activity of the pMFC and the post-decisional preference change for the first time. Notably, Izuma and colleagues (2015) down-regulated the pMFC right after the choice task and just before the rating II task.

Many neuroimaging studies (Izuma et al., 2010; Qin et al., 2011; Sharot, De Martino, & Dolan, 2009) have employed the free-choice paradigm by focusing on neural activity during the rating II task. Such an approach implies that preference changes take place during the rating II task when participants reduce cognitive dissonance by reevaluation of the option. However, it is also possible that post-decisional spreading of alternatives already happens either during or right after the choice task to reduce negative emotions during choices.

In a recent EEG study, Colosio and colleagues (2017) disentangled the neural signatures of cognitive dissonance during the choice task. The authors observed stronger ERN at the pMFC during difficult (high degree of cognitive dissonance) decisions as compared to easy (low degree of cognitive dissonance) decisions. Furthermore, the magnitude of the ERN was significantly correlated with the subsequent behavioral preference change. Stronger conflict-related pMFC activity (e.g., larger ERN) was followed by stronger preference changes for rejected items. The resting-state of the frontocentral cortices predicted the magnitude of the ERN and the subsequent preference change: long-range temporal correlations (LRTC) of alpha oscillations correlated with the magnitude of the ERN and the spread of alternatives. LRTC is a relatively new approach to electrophysiological data that helps determine the intrinsic functional state of a targeted cortical region. Thus, this EEG study demonstrated that individual differences in cognitive dissonance are reflected during both the resting state and choice-related activities of the pMFC throughout the early stages of the free-choice paradigm.

Dorsal lateral prefrontal cortex. In addition to the pMFC, the left dorsolateral prefrontal cortex (dlPFC) has also been regularly associated with cognitive control and conflict resolution (Botvinick et al., 2001; Botvinick, Cohen, & Carter, 2004; Miller & Cohen, 2001).

Both fMRI and EEG studies have linked the activity of the left dlPFC with post-decisional preference change, which indicates the important role of the left dlPFC in cognitive dissonance resolution (Harmon-Jones, Gerdjikov, & Harmon-Jones, 2008; Qin et al., 2011). A recent study by Managrelli et al. (2015) found that post-decisional preference changes were significantly reduced after cathodal transcranial direct current stimulation over the left (but not the right) dlPFC, which showed the causal role of the left dlPFC in cognitive dissonance. Other studies have suggested that dlPFC activity does not reduce cognitive inconsistency; rather, it contributes to more general cognitive control mechanisms (Izuma et al., 2015) and performance adjustment (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). Thus, the role of the left dlPFC is still under debate and requires further study. It would be particularly interesting to study the relationship of the pMFC and the left dlPFC during choice-induced adjustments of preferences.

Nucleus accumbens and the posterior cingulate cortex. Recent studies have also demonstrated activation of nucleus accumbens (NAcc) during the making of difficult choices (Izuma et al., 2010; Kitayama et al., 2013). NAcc play a key role in action selection by integrating cognitive and affective information that is processed by the frontal and temporal cortices (Floresco, 2015). NAcc are involved in reward expectation (Knutson, Delgado, & Phillips, 2009) and the monitoring of subjective values (Bartra, McGuire, & Kable, 2013). Izuma and colleagues (2010) also found that changes in activity of NAcc for rejected items were significantly lower than for selected ones. Similarly, Kitayama and colleagues (2013) found a significant, positive correlation between increased preference for chosen items and the NAcc. However, it remains unclear at which stage of the free-choice paradigm that NAcc become involved in post-decisional preference changes.

The posterior cingulate cortex (PCC) has been associated with an extensive number of cognitive functions, including conscious awareness and cognitive control (Leech, Kamourieh, Beckmann, & Sharp, 2011), emotional memory encoding (Maddock, Garrett, & Buonocore, 2001), memory retrieval and planning (Vann, Aggleton, & Maguire, 2009), maintaining changes in the external environment

(Pearson, Heilbronner, Barack, Hayden, & Platt, 2011), and controlling the balance between external and internal attention (Leech & Sharp, 2014). Previous fMRI studies have observed stronger activity of the PCC either during difficult choices (Kitayama et al., 2013; Qin et al., 2011; Tompson, Chua, & Kitayama, 2016) or after difficult choices (Izuma et al., 2010) as compared to easy choices. Another study showed that PCC activity is positively correlated with the perceived desirability of objects (Kawabata & Zeki, 2008). All these results suggest that the PCC might play a central role in preference adjustments during the spreading of alternatives. Thus, further studies are needed to understand the roles of NAcc and the PCC in cognitive dissonance.

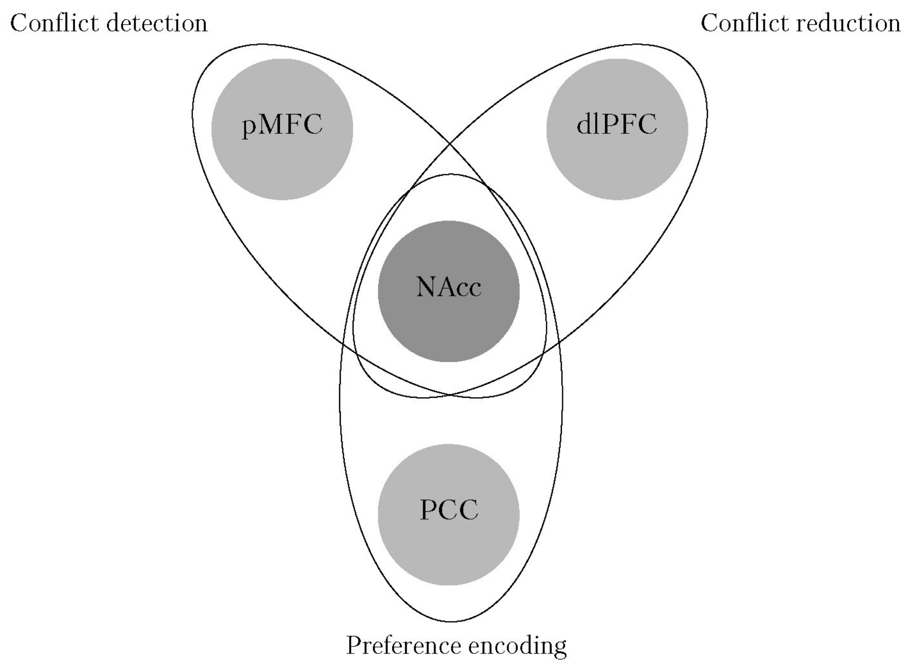
Conclusions

Overall, evidence from cognitive and social neuroscience has suggested that the activities of the pMFC, dlPFC, NAcc, and PCC underlie post-decisional preference changes that are induced by cognitive dissonance. However, previous studies have not suggested a univocal neurocognitive mechanism (model) of cognitive dissonance.

Many neuroimaging studies have suggested that NAcc create an anatomical hub that connects the PFC, dlPFC, and PCC (Di Martino et al., 2008). Figure 1 illustrates a hypothetical neurocognitive mechanism of post-decisional preference

Figure 1

A hypothetical neurocognitive mechanism of post-decisional preference changes



changes that were evoked by cognitive dissonance. Here, (a) the pMFC detects internal conflicts during difficult choices; (b) the dlPFC implements cognitive control to change preferences and reduce cognitive dissonance; (c) the NAcc code preferences and emit a learning signal, which are important for preferences changes and choice justification; (d) the PCC encodes long-lasting changes of preferences. Further studies should combine different neuroimaging methods to develop and clarify the proposed model of post-decisional preference changes.

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Нейромеханизмы изменения преференции после принятия решений

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Резюме

Процесс выбора не только основывается на личных предпочтениях, но также влияет на дальнейшее поведение человека. Экономисты и психологи приводят множество доказательств того, что после выбора между двумя одинаково привлекательными альтернативами происходит уменьшение ценности отвергнутой альтернативы по сравнению с той, которой было отдано предпочтение, т.е. наблюдается «расхождение альтернатив» как результат переживания когнитивного диссонанса. В экспериментальных исследованиях принятия решений подобные изменения предпочтений изучаются с помощью парадигмы «свободного выбора». В последнее время феномен изменения предпочтений вследствие выбора, вызванного когнитивным диссонансом, оказался в фокусе специалистов в области когнитивных нейронаук. В результате появились убедительные доказательства вовлечения задней медиальной области лобной коры (зМЛК) в процесс изменения мнения в результате переживания внутренних конфликтов. Как показали психофизиологические исследования, в частности методами функциональной магниторезонансной томографии, столкновение конфликтующих представлений отражается в изменение активности зМЛК. Вместе с тем экспериментальные данные указывают на связь зМЛК с другими областями мозга, включая дорзальные области лобной коры. По мнению авторов, мозговые механизмы, лежащие в основе когнитивного диссонанса, изучены недостаточно полно. В данной статье приведен обзор новейших представлений о нейрокогнитивных механизмах когнитивного диссонанса, а также результатов функционального нейрокартирования взаимодействия различных областей мозга, принимающих участие в процессах изменения предпочтений в результате выбора. В заключение представлены новые методы исследований функционального картирования (к примеру, транскраниальная магнитная/электрическая стимуляция), позволяющие существенно углубить представления о механизмах изменения предпочтений в результате выбора.

Ключевые слова: когнитивный диссонанс, изменение предпочтений, принятие решений, медиальная префронтальная кора, прилежащее ядро, дорсолатеральная префронтальная кора.

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