



## Recent Developments in Neuroscience Research

### Human Motivation

"Your Choice" Motivates You in the Brain: The Emergence of Autonomy Neuroscience  
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# “YOUR CHOICE” MOTIVATES YOU IN THE BRAIN: THE EMERGENCE OF AUTONOMY NEUROSCIENCE

Kou Murayama, Keise Izuma, Ryuta Aoki and  
Kenji Matsumoto

## ABSTRACT

*Studies in psychology have long revealed that making personal choice involves multiple motivational consequences. It has only been recent, however, that the literature on neuroscience started to examine the neural underpinnings of personal choice and motivation. This chapter reviews this sparse, but emergent, body of neuroscientific literature to address possible neural correlates underlying personal choice. By conducting the review, we encourage future systematic research programs that address this topic under the new realm of “autonomy neuroscience.” The chapter especially focused on the following motivational aspects: (i) personal choice is rewarding, (ii) personal choice shapes preference, (iii) personal choice changes the perception of outcomes, and (iv) personal choice facilitates motivation and performance. The reviewed work highlighted different aspects of personal choice, but indicated some overlapping brain areas – the striatum and the ventromedial prefrontal*

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*cortex (vmPFC) – which may play a critical role in motivational processes elicited by personal choice.*

**Keywords:** Self-determination; reward network; social neuroscience; intrinsic motivation

In our daily life, we make numerous personal choices. These include choices between specific behaviors (e.g., “Should I fight or run away?”) as well as choices between higher level goals (e.g., “Should I go to a graduate school or get a job at a company?”). We also encounter various situations where we are not allowed to make a personal choice and are forced to engage in a specific option for various reasons (e.g., “I have to work for the development of this software, because this is the current priority of our company”). Do you think you would have different reactions when you can make your own choice as opposed to when you are forced to take a specific option? The answer is likely to be yes (we believe). In fact, as reviewed later, there have been numerous empirical studies supporting the idea that personal choice and forced-choice would have different impacts on motivation and performance (for a review, see [Patall, 2012](#)).

Importantly, despite the voluminous research on choice and motivation in the literature of psychology, the role of personal choice in motivation has attracted much less attention in neuroscience ([Leotti, Iyengar, & Ochsner, 2010](#)). This is partly due to the fact that neuroscientific theories of motivation often base their models on the standard reinforcement learning model ([Sutton & Barto, 1998](#)), which is an extended version of the traditional models of behaviorism. According to the standard view of behaviorism, people’s motivated behavior is solely determined by the contingency between the action they take and the delivery/absence of rewards. That is, this traditional view is basically indifferent to whether the choice of action was made out of one’s own will (i.e., personal choice) or determined by others (i.e., forced-choice). Therefore, from a perspective of behaviorism and reinforcement learning model, it is not as obvious as we suppose that personal choice and forced-choice would elicit different psychological process in human behavior. Indeed, it has only been recently that researchers proposed a reinforcement learning model that formally incorporated how personal choice (as opposed to forced-choice) can bias the decision-making process ([Cockburn, Collins, & Frank, 2014](#)). To be clear, there is a vast amount of neuroscientific research that has addressed the factors that guide

people's choice or decision making. Also, reinforcement learning models are often considered as autonomous models, in that the model formulates how agents can learn optimal decision making in dynamic environments with trial and errors, without assuming any a priori knowledge. Some forms of reinforcement learning are indeed remarkably powerful to actively learn optimal choices in very complicated environments (especially, the so-called model-based learning; Daw, Gershman, Seymour, Dayan, & Dolan, 2011; O'Doherty, 2012; Sutton & Barto, 1998; see also Tolman, 1948). Nevertheless, these models do not consider that agents have the natural inclination to give special privileges and preferences to personal choice over forced-choice. Thus, in neuroscience, the idea that "your choice" would make a difference is still a new topic which has much room for future research.

The purpose of this chapter is to provide an overview of the sparse, but emergent neuroscientific literature on the neural correlates underlying the psychological effects of personal choice. The research we will cover has been studied rather independently, and these studies have rarely been brought together under the topic of personal choice and motivation (for an exception, see Leotti, Cho, & Delgado, 2015). Given the limited number of the relevant research, we do not provide an integrative view about the neural mechanisms underlying personal choice – time is not ripe yet. By putting together different lines of neuroscientific research related to personal choice, however, we are hoping to highlight the coherence and the importance of the topic in a broader sense, calling for future systematic research programs on this topic.

## PERSONAL CHOICE IS REWARDING

Making a personal choice involves cognitive effort. To decide between options, people have to carefully consider both the positive and negative potential consequences of the options and determine how to weigh these qualitatively different aspects. This is a demanding task. In fact, Vohs et al. (2008) showed that making a series of choices between consumer products or university courses produces the depletion of self-regulatory resources, impairing the performance of the subsequent self-regulation behavior (e.g., drinking a bad-tasting drink). Also, generally speaking, people do not like demanding tasks or exerting mental effort, and people do indeed avoid or devalue effortful tasks (Botvinick, Huffstetler, & Mcguire, 2009; Kool,

McGuire, Rosen, & Botvinick, 2010). Choice is demanding and people do not like demanding tasks. A logical consequence of these two propositions is, of course, that people should hate making personal choices. However, the reality is opposite – people *love* personal choices. People seek opportunities to decide on their own will, and people would become much happier if they had an opportunity to make their own mind. We are natural-born choice seekers.

Some may argue that people like choices because the freedom to choose can potentially increase the likelihood to obtain better outcomes. This can explain part of the reason why people like personal choice. But the literature in psychology has found that people prefer, or value, the freedom to choose even if the choice outcome is irrelevant with their choices or if choice outcomes are inconsequential (see also Bartling, Fehr, & Herz, 2014 on this topic in the literature of economics). For example, in Suzuki's (2000) study, participants were asked to select a two-choice task or single response task. In the two-choice task, participants can select one of the two cards, whereas in the single response task, participants have to select the card presented on the screen. Participants can receive points based on what they found on the card they eventually selected. They found that participants preferred to select the two-choice task even if they knew their expected amount of points had nothing to do with their choice (see also Suzuki, 1997). Bown, Read, and Summers (2003), in their paper titled "*the lure of choice*," showed that participants are more likely to select an item when the item was initially part of a choice than when it was presented on its own. Perdue, Evans, Washburn, Rumbaugh, and Beran (2014) revealed that even capuchin monkeys prefer the option that allows them to select the order of task completion in comparison to the option that provides a pre-determined task order.

Given these findings, it is straightforward to hypothesize that choice has some inherent rewarding value. Previous neuroimaging studies revealed the brain network that supports people's preference, or value (Kable & Glimcher, 2009; Knutson & Cooper, 2005; for a meta-analysis, see Bartra, McGuire, & Kable, 2013). These brain areas are typically called the "reward network," and are deemed to play a pivotal role in representing and updating various types of subjective valuation. The reward network includes the ventral tegmental area (VTA), the striatum (e.g., nucleus accumbens, caudate), and the ventromedial prefrontal cortex (vmPFC).

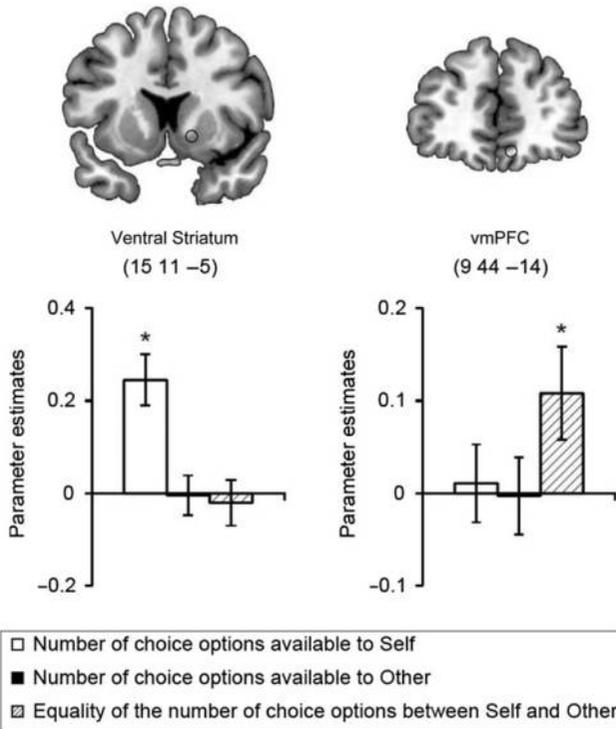
The hypothesis that choice entails reward value can be directly tested by using neuroimaging. In the experiment conducted by Leotti and Delgado (2011), participants were presented with a symbolic cue that informs whether they can make a choice or not in the upcoming trial. In the choice trials, participants could freely choose one of the keys. In the no-choice

trial, participants were forced to accept a computer-selected key. When participants pressed a key, they received feedback regarding the amount of monetary reward they obtained. Critically, all the keys had the same expected reward value – therefore, the choice was actually irrelevant to the actual consequences, and in fact all participants earned approximately the same amount of monetary rewards. Nevertheless, like the previous behavioral studies (e.g., Suzuki, 2000), participants indicated preference for the cue that predicts choice trials. More importantly, their analysis using functional magnetic resonance imaging (fMRI) showed the increased activations of the bilateral ventral striatum and the midbrain in response to choice cues (as compared to forced-choice cues), indicating that the cue signaling upcoming choice had rewarding characteristics. This finding was replicated by other fMRI studies (Leotti & Delgado, 2014; Murayama et al., 2015).

Fujiwara et al. (2013) examined the rewarding nature of choice from a different angle. They put participants in a situation where participants have to select between (1) an option that would give participants a specific amount of money (e.g., 30 Japanese Yen) and (2) an option that would give participants a certain number of choice options out of which they could pick up one, everyday consumer product. This experimental paradigm allowed the researcher to gauge the value of choice as a function of the number of choice alternatives. The results showed that participants value having more choice alternatives (interestingly, some participants also exhibited preference for choice from a larger number of low-value items than a forced-choice of single high-value item), and the number of choice alternatives is positively related to the striatal activation in the brain, indicating that the rewarding property of choice increases as the number of choice alternative increases. These results suggest that people value not only the choice itself, but also the number of potential choice options.

Further elaborating the effects of the number of choice options on the activation of the reward network in the brain, recent fMRI work by Aoki et al. (2014) showed that the effects of the number of choice alternatives is also influenced by social context. In this study, participants performed a two-person choice task in which the number of choices (one, two, or four) available to a participant and a confederate was individually manipulated for each trial. Participants could earn monetary rewards by choosing a correct option, which was revealed after the choice of the participants. Importantly, they were explicitly told that the number of their available options was nothing to do with the probability of winning the outcome, and that the win or loss of the other player (i.e., confederate) was independently determined. That is, the other player's outcomes, under no

circumstances, could influence the participants' probability of winning. Despite the fact that the number of choice options was irrelevant to the probability of winning, they observed an increased activation in the ventral striatum as the number of choice options available to participants increased. In addition, they also found that the equality of choice options between the participant and the other player (i.e., social equality in choice opportunity) activated another critical area of the reward network – the vmPFC (Fig. 1). These results demonstrated that choice



*Fig. 1.* Differential Effects of the Number of Choice Options Available to Participants and the Equality of Choice Options on the Ventral Striatum and the vmPFC as Reported by Aoki et al. (2014). *Notes:* The ventral striatum was significantly activated by the number of choice options available to participants, whereas the equality of choice options influenced the activation in the vmPFC. The equality of choice options was defined on the basis of the difference in the number of options between self and other (i.e., smaller difference indicates greater equality).

opportunities are processed in the ventral striatum and the vmPFC in different ways – whereas the striatum represents the absolute number of choice opportunities, the vmPFC, a key brain region previously implicated in the processing of social values (e.g., Heekeren, Wartenburger, Schmidt, Schwintowski, & Villringer, 2003; for a review, see Rilling & Sanfey, 2011), represents the valuation of equality in choice opportunity between individuals.

## PERSONAL CHOICE SHAPES PREFERENCE

Choice is guided by preference. You choose to order a coffee but not a tea if you have personal preference to drink coffee over tea. No one would disagree with this presumption (i.e., “I choose it because I like it”). But what is more controversial is the idea that our personal choice can also change preference (i.e., “I like it because I chose it”). That is, once you make your personal choice to drink a coffee, you may increase your preference for coffee and decrease your preference for tea. The idea of this “choice-induced preference change” was first demonstrated by Brehm (1956), and it spawned a number of follow-up research investigations (for a meta-analysis, see Kenworthy, Miller, Collins, Read, & Earleywine, 2011).

Choice-induced preference change is typically tested through the “free-choice paradigm.” In this paradigm, participants are first asked to rate (or rank) several items (e.g., music albums, posters, foods, political candidates, jobs, etc.) according to their preference (first rating task). Second, they are asked to choose between two of the items that had similar preference ratings in the first rating task (choice task). Finally, they are asked to rate their preference for the same items one more time (second rating task). Studies found that after making a difficult choice between two equally preferred items, participants’ preference for the chosen item increases while preference for the rejected item decreases (e.g., Gerard & White, 1983; Heine & Lehman, 1997; Steele, Spencer, & Lynch, 1993). This process of choice-induced preference change is traditionally explained by cognitive dissonance theory (Festinger, 1957). When there is an inconsistency between preference and behavior (i.e., choosing something I don’t like), it causes an uncomfortable feeling called “cognitive dissonance,” which in turn motivates a person to modulate their preference in order to restore the consistency.

Several neuroimaging studies have been conducted to examine the neural mechanisms underlying choice-induced preference change (Izuma et al., 2010; Jarcho, Berkman, & Lieberman, 2011; Kitayama, Chua, Tompson, & Han, 2013; Qin et al., 2011; Sharot, De Martino, & Dolan, 2009). Specifically, these studies sought to address the following two main questions. First, by examining the brain areas associated with the changed preference, researchers tested whether choices could alter the neural representation of preference, or whether choice-induced preference change is just a superficial phenomenon seen only in the self-report (e.g., demand characteristic bias). In most of the past behavioral studies, participants' preference was assessed by self-reported questions, meaning it is possible that participants actually faked their preference which in turn could mean that the observed choice-induced preference change did not reflect the change of true preference. Neuroimaging methodology has the potential to overcome this essential (but quite common) limitation of behavioral experiments in psychology, because as indicated earlier, previous studies have revealed the brain network that supports people's preference, or value (see Bartia et al., 2013), making it possible to validate the results based on self-report questions.

Sharot et al. (2009)'s study is the first that examined the neural correlates of the preference change induced by personal choice with fMRI. Using a standard free-choice paradigm, Sharot and colleagues presented participants with many different pairs of destination names for a vacation (e.g., Thailand), and asked them to choose one of the two options based on where they would rather take a vacation. Consistent with choice-induced preference change, participants' preference changed in line with their choice – in the second rating task, destinations they chose showed increased preference, whereas destinations they rejected showed decreased preference in comparison to the first rating task. Importantly, they also observed that post-choice changes in preference were correlated with the caudate nucleus activity (within the striatum), indicating that choice-induced preference can be observed even in the neural representation of preference (see also Qin et al., 2011).

Another important question that neuroimaging studies sought to address is the psychological mechanisms underlying the choice-induced preference change. Cognitive dissonance theory (Festinger, 1957) indicates the resolution of cognitive dissonance as the key psychological mechanism. Reviewing the past literature in social neuroscience, Izuma (2013) argued that the posterior medial frontal cortex (pmFC; this area consists of the dorsal anterior cingulate cortex, dACC, the dorsomedial prefrontal cortex,

and the supplementary motor area; Izuma, 2013) plays a critical role in processing cognitive inconsistency (the discrepancy between one's own belief and external input; see also Harmon-Jones, 2004). In fact, Van Veen, Krug, Schooler, and Carter (2009) adapted the induced compliance paradigm (another popular paradigm to induce cognitive dissonance) to the fMRI scanner and found that the pMFC is involved in cognitive dissonance (see also Izuma & Adolphs, 2013). As such, the activation of the pMFC in the free-choice paradigm could provide some compelling evidence for the dissonance resolution as the mechanisms of choice-induced preference change. Consistent with this prediction, fMRI studies (e.g., Kitayama et al., 2013) found the involvement of several brain regions including the pMFC when participants made a difficult choice (i.e., the choice that would induce the highest cognitive dissonance). Although we need to be cautious when inferring cognitive processes that are solely based on the neuroimaging data (the issue called "reverse inference"; Poldrack, 2006), these findings suggest a critical role for cognitive dissonance reduction in choice-induced preference change.

One important reservation for the findings discussed so far is that all of these studies have used the traditional free-choice paradigm. A recent paper by Chen and Risen (2010) pointed out an important methodological problem in this traditional paradigm, arguing that all findings from the studies using the free-choice paradigm are inconclusive (for more accessible summary, see Izuma & Murayama, 2013; Risen & Chen, 2010). In short, the critical point is that, even if participants gave similar ratings to two items in the first rating task, the fact that a participant chose a particular item in the choice task indicates that the participant actually preferred that item over the other from the outset. Thus, the higher preference ratings in the second rating task do not necessarily mean that the act of making a choice changed the true preference – the higher preference ratings in the second rating task may simply reflect the pre-existing preference. Izuma and Murayama (2013) conducted a series of statistical simulations to demonstrate the validity of the argument.

This critical methodological issue was addressed by an fMRI study reported in Izuma et al. (2010). In this chapter, the authors added a control condition where participants made a choice *after* the second rating task (see also Chen & Risen, 2010). Because the second rating was made before the choice task, rating change from the first rating task to the second rating task can be solely attributed to participants' pre-existing preferences. Thus, the presence of choice-induced preference change can be tested by comparing this control condition (called "Rate-Rate-Choose" condition)

with the traditional experimental condition explained earlier (called “Rate-Choose-Rate” condition). Importantly, with this new control condition, Izuma et al. still found that (1) making a choice does indeed change self-report preference as well as its neural representation (i.e., striatum activity) and (2) the pMFC tracked the degree of cognitive dissonance (Fig. 2). These results provide a nice replication of the previous findings with a rigorous methodology, confirming the critical importance of the reward network and the pMFC in choice-induced preference change.

One of the limitations of these fMRI studies is that their findings are essentially correlational (i.e., the degree of cognitive dissonance is correlated with the degree of activation in the pMFC). Therefore, these results cannot exclude the possibility that the pMFC activity merely reflects an epiphenomenon of cognitive dissonance such as passive emotional reactions to inconsistency, rather than playing an active causal role in inducing preference change to resolve inconsistency. To directly address this limitation, Izuma et al. (2015) conducted an experiment using transcranial magnetic stimulation (TMS). TMS is a tool for noninvasive stimulation of neuronal tissue in the brain, which, in combination with cognitive tasks, allows us to examine whether the stimulated brain area has causal influences on cognition or behavior. In this study, the researchers applied a 1-Hz 25-min repetitive TMS to pMFC in order to temporarily downregulate the neural activity within that area when participants performed the second rating

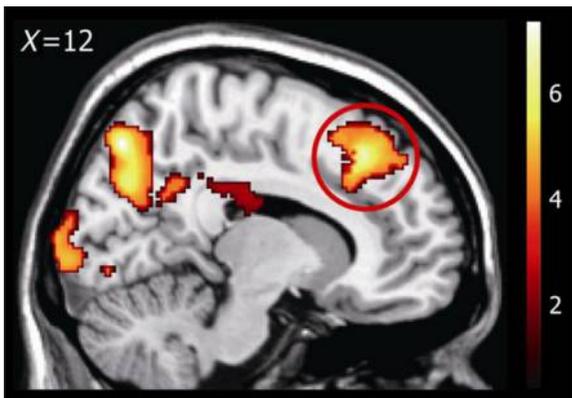


Fig. 2. An Area in the pMFC (dACC) Significantly Correlated with the Degree of Cognitive Dissonance as Reported by Izuma et al. (2010; see also Izuma et al., 2013).

task (i.e., when cognitive dissonance is produced). To address the methodological issue proffered by [Chen and Risen \(2010\)](#), they used a “choice-blindness” paradigm ([Hall, Johansson, & Strandberg, 2012](#); [Hall et al., 2013](#)), which allowed the researchers to randomly assign participants’ choices to preference congruent and preference incongruent conditions (i.e., they manipulated cognitive dissonance independently of the pre-existing preference). They observed choice-induced preference change in a sham stimulation condition and a control stimulation condition, but importantly, these preference changes were significantly reduced in the pMFC stimulation condition. These results indicate that the pMFC plays an active causal role in cognitive dissonance (see also [Mengarelli, Spoglianti, Avenanti, & Di Pellegrino, 2015](#), for another TMS study on choice-induced preference change).

## PERSONAL CHOICE CHANGES THE PERCEPTION OF OUTCOMES

Imagine that you achieved a project. When the project is something that you decided to work on out of your own will, you are likely to be happier than when the project was assigned by your boss. The objective value of success would not be different depending on whether you made a choice to do that or not, but the subjective value can be influenced by such a factor. This point is nicely illustrated in [Cockburn et al. \(2014\)](#)’s study. In this study, participants were presented with pairs of stimuli with specific expected reward values. For each trial, they selected one of the two stimuli and received or lost points. This task allows participants to learn the expected values of the stimuli over the trials. Importantly, for half of the trials (free-choice condition), participants freely selected stimuli, whereas for the other half of the trials, participants were not allowed to select a stimulus; instead, participants were forced to select a pre-determined stimulus (forced-choice condition). Unbeknownst to participants, these forced-choice trials were matched (yoked) to the trials in the free-choice condition, making it possible to directly compare the subjective value of the stimuli with and without the freedom to choose stimuli. The results showed that participants preferred the stimuli that they had freedom to choose, in comparison to the stimuli that they were forced to choose, even if these stimuli had identical rewarding history. These findings provide strong behavioral evidence that making a choice adds value to the outcome people receive.

A number of studies have demonstrated that making a personal choice changes the perception of outcomes in a variety of ways. For example, in [Rose, Geers, Rasinski, and Fowler \(2012\)](#), participants underwent a cold pressor task to induce pain and offered two pain-relieving treatments. Participants in the choice condition could choose one of the two treatments, whereas participants in the no-choice condition were given the treatment that the experimenter randomly determined. In fact, these two treatments were identical inert ointment mixtures and therefore choice should not have made any differences in pain perception. However, the results showed that participants in the choice condition reported significantly less pain than participants did in the no-choice condition, indicating that individuals choosing their treatment – even though it was a bogus treatment – could reduce the subjective feeling of pain compared to those who were forced to take a specific treatment ([Geers & Rose, 2011](#); [Salomons, Johnstone, Backonja, Shackman, & Davidson, 2007](#); see also [Salomons, Nusslock, Detloff, Johnstone, & Davidson, 2014](#)).

Although not directly testing the effect of choice, researchers also examined whether the control belief (i.e., the belief that one can control external environment) can reduce pain at the neural level. In one study ([Salomons, Johnstone, Backonja, & Davidson, 2004](#)), participants were presented with cues before painful, thermal heat. In the controllable condition, participants were instructed that they could reduce the hot stimulus to a non-painful duration by manipulating a joystick in some way, which participants needed to figure out with trial and errors. In the uncontrollable condition, participants were asked to respond as they did in the controllable condition but were instructed that their response would have no effect on the duration of the heat. Although participants were led to believe that the controllable condition could provide them with more control over the delivery of heat, participants actually received the same amount of painful thermal heat in both conditions. The fMRI results indicated that the areas of insular, secondary somatosensory, and ACC, which are commonly activated in response to peripheral nociceptive input, were also activated in response to the thermal stimulus in both conditions. Importantly, however, the activation of these areas was significantly reduced in the controllable condition than in the uncontrollable condition, suggesting that control belief can alleviate pain perception even at the neural level.

One of the most popular effects of personal choice on the subjective perception of outcome is the illusion of control. In the seminal work of [Langer \(1975\)](#), participants purchased a lottery ticket, and were either allowed to freely choose their ticket (choice group) or were assigned a ticket

(no-choice group). The objective chances of winning were 1 in 26 in both conditions. Participants were then offered an opportunity to exchange their ticket with a new one, where the objective chances of winning would be 1 in 21. The results showed that the majority of participants in the choice group decided to keep their original lottery ticket despite that the objective chances were higher for the new ticket. These results suggest that participants overestimated the probability of winning the lottery if they had the opportunity to freely select a ticket. The act of making a personal choice favorably distorts the objective chance of success.

Research has examined how illusion of control influences the neural representation of the decision outcome. In [Kool, Getz, and Botvinick \(2013\)](#), participants were presented with three identical spinner dials at once, depicted as wheels of fortune. These three spinner dials represented the chance of winning. Importantly, participants were explicitly informed that the three spinners in each trial had an equal probability of a win outcome. In half of the trials, participants could choose a specific spinner (choice condition), whereas in the other half participants could indicate their preference but their preferred spinner dial was vetoed and replaced with the one that they did not choose (forced-choice condition). After the selection of a spinner, participants reported their confidence of winning using a visual analog scale. Again, participants knew that all of the spinners had an identical, objective chance of winning. However, consistent with the original illusion of control study, they found that the reported subjective probability of winning was higher in the choice condition than in the forced-choice condition. Based on these results, they hypothesized that, because participants overestimated the probability of winning in the choice condition, the choice condition would produce less “surprise” (called reward prediction error; actual reward value—expected reward value) at the positive outcome, which would manifest as the decreased activation in the ventral striatum (the brain area that represents reward prediction error; [Montague & Berns, 2002](#)). Contrary to their hypothesis, however, the choice condition and the forced-choice condition did not show differential activation in the ventral striatum, indicating that illusion of control would not influence the neural representation of reward prediction error. Instead, the choice condition showed enhanced activation in the posterior cingulate cortex, the ACC, and the middle temporal gyrus when the outcome was presented. These results indicate that the distorted probability perception due to illusion of control may be represented in a different way from reward prediction error in the brain (for a similar results, see [Murayama et al., 2015](#); [Vassena, Krebs, Silvetti, Fias, & Verguts, 2014](#)).

## PERSONAL CHOICE FACILITATES MOTIVATION AND PERFORMANCE

So far, we have discussed that personal choice would have a rewarding property, enhance the preference for the option the person chose, and bias the interpretation of the outcomes in a way that would enhance the positive feelings about the outcome. Together these findings suggest that providing a personal choice would be a good way of enhancing one's motivation and performance. In fact, there is a large body of literature in psychology showing that personal choice (as compared to forced-choice) would facilitate task motivation and performance (for a meta-analysis, see [Patall, Cooper, & Robinson, 2008](#)). The positive link between the choice and motivation is one of the central tenets of the self-determination theory ([Deci & Ryan, 1985](#); [Ryan & Deci, 2000](#)). According to the self-determination theory, people have the basic psychological needs for autonomy and factors that satisfy the needs would enhance people's intrinsic motivation (i.e., motivation to voluntarily engage in a task for the inherent pleasure and satisfaction derived from the task itself), resulting in improved task performance and well-being. Thus, personal choice, which would provide people with the sense of autonomy and personal control, can have adaptive functioning that facilitates people's motivation and task performance.

In a classic study by [Zuckerman, Porac, Lathin, and Deci \(1978\)](#), university student participants were provided with puzzle pieces and asked to solve puzzles. In the choice condition, there were drawings of six configurations and they were told that they could work on three of the configurations that they chose. In the forced-choice condition, participants were provided with pre-determined drawings of three configurations (these configurations were yoked to those selected by the participants in the choice condition) and they were told to work on these three configurations. After the task, the experimenter covertly observed the participants who were left alone in a lab room and measured how long the participants voluntarily worked on the new set of puzzles left in the same room. This voluntary engagement in the task during this period was used as the index of intrinsic motivation. The results showed that participants in the choice condition were voluntarily engaged with the puzzle significantly longer than those in the forced-choice condition, suggesting that providing personal choice would enhance people's intrinsic motivation. In another study, the effects of personal choice were examined in educational contexts with elementary schoolchildren ([Cordova & Lepper, 1996](#)). Participants played with educational computer activities in which they can learn the topic of arithmetical

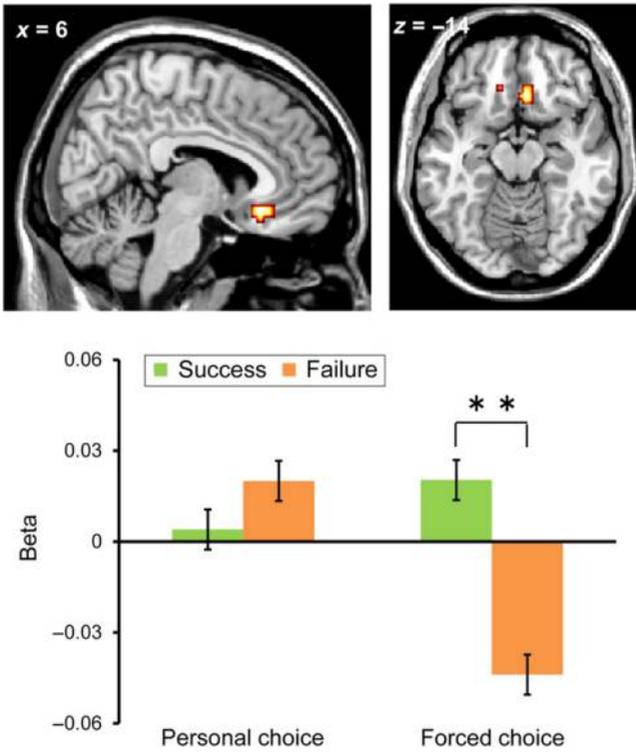
order-of-operations. Participants in the choice condition were allowed to change instructionally irrelevant features of the program, such as the specific icons representing the child and the computer, whereas participants in the forced-choice condition were not. The results showed that personal choice facilitated students' intrinsic motivation as well as task performance.

How does personal choice facilitate people's motivation and performance? Some neuroscientific studies provided clues to this question. In Legault and Inzlicht (2013)'s study using electroencephalography (EEG), participants performed a Stroop task, where they were presented with a series of colored words and asked to identify the color of the ink with which the word is printed (e.g., the word BLUE printed in red ink). Before the task, participants in the choice condition read a descriptive list of four computer tasks and were asked to select one computer game that they wanted to play the most. Actually, these tasks described the Stroop task in different ways and participants were directed to the same Stroop task regardless of their choices. Participants in the forced-choice condition, on the other hand, saw the same list of the task descriptions but were pressured to select a specific task that the experimenter suggested. Consistent with the previous findings, providing personal choice of the task improved the task performance of the Stroop task (i.e., error rate of the trials where the color of the ink and the presented word are incongruent).

More importantly, the authors also examined the effects of personal choice on error-related negativity (ERN), which is characterized as a pronounced negative deflection on EEG signal that occurs within 100 ms of making an error on a task. Previous studies have suggested that the ERN reflects an error detection system (presumably located in the ACC) that monitors performance (Holroyd & Coles, 2002). Some other studies provided a complementary view, indicating that ERN reflects motivational and affective responses to errors (Hajcak & Foti, 2008; Luu, Collins, & Tucker, 2000). From both perspectives, ERN is considered critical to improve task performance. The authors found that participants in the choice condition showed a greater magnitude of the ERN than the participants in the forced-choice condition, and also that an increased magnitude of the ERN mediated the relationship between choice manipulation and improved task performance. These results suggest that personal choice enhanced task performance by increasing task monitoring or motivational responses after failure. In fact, participants in the choice condition showed slower reaction time after failure, which possibly reflects behavioral adjustments to reduce further errors.

These findings indicate the critical role of failure feedback processing to understand the facilitative effects of personal choice in motivation and performance. This idea is also supported by a recent neuroimaging study. In Murayama et al.'s (2015) experiment, which used fMRI, participants played with a game-like task called "stopwatch task." For each trial, they could decide the design of the stopwatch that they would play with, but participants were also explicitly told that the design of the stopwatch was nothing to do with task difficulty (i.e., the choice of appearance would in no way, directly influence task performance). Participants completed the task in two types of trials. In choice trials, participants could freely choose the design of stopwatch that they would play with. In forced-choice trials, participants were forced to choose a specific design which was suggested by a computer. Corroborating the previous findings, task performance was enhanced when participants were provided with personal choice as compared to forced-choice. Importantly, they also found that this enhanced task performance in the choice trials was related to the failure feedback processing in the brain. When negative feedback about the task was delivered, the vmPFC showed decreased activation (in comparison to the success feedback) in the forced-choice trials (Fig. 3). This pattern is consistent with the past neuroscientific literature, indicating that negative feedback serves as an aversive outcome (Hare, O'doherty, Camerer, Schultz, & Rangel, 2008; Noonan, Mars, & Rushworth, 2011). In the choice condition, however, this decrease in the vmPFC activation was not observed. In other words, negative feedback was no longer aversive in the choice trials. The authors interpreted these findings as people offsetting the negative emotional value of failure, by treating the feedback informationally and thus embracing the positive experience of using the feedback on their own behalf. It is also worth mentioning that the striatum, another key brain structure in the reward network, did not show this pattern of activation, indicating that the vmPFC and the striatum may play different roles in doing the task (for another interesting dissociation between the striatum and the vmPFC in response to negative feedback, see Bhanji & Delgado, 2014).

A related, but different line of classical research in cognitive psychology revealed the beneficial effects of personal choice on memory performance (Monty & Permuter, 1975; Monty, Rosenberger, & Perlmutter, 1973; Perlmutter, Monty, & Kimble, 1971; Perlmutter, Scharff, Karsh, & Monty, 1980; Takahashi, 1992). In these experiments, participants are typically presented with cue-target word pairs, but unlike standard memory experiments, there are multiple (typically five) cues or targets. In choice conditions,



*Fig. 3.* Right vmPFC Activation Showing a Significant Choice Condition by Outcome Valence Interaction in Response to Task Feedback as Reported by Murayama et al. (2015). *Notes:* In response to success feedback, the vmPFC activation in the self-determined-choice (i.e., personal choice) condition was not different from that in the forced-choice condition. On the other hand, the self-determined-choice condition showed higher vmPFC activation as compared to the forced-choice condition in response to failure feedback.

they can select one target (when multiple targets are presented) and the selected cue-target word pairs are presented in the subsequent learning phase. In forced-choice conditions, a specific target word is assigned by the experimenter, and these assigned cue-target word pairs are presented in the subsequent learning phase. Findings from these studies repeatedly showed that memory performance would be enhanced for the word pairs for which participants had opportunity to select cues or targets (Monty et al., 1973; Perlmutter et al., 1971). It is worth noting that the effect of personal choice

on memory performance seems to be stronger after a 24-hour delay, rather than in immediate tests (Monty & Permuter, 1975).

Studies in cognitive neuroscience (Lisman & Grace, 2005; Shohamy & Adcock, 2010) have revealed that activation in the striatum (i.e., part of the reward network) facilitates declarative memory by modulating the activation in the hippocampus (i.e., memory system in the brain). In fact, several studies demonstrated that the provision of extrinsic rewards (e.g., money) can enhance memory performance, especially after a long delay (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Murayama & Kitagami, 2014; Murayama & Kuhbandner, 2011; Wittmann et al., 2005). As described earlier, several studies showed that personal choice can also activate the reward network in the brain (Aoki et al., 2014; Fujiwara et al., 2013; Leotti & Delgado, 2014; Leotti et al., 2010), indicating that choice has a rewarding property. Then, we can hypothesize that choice enhances memory performance through the modulation of the striatum into the hippocampal memory system. A recent study by Murty, Dubrow, and Davachi (2015) directly tested this hypothesis using fMRI. These studies found that the striatal activation in response to choice opportunity cue indeed predicted memory performance after 24-hours delay in choice condition, and that the coupling activation between the striatum and the hippocampus was observed only for the items that participants correctly remembered. These findings indicate that personal choice facilitates memory performance in a different way, as it enhances the performance of tasks that requires feedback learning.

## **PUTTING IT ALL TOGETHER: INTEGRATING THE PSYCHOLOGICAL EXPERIENCE AND BEHAVIORAL ACT OF PERSONAL CHOICE WITH NEUROSCIENTIFIC EVIDENCE AND EXPLANATIONS**

Our literature review showed that the mere act of making a personal choice would involve a variety of psychological processes, and the emergent body of the neuroscientific literature indicated that these choice effects are supported by several distinct brain areas. One of the key brain areas that repeatedly emerged in our literature review was the striatum. The striatum is activated when people expect choice opportunities (Aoki et al., 2014; Fujiwara et al., 2013; Leotti & Delgado, 2011, 2014; Murayama et al., 2015), and choice-induced preference change manifests as the increased

activation in this brain area for the items that participants chose. These observations indicate that some of the choice effects may be parsimoniously explained by a broader, reward process in the brain (see also Hidi, 2015). For example, although different researchers proposed different psychological mechanisms to explain the facilitative effects of personal choice on memory performance (e.g., multiple-cues hypothesis; see Toyota, 2013), memory consolidation caused by the reward processing in the brain (Shohamy & Adcock, 2010) would provide a simple but more powerful and clearer explanation for the past findings (Murty et al., 2015).

The vmPFC, a different brain area that also constitutes the reward network, involves choice effect as well, but this area seems to play a more nuanced role. In fact, in the papers that we reviewed, the activation of the vmPFC is consistently modulated by task context or social environment, whereas the activation of the striatum is not. For example, Aoki et al. (2014) showed that the striatum was responsive to the number of choice opportunities, but the vmPFC was more sensitive to the social comparison of these choice opportunities. Murayama et al. (2015) also found that the choice effects modulate the feedback processes in the vmPFC, but not in the striatum. Kool et al. (2013) reported the insensitivity of the striatum activation to a contextual factor (i.e., illusion of control). Both the striatum and the vmPFC have been strongly implicated in reward-related processing in the brain (Haber & Knutson, 2010), but their functional dissociation has not been well documented in the literature, except for relatively few cases (Hare et al., 2008; Knutson, Fong, Adams, Varner, & Hommer, 2001). We speculate that, in contrast to the vmPFC, the striatum may entail crude and automatic valuation processes that are relatively insensitive to the context. This idea actually corroborates the large body of literature in psychology, proposing that the human evaluation process is supported by two qualitatively different systems – an automatic, general process and an elaborative, context-specific process (dual-process model; Cacioppo & Petty, 1985; Kahneman, 2003). This dichotomy may also be related to the distinction between model-free and model-based mechanisms in reinforcement learning, which has attracted recent attention in decision neuroscience (Daw et al., 2011; O'Doherty, 2012). It is possible that this distinction may map onto the functional dissociation between the striatum and the vmPFC especially in the context of choice effects (Murayama et al., 2015). Further research is needed to clarify the distinct roles of these brain regions in the psychological processing of personal choice.

Another brain area that seems to be important to understand the neural underpinning of personal choice is the pmPFC (especially the dACC).

Cognitive dissonance induced by difficult choice was related to the pMFC activity (Izuma et al., 2010; Kitayama et al., 2013). Effects of personal choice were also mediated by the dACC activation, especially in relation to the processing of negative feedback (Legault & Inzlicht, 2013). The activation of the dACC was observed in response to (unsigned) prediction error signals when the illusion of control was induced (Kool et al., 2013). Personal choice also alleviated the activation of the dACC in response to painful stimuli (Salomons et al., 2004). One interesting feature of the pMFC is that, unlike the vmPFC, the pMFC receives strong projections from motor-related areas such as the primary motor cortex and the supplementary motor area, suggesting that part of the effects of personal choice may be mediated by motor-related signals (consistent with the idea of embodied motivation; e.g., Zhang & Risen, 2014). However, given that the dACC has been implicated in various psychological functioning, including conflict monitoring (Botvinick, Cohen, & Carter, 2004) and outcome saliency (Litt, Plassmann, Shiv, & Rangel, 2011), we do not believe it is appropriate to provide a single general account of how the pMFC or dACC plays a role in different experimental paradigms involving personal choice. Rather, the role of this brain area in studies of personal choice should be discussed on an individual basis, taking into account experimental contexts and psychological mechanisms that are specific to each study.

## AUTONOMY NEUROSCIENCE

These studies are clearly still at a nascent stage, but the accumulating evidence we reviewed above shows some consistent pattern of findings, which indicates the importance of studying the topic in a more systematic and integrative manner. To facilitate the interactions and the integrity of the past and future research programs, we suggest that research be conducted as a new realm in social and cognitive neuroscience, which we shall call “autonomy neuroscience.” As emerged from our literature review, autonomy neuroscience is an interdisciplinary field devoted to the neuroscientific understanding of how and why our autonomous decision making (as opposed to controlled or forced decision making) motivates our behavior. Autonomy neuroscience is different from decision neuroscience – one of the most popular realms in cognitive neuroscience – in that decision neuroscience is concerned only with the factors that make people adopt (or avoid) specific choices (e.g., value, cost, prediction error), but not with the distinction between autonomous decision making (e.g., personal choices)

and controlled decision making (e.g., forced-choices). Autonomy neuroscience is also different from the large body of literature on the neuroscience of consciousness and free will (e.g., Haggard, 2008). This line of research examines the neural mechanisms underlying the consciousness or agency itself, but does not address the motivational aspects of autonomous behavior. In short, autonomy neuroscience addresses how and why “your” choice motivates you in the brain.

It should be noted that we do not argue that the “active-agent” or “autonomous” view of human behavior is unequivocally correct. In fact, recent research in cognitive science has revealed that our decision-making process is not always mediated by active, willful cognitive processing (Haggard, 2008; Johansson, Hall, Sikstrom, & Olsson, 2005; Shimojo, Simion, Shimojo, & Scheier, 2003; Wegner, 2003). Many of these studies showed that our decisions are sometimes determined prior to when we feel we made a choice, suggesting that our sense of agency or autonomy may not play a critical role in our choices. However, regardless of whether our choices are real or not, it is possible that (the sense of) personal choice and forced-choice would elicit different psychological and motivational processes. The question of whether we are autonomous or have free will and the question of whether the sense of autonomy or personal choice motivates people are separate issues.

## ADDITIONAL CONSIDERATIONS

Several remarks should be noted. First, to provide rigorous neuroscientific evidence about the effect of personal choice, there is one inherent methodological challenge that we need to bear in mind – an item selection effect. For example, when we compare choice and forced-choice conditions, participants in the choice condition can choose the items that they like, and participants in the forced-choice condition are typically assigned to the items that are yoked to the choice made by the participants in the choice condition. This means that participants in the forced-choice condition may be assigned to the items that they do not like. Therefore, the comparison between the choice condition and the forced-choice condition confounds the effect of personal choice with the effects of pre-existing (or momentary) personal preferences. In other words, as long as we let participants choose what they want, we cannot randomly assign stimuli or tasks between choice and forced-choice conditions, and therefore, we cannot make causal inference in a strict manner. This issue is essentially the same with the criticism

raised by [Chen and Risen \(2010\)](#) on choice-induced preference change. In our literature review, only a limited number of studies explicitly noted and addressed this issue of item selection bias (e.g., [Izuma et al., 2010](#); [Murayama et al., 2015](#)). To understand the precise neural mechanisms underlying choice, future research, especially the studies that compare choice and forced-choice (or no choice) conditions, should attend more closely to this methodological issue.

Second, all of the neuroscientific studies we reviewed focused on the positive aspects of personal choice, but personal choice does not always benefit people. One of the most popular examples of a negative aspect of personal choice is choice overload ([Iyengar & Lepper, 2000](#)). Choice overload is a phenomenon where people have difficulty in making a decision when they are faced with too many options. In one study ([Iyengar & Lepper, 2000](#)), participants were provided with the opportunity to make a selection from a limited array (6) or an extensive array (30) of chocolates. Participants in the extensive choice condition (in comparison to the limited choice condition) found the choice more enjoyable but frustrating, and importantly exhibited more dissatisfaction and regret about their choices (but see also [Chernev, Böckenholt, & Goodman, 2015](#); [Simonsohn, Nelson, & Simmons, 2014](#); which question the robustness of the findings). These results indicate that, although increased number of choice options would produce increased rewarding value ([Aoki et al., 2014](#); [Fujiwara et al., 2013](#); [Suzuki, 2000](#)), having too many options does not always bring adaptive psychological consequences.

Similarly, choice may be rewarding, but this does not necessarily mean that personal choice always brings benefits to the agent. This would sometimes create a paradoxical situation where people prefer the freedom to choose based on the belief that such freedom would allow them to maximize the positive outcome, but such preference inadvertently diminishes positive outcomes. In social psychology, for example, researchers found that people tend to prefer the freedom to choose even though such freedom would actually prevent people's reappraisal process about the decision, resulting in reduced well-being. [Gilbert and Ebert \(2002\)](#) asked students to enroll in an extracurricular photography class. In the class, the students took photographs and selected their two favorite photographs. Then students were asked to pick one of the photographs to keep for themselves and to donate the other to the school. Before making their decision, half of the students were told their choice was final and the other half were told they would have several days to contemplate their choice and exchange the photograph if they so desired. There are many situations like this in our

daily life (e.g., you have an option of returning an item that you purchased if you do not like that). You may think that it would be good to have the option of exchanging the photograph later, as this would give you a more flexible choice. However, it turned out that those who were allowed to exchange it were less pleased with their selection than those who were forced to finalize the selection. This is because being committed to a specific option would make people engage in the psychological reappraisal process that justifies the choice of the option (this is a similar process with choice-induced preference change).

As another example, in the realm of self-regulated learning in cognitive psychology, there are many instances where people tend to choose study strategies that they believe to be beneficial but they are actually suboptimal, especially for long-term learning (Bjork, Dunlosky, & Kornell, 2013). In some cases, providing a forced-choice of study strategies would benefit learning more than providing participants with the complete freedom to select study strategies (Kornell & Bjork, 2008; Murayama, Blake, Kerr, & Castel, *in press*). In sum, these ironic consequences of personal choice have not received a great deal of attention in the neuroscience literature, and may merit future inquiry.

Third, and relatedly, although our chapter may have implied that choice is generally motivationally beneficial, the effects of choice should be considered with context. In fact, research in educational psychology has often found that choice is motivating only when the choice is meaningful and valuable to people (Katz & Assor, 2007). For example, a study showed that the provision of choice did not facilitate motivation when choice has to be made among mandated options (Reeve, Nix, & Hamm, 2003). Providing choice options would be easy to implement in many practical settings such as education. But given that choice can take myriad of different forms in real-life settings, and not all the choices are equally beneficial, we need to be careful to translate research findings into practical contexts.

Fourth, the question of why people value the freedom of choice would also merit future inquiry. Some researchers argue that people's preference for choice has been adaptively selected for evolutionary survival and that we have an innate tendency to seek the freedom of choice (Leotti et al., 2010). However, it is also possible that personal choice would on average allow people to receive more rewards in their life history, and therefore the preference for choice may simply reflect individual's reinforcement history. This perspective can also explain why there are large individual differences in our preference for choice (Rotter, 1966). In addition, there are several studies that showed the cultural influences on the

functionality and the value of personal choice (Iyengar & Lepper, 1999; Savani, Markus, & Conner, 2008), indicating the importance of social environment. These two possibilities are not mutually exclusive, but unfortunately, none of the current behavioral, neuroimaging, or animal studies can directly answer the question of whether, and to what extent, people have the inborn tendency to value personal choice. A broader approach such as developmental examination or behavioral genetics would be a good future avenue to address this question.

## CONCLUSION

In his very influential paper published in 1977, Albert Bandura proposed that people strive and are able to exercise control over events that affect their lives – people are “active agents” that enjoy their own choices to change outcomes and environments (Bandura, 1977). A similar proposal was made by Deci and Ryan (1985), who claimed that humans are naturally inclined to make personal choices and actively interact with the environment to satisfy the basic need for autonomy. The idea that we value our own choice and autonomy excited a number of researchers in psychology, and indeed, it set a foundation for the contemporary theories on motivation. But this enthusiasm has not apparently been shared by researchers in neuroscience; as indicated in the introduction, behavioristic views on motivation has overshadowed potential motivating quality and value of personal choice (as opposed to forced-choice). The current chapter reviews this sparse, but emergent, body of neuroscientific literature to address possible neural correlates underlying personal choice, especially focusing on the following motivational aspects – (i) personal choice is rewarding, (ii) personal choice shapes preference, (iii) personal choice changes the perception of outcomes, and (iv) personal choice facilitates motivation and performance. The evidence is not conclusive, but we hope that this review would leverage more extensive neuroscientific work on personal choice, and more broadly, contribute to the future prospect of “autonomy neuroscience.”

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