Self-Control in Social Decision Making: A Neurobiological Perspective

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15.1 Introduction

The social world is becoming ever more integrated and connected (Friedman 2006); decisions thus have more of an impact on a greater number of people. Social norms are standards of behavior that help regulate such complicated group functioning, and people who indulge in selfish whims that flout social norms risk a range of negative outcomes (Kurzban and Leary 2001). Critical in overcoming selfish urges to act in the interest of others is self-control—the process in which thoughts, emotions, or prepotent responses are inhibited to efficiently enact a more focal goal. This is evident in many everyday situations. Patiently listening to an in-law’s insipid tale, volunteering time and resources to a social cause, or remaining faithful in a long-term relationship all constitute a social dilemma that requires self-control of selfish impulses. And in contrast with work on the nonsocial forms of self-control (Cohen and Lieberman 2010), evidence about the underlying neural mechanisms of self-control in social decision making has only recently begun to emerge. Researchers have consequently combined neuroscience methods with social interaction games to elucidate the complexities of this unique mental ability displayed in a social context.

We had two aims in writing this chapter. The first was to outline research on self-control in social decision making with a particular focus on research that converges on a seemingly common neural substrate—the lateral prefrontal cortex (PFC). The second aim was to review newly developing opportunities and challenges unique to this field. Thus, we first outline the combination of neuroscience methods and social interaction games in researching self-control in social decision making (Sect. 15.2). We then examine functional magnetic resonance imaging (fMRI) and transcranial magnetic stimulation (TMS) research from three social decision-making domains—norm compliance, costly punishment, and moral decision making—that all highlight the involvement of the lateral PFC in self-control in social decisions (Sect. 15.3). Research is then reviewed in which neural traits, such as baseline cortical activation in the lateral PFC, explain sources of individual differences in self-control capacity (Sect. 15.4). We then examine how basic neurobiological processes involved in stopping a motor response appear to be involved in self-control in social decision making (Sect. 15.5). Finally, key research questions are discussed to help further research that investigates the processes that allow people to maintain and realize stable goals in a dynamic and often uncertain social environment (Sect. 15.6).

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15.2 Examining Self-Control in Social Decision Making: Neuroscience and Social Interaction Games

Neuroscience methods can help reveal the neurobiological systems that implement social behaviors (for a review, see Rilling and Sanfey 2011). The researcher can both image and modulate brain activity to provide a unique window into neural processes that mediate decision making and choice. Self-control in social decision making is thus well suited to neuroscience methods. Because self-control is the process in which thoughts, emotions, or prepotent responses are inhibited to efficiently enact a more focal goal (Thaler and Shefrin 1981), successful self-control processes are not directly observable. Researchers have been forced to infer self-control from other theoretically relevant variables. For example, response-inhibition processes are often inferred from failures to inhibit a response (e.g., number of errors committed) or the speed of correct responses. Such indirect measures, however, can fail to differentiate between patients who have poor self-control, i.e., those characterized by a disinhibited pathology, and healthy controls (e.g., Kemner et al. 1996; Karayanidis et al. 2000). Neuroscience methods allow the researcher to directly image and even modulate brain processes that underlie self-control.

Similarly, social interaction paradigms have certain features that make them ideally adaptable to the study of self-control in social decisions. First, most games involve a cost. That is, participants must sacrifice, often money, to behave in certain ways. For example, in the ultimatum game (UG), one player (often called the proposer) is given a sum of money (or points that will be exchanged for money at the end of the game) and must decide how much to share with another player (i.e., the responder). The responder can either accept the offer or reject it and ensure both players get no money at all. Thus, the responder can punish the proposer for an unfair offer, but at a personal cost. In comparison to hypothetical scenarios or questionnaires, behaviors in these social interaction games have real, easily quantifiable consequences. Additionally, social interaction paradigms are highly malleable. They are readily and precisely modified to suit different research questions or to operationalize a number of social phenomena; for example, games in which each trial involves a new interaction partner controls for reputational concerns. Games that involve repeated trials with the same interaction partner elucidate longer term, iterative social processes. Anonymity, cost, reputation, etc. are all precisely manipulated within the social interaction paradigm.

Together, these features equip the researcher with a set of tools with which to examine self-control in social decision making. Behaviors in social interaction paradigms involve a direct conflict between selfish actions and actions that benefit others. Combining social interaction games that involve a social dilemma with neuroscience methods thus provides a paradigm that can precisely operationalize self-control in a social context and discern the underlying neural processes. We focus our chapter on research that has used social interaction paradigms like the UG and brain stimulation techniques that allow causal inferences about the neural mechanisms of self-control. These studies reliably point to the lateral PFC.

15.3 Self-Control in Social Decision Making: The Lateral PFC

Observations of patients with PFC lesions were the first to suggest that the PFC may play a critical role in self-control in a social context. In general, frontal PFC lesions were associated with poorer social behavior (Damasio 1996; Shallice and Burgess 1991; Stuss and Benson 1986). For example, patients with PFC lesions demonstrate socially inappropriate behavior and personality disturbances associated with impulsiveness (Tranel et al. 2002; Clark et al. 2003). Such findings indicate that the PFC may be involved in self-control abilities. However, it is difficult to experimentally test this hypothesis in lesion patients under controlled conditions. Moreover, lesion studies often have a low number of patients and the possibility of functional reorganization after brain lesions may cast doubt on the interpretation of the results (Rorden and Karnath 2004).

Functional neuroimaging has been used to extend lesion research by noninvasively measuring brain activity in healthy individuals during social decision making. These studies have provided critical correlational evidence on PFC involvement in self-control in social decision making (e.g., Sanfey et al. 2003; Spitzer et al. 2007). Imaging methods, however, do not allow causal inferences to be made about changes in brain activity or mental processes. A direct investigation of causal brain–behavior relationships requires controlled modulation of brain activity with direct measurement of changes in behavior. One method that allows such an investigation is TMS. TMS noninvasively increases or decreases cortical excitability in targeted brain regions by pulsed magnetic fields through a contiguous scalp location. If TMS is applied at a low frequency for several minutes, the function of a stimulated area can be temporarily disrupted (Robertson et al. 2003), producing a kind of "transient lesion" in the healthy brain. The behavioral impact of disrupting this region can then be observed. Using TMS, researchers have begun to examine whether modulation of prefrontal brain functioning impacts self-control in healthy individuals. In the next section, we review evidence from different social situations that require self-control, including norm compliance, costly punishment, and moral dilemmas, first in adults (Sect. 15.3.1) and second in samples from across the life span (Sect. 15.3.2). This evidence converges to demonstrate the importance of the lateral PFC. Note, we use the term lateral PFC to refer to both dorsolateral and ventrolateral regions. Certainly, somewhat different regions of the lateral PFC may be activated in the separate studies. However, we provide an inclusive, rather than divergent, overview of research grounded by the consistent involvement of the lateral PFC.

15.3.1 Evidence in Healthy Adults

15.3.1.1 Norm Compliance

The threat of punishment is an important factor in norm compliance (Boyd et al. 2003; Fehr and Gächter 2002). For example, when there is no threat of punishment, people are generally more selfish, whereas when the threat of punishment looms, people are more cooperative and giving, e.g., more compliant with the norm for fairness (Fehr and Gächter 2002). To avoid punishment for norm violation, then, people must implement self-control to override selfish interest. Spitzer et al. (2007) used fMRI to examine the neural mechanisms associated with such norm compliance under the threat of punishment. In this study, participants played as a proposer in a social interaction game that was required to split a sum of money with a playing partner (the responder). There were two conditions; one in which the proposer could be punished by the responder and another where he or she could not be punished. During these interactions, participants' brain activity was measured with fMRI. The authors found that in comparison to the nonpunishment condition, the punishment condition elicited greater activation in the left and right lateral PFC and this activation correlated with the degree to which participants increased their offers under the threat of punishment. Because the threat of punishment prompts increased compliance with the norm for fairness, the authors suggested that lateral PFC activation represented increased self-control implemented to override the impulse to keep the money and make a low offer.

Norm compliance is not merely enacted to avoid punishment, however. Social rewards can also motivate normative behavior. Reputation, for example, is a kind of social currency accrued over time by engaging in actions valued by the group, particularly those that comply with norms. These behaviors that garner reputation are often costly. That is, they signal to other people that the individual is willing to sacrifice in order to cooperate or reciprocate trust in a social interaction. Though defection or breaking trust may be more rewarding in the short term, a good reputation is more beneficial over the long term. Reputation building thus requires self-control as people must forego immediate selfish temptations for the longer-term payoff of favorable social standing. Because reputation building does indeed involve self-control, one would expect that this ability involves the lateral PFC. To examine whether the lateral PFC was causally involved in reputation building, Knoch et al. (2009) conducted a brain stimulation study with TMS. In this study, participants played a modified trust game in which they could return or not return money to an investor. There were two game conditions, a reputation condition in which the investor could see prior decisions made by the participant and an anonymous condition in which no interaction history was visible. Thus, building a good reputation of trustworthy behavior would increase the likelihood that the investor would transfer money in the reputation condition, thereby increasing the participant's payoff. Participants were randomly assigned to one of the three TMS conditions, right lateral PFC disruption, left lateral PFC disruption, and a sham TMS condition. Results showed that right lateral PFC disruption caused a decrease in returning the investment when interaction history was visible, even though participants across TMS conditions were still equally aware of the benefits of building a good reputation. Thus, right lateral PFC disruption specifically antagonized the ability to resist the temptation to keep the money.

15.3.1.2 Costly Punishment

As demonstrated by the Spitzer et al. (2005) study, the threat of punishment guides norm compliance. Costly punishment—the degree to which people sacrifice personal resources to reprimand norm violators—is central to maintaining social norms. People are willing to sanction wrong doers at their own expense. Delivering costly punishment thus requires self-control in order to overcome the self-interested choice of keeping personal resources. This social dilemma is neatly captured by the UG. In this game, two people interact, one as a proposer who is instructed to offer the other person a division of real money, the other as a responder who is instructed to reject or accept the proposed division. A rejection decision ensures that both parties get no money. Thus, the responder can punish the proposer for an unfair offer, but such behavior is costly. In a landmark neuroimaging study, Sanfey et al. (2003) examined costly punishment in the UG. Participants played this game in the role of the responder as brain activity was measured with fMRI. The researchers found that unfair monetary offers prompted rejection of the offer and elicited left and right lateral PFC and anterior insula activation (Sanfey et al. 2003). Knoch et al. (2006) directly extended this evidence by manipulating activity in the lateral PFC with TMS. As in the Sanfey et al. (2003) study, they had participants act as responders in the UG. However, subjects were randomly assigned to one of three TMS conditions, right lateral PFC disruption, left lateral PFC disruption, and a sham TMS control. Knoch et al. found that right, but not left, lateral PFC disruption caused a decrease in the rejection of unfair offers. Because the rejection of unfair offers involved losing money to enact normative behavior, these results indicated that the right lateral PFC implemented self-control to mute selfish concerns in favor of punishing the proposer for unfair offers. This same effect of right lateral PFC disruption on the rejection rates of unfair offers has been demonstrated in separate studies (Baumgartner et al. 2011; van 't Wout et al. 2005) and with a different method used to modulate frontal activity (i.e., with transcranial direct current stimulation, Knoch et al. 2008).

One might suggest, however, that the complex processes of self-control in social decision-making tasks involve a distributed neural network and not just the lateral PFC. Neural imaging identifies neural correlates but does not identify causal roles of those brain regions. Brain stimulation identifies causal relationships between brain regions and decision making but does not identify changes to the broader neural network. However, if these two methods are combined, one can overcome the separate limitations of each method. That is, the researcher can examine how modulated brain activity implements changes in a neural network to cause the behavior of interest. With this benefit in mind, Baumgartner et al. (2011) combined TMS with fMRI to examine the effect of right and left lateral PFC disruption on neural activity and costly punishment behavior. Participants first had either the left or the right lateral PFC disrupted and then played the same UG in the role of the responder, during which brain activity was measured. Results demonstrated that TMS of the right PFC disrupted recruitment of the right lateral PFC to unfair offers and increased acceptance rate of those unfair offers. Additionally, participants who made more costly punishment decisions to unfair offers showed increased activation in and connectivity between the right lateral PFC and the ventromedial PFC after receiving an unfair offer. TMS over the right lateral PFC, however, eliminated these effects. By combining brain stimulation with brain imaging, the authors identified a prefrontal network consisting of the right lateral PFC and the ventromedial PFC as the drivers of costly punishment, a social behavior that requires self-control.

15.3.1.3 Moral Decision Making

Moral choices are inherently social and would appear to also require self-control. Tough decisions must be made as emotions and opposing moral values clash with cold, calculated logic. Tassy et al. (2012) examined whether the right lateral PFC was causally involved in moral dilemmas using TMS. Participants were randomly assigned to either a right lateral PFC disruption or sham TMS condition and then read scenarios that required the participant to select one of two outcomes that contrasted important moral values (e.g., killing is wrong vs. letting innocent people die is wrong). One option typically required a morally wrong act that nevertheless caused a much better outcome (i.e., a utilitarian choice). Results demonstrated that compared to the sham condition and to nonmoral decisions, TMS disruption of the right lateral PFC caused a reduction in subjective utilitarian choices (but an increase in objective utilitarian choices). In other words, disrupting the right lateral PFC reduced the preference to personally engage in difficult actions that benefited more people (e.g., killing one person to save many more lives). Although the authors interpreted these findings as demonstrating that right lateral PFC disruption knocked out the ability to integrate emotional information into the decision-making process, these results also fit the notion that the lateral PFC implements self-control to inhibit the automatic emotional reaction to engage the choice that benefits more people (e.g., save more people) but is personally costly (e.g., engage in a difficult behavior to save more people).

15.3.2 Evidence Across the Lifespan

Social decision making, and the ability to restrain selfish choices, appears to develop throughout childhood and adolescence (Garon et al. 2008) in conjunction with a growing regard for others (van den Bos et al. 2011). For example, children increasingly share more over childhood (Benenson et al. 2007), inequity aversion emerges between the ages of 3 and 8 (Fehr et al. 2008), and development shows a general trend from marked selfish behavior to increased perspective taking and relational concern (Steinberg 2009). Recent efforts have begun to unravel the development of self-control behavior by examining the underlying cognitive or neuronal mechanisms.

Steinbeis et al. (2012) examined the development of norm compliance in childhood by examining cortical activity and structure changes associated with offers made in the UG versus the dictator game (DG) in children ranging in ages from 6 to 13. The DG is similar to the UG in that a proposer decides how much money to share with another person. However, in the DG, the other person cannot accept or reject the proposer's offer. Functional and structural scans were acquired to examine both brain activity and anatomical differences associated with increased norm compliance under the threat of punishment (e.g., higher offers in the UG vs. the DG). Results showed that increasing age was associated with both higher offers in the UG versus the DG and greater activity elicited in the lateral PFC when making offers in the UG compared to in the DG. Moreover, this lateral PFC activity was correlated with larger offers under the threat of punishment. Similarly, cortical thickness in the left lateral PFC was also correlated with the same shift to higher offers in the UG compared to the DG. Thus, younger children appeared less able to engage the lateral PFC to implement control over tempting selfish desires under the threat of punishment.

Van den Bos et al. (2011) examined adolescent neural development and trust reciprocation in three different groups chosen based on key developmental stages, a 12–14 group, a 15–17 group, and an 18–22 group. Participants played a modified trust game in the role of a trustee as fMRI was acquired during the game. Participants could return or keep an investment made by an investor under conditions of low or high risk. A high-risk investment thus signaled greater trust in the participant to return the money, a signal that could be reciprocated by returning the investment. Thus, under high risk, self-control was required to override the selfish impulse to keep all of the money in order to reciprocate trust and return the investment. Results showed that participants reciprocated more as age increased. Additionally, among the 18–22 group, right lateral PFC activation predicted increased reciprocity. These findings demonstrate that increasing engagement of the lateral PFC across adolescence is associated with prosocial behavior in social decision making.

As compared to the increase in self-control across childhood and adolescence, in old age there is a general decline in self-control and a decline in PFC function and structure (Dempster 1992). Moreover, there is evidence that reduced self-control in older adults appears to be specifically attributable to changes in lateral PFC functioning (Sharp et al. 2006). In a review article, von Hippel (2007) directly related the reduced self-control that is associated with aging to deficits in social conduct. Older adults, who show deficits in nonsocial self-control, such as inhibiting nonrelevant stimuli to efficiently implement motor or vocal responses, show more overt prejudice against minorities, display increased socially inappropriate behavior, and show poorer regulation of social emotions (von Hippel 2007). Given that previous research has associated self-control decline with the lateral PFC, whether or not these social deficits are specifically due to atrophy in or disruption of the lateral PFC is an intriguing open question in need of future study.

In any case, evidence across the life span generally corroborates the evidence from healthy adults that the lateral PFC is integral in implementing self-control in social decision making. Specifically, the development of the lateral PFC over the life span tracks and predicts the developmental trajectory of self-control in social contexts.

15.4 Neural Traits Explain Individual Differences in Self-Control Capacity

One person struggles with sexual temptations, another person effortlessly resists the same enticement. One person keeps a cool comport under social stress, another is mercurial under the same pressure. One person shows seemingly boundless consideration for other people, another person shows little to no regard for others. People appear to have stark differences in the capacity for self-control across social contexts. But from where do these differences originate? To answer that question, the neural trait approach holds unique promise (Nash and Knoch in press). A neural trait may be defined as a quantifiable brain-based characteristic that is stable over time. In the field of social neuroscience, most studies that have employed the neural trait approach have focused on the characteristics of brain structure, using anatomical MRI, or resting-state brain activity, using electroencephalography (EEG) or fMRI. Generally, the neural trait approach involves indexing task-independent, brain-based differences and examining whether these indices predict behavior or psychological processes of interest. Neural traits can explain how and why people display a remarkable amount of variance in self-control capacity in social choices. The neural trait approach carries with it a further advantage. Because resting EEG and structural MRI can be measured separately from behavioral performance, researchers can then measure behavioral performance in more ecologically valid environments—that is, outside of the MRI scanner or without being hooked up to EEG electrodes.

As such, given that the lateral PFC appears integrally involved in implementing self-control in social decision making, one might expect that neural traits involving the lateral PFC might explain sources of the significant heterogeneity found in costly punishment behavior. Knoch et al. (2010) specifically explored this possibility by using resting-state EEG. Frequency-based measures of resting-state EEG in healthy adults are stable, heritable, and unique to the individual (Dunki et al. 2000; Näpflin et al. 2007). In fact, patterns of baseline cortical activation appear idiosyncratic as they can predict who the individual is at up to a 99% recognition rate (Dunki et al. 2000; Näpflin et al. 2007), suggesting that baseline cortical activation powerfully captures individual differences in characteristic neural function, akin to identifying a "neural fingerprint." In the Knoch et al. (2010) study, participants first had resting-state EEG measured. After that, participants played the role of the responder in the UG. A whole-brain correlational analysis between source-localized baseline EEG activity and costly punishment behavior revealed that the costly punishment behavior was predicted by baseline cortical activation in the right lateral PFC. That is, higher baseline cortical activation in this area predicted higher levels of costly punishment behavior. Moreover, this baseline cortical activation explained approximately 50% of the variance in costly punishment, demonstrating the potential power of the neural trait approach. Thus, based on fMRI and TMS research in which the lateral PFC was integral in implementing self-control to enact costly punishment, these findings are consistent with the idea that resting-state activation in the lateral PFC reflects self-control capacity.

Individual differences in self-control capacity may also be examined by assessing potential genetic contributions (e.g., Boettigger et al. 2007; Kuhnen and Chiao 2009). The *intermediate phenotype model* holds that genes impact behavior through neural mechanisms (Meyer-Lindenberg and Weinberger 2006). To be an effective, brain-based intermediate phenotype, certain criteria have been articulated, such as the characteristics of stability and heritability (Gottesman and Gould 2003; Green et al. 2008; Kanai and Rees 2011). Baseline cortical activation and brain anatomy are both highly stable and heritable in healthy adults, as noted above. Neural traits are thus ideal intermediate phenotypes. As an example, Gianotti et al. (2012) employed the intermediate phenotype approach in examining delay discounting—the degree to which people overlook or "discount" future rewards in favor of smaller, sooner rewards, depending on the amount of delay of the future reward. Delay discounting has direct relevance to self-control and social conduct (Beck and Triplett 2009; Casey et al. 2011; Mischel et al. 2011; Reimers et al. 2009). In this study, participants were genotyped on the COMT Val158Met polymorphism, which has been associated with delay discounting in past research (Boettiger et al. 2007; Paloyelis et al. 2010). Participants also had resting EEG measured and then completed a task in which they made a series of decisions between smaller-sooner rewards and later-larger rewards that differed in magnitude and delay. Results demonstrated that participants with more Val alleles (greater COMT activity and lower dopamine levels in the PFC) exhibited greater delay discounting. This effect was mediated by the baseline cortical activation levels in the lateral PFC: Higher numbers of Val alleles lead to lower baseline activation in the left lateral PFC which, in turn, biases choices toward greater impatience. These findings thus converge with the costly punishment findings to support the idea that dispositional differences in the lateral PFC might reflect differences in a general self-control capacity.

15.5 Connecting Self-Control in Nonsocial and Social Domains

To summarize the above research, it is apparent that across correlational and causal research, at different stages of development, the lateral PFC is consistently involved in implementing self-control in social decision making in a variety of social contexts. Given this, it is reasonable to assume that this brain area is a common mechanism for self-control in social decision making. However, self-control is invoked across a wide range of other, nonsocial, regulatory processes, including motor inhibition, delaying gratification, and inhibiting cognitions or emotions (Heatherton 2011). Further, self-control in one nonsocial domain can impact self-control in subsequent, unrelated domains (Berkman et al. 2011; Muraven and Baumeister 2000). Individual differences in self-control have been shown to be relatively stable throughout the life span and across a variety of situations (Casey et al. 2011) and a range of psychopathological disorders characterized by motor inhibition deficits often co-occur with impulsive social conduct (Aron and Poldrack 2005; Heatherton and Wagner 2011; Robbins et al. 2012).

Together, these studies further suggest that self-control involves a common process across social and nonsocial contexts, a notion buttressed by cutting-edge neuroscience research. Tabibnia et al. (2011), in a research paradigm that used the neural trait approach, specifically examined whether there were common anatomical substrates that could predict performance in motor and affective control using structural MRI. They found that gray matter volume in a region in the right lateral PFC predicted both better inhibitory control and better emotion regulation. Berkman et al. (2009) found neural evidence of self-control "spill-over." In this study, participants completed an emotional Go/NoGo task while brain activity was indexed with fMRI. The Go/NoGo stimuli were faces that were either male or female with positive or negative emotion. Importantly, participants only responded to gender to initiate or inhibit a response. However, inhibiting a response caused unintended reductions in emotion-related brain activity. That is, engaging self-control in a motor control task engaged the right lateral PFC, caused unintended reductions in activation in the amygdala, and increased negative connectivity between these regions. Thus, the degree to which the lateral PFC was engaged during motor control was associated with unintended affect regulation. And in a recent review of the neuroscience literature on self-control, it was concluded that the self-control of motor responses, emotions, desires, and cognitions reliably involve the right lateral PFC (Cohen and Lieberman 2010). In sum, nonsocial and social forms of self-control have been linked to the same brain area. However, evidence for the link between nonsocial and social forms of self-control is unclear.

To explore whether basic self-control processes, such as motor-response inhibition, could predict self-control in a complex social context, Nash et al. (2013) had participants first complete a Go/NoGo task as EEG was recorded. To index motor control processes, two established electrophysiological indices were measured: the NoGo Anteriorization (NGA; Fallgatter and Strik 1999) and peak amplitude of the NoGo-P300. Participants then played a social interaction game in which they promised whether or not they would return money to ostensibly real partners, but were later given the opportunity to break that promise. Recall that a response requires self-control if a prepotent impulse must be inhibited at the decision point (Thaler and Shefrin 1981). The game was designed to ensure that the prepotent response was to follow through with the promise to return money. Thus, the response that required self-control was breaking the promise. Results demonstrated that a larger NGA and larger NoGo-P300 peak amplitudes both predicted more broken promises. This study provides some of the first evidence that connects nonsocial with social forms of self-control.

15.6 Future Opportunities and Challenges

This chapter has explored research that combined neuroscience methods with social interaction paradigms to discern the underlying processes of self-control in social decision making. A noteworthy feature is evident—one that has been noted by several others (Cohen and Lieberman 2010; Frith and Singer 2008; Tabibnia et al. 2008)—in that self-control appears to involve a common mechanism. The lateral PFC is involved in the implementation of both nonsocial and social forms of self-control. In the next section, we consider the opportunities and challenges presented by these and other relevant findings.

15.6.1 Potential Applications

What, then, is the significance of the notion that self-control, in both social and nonsocial domains, appears to involve a common neural substrate? We would suggest that exciting avenues for future research are afforded, particularly if such study draws upon findings from its parent disciplines of neuroscience, behavioral economics, and social psychology. For example, a considerable amount of social psychological research indicates that self-control is limited in some fashion. Self-control can be temporarily disrupted or exhausted through continued use (Lopez et al. 2014, this volume, Chap. 4). Prospective research could explore whether training manipulations that boost basic forms of self-control over the long term (Houben and Jansen 2011; Klingberg 2010) could potentially promote lasting improvements in the regulation of social behavior. Additionally, a number of psychopathological disorders are characterized by chronic self-control problems (Aron and Poldrack 2005). As these disorders are often comorbid with social difficulties (Robbins et al. 2012), this chapter further supports the idea that diminished self-control may produce these social deficits (Heatherton and Wagner 2011). As self-control has been related to specific neural traits, such as baseline cortical activation in the lateral PFC (Knoch et al. 2010; Gianotti et al. 2012), training manipulations of specific neural traits might allow researchers to effect longer-lasting changes to even the most complex of preferences or decision-making behaviors, such as adherence to social norms. For example, techniques such as neurofeedback, meditation, or repeated practice of certain skills have the capacity to increase baseline cortical activation or cortical volume in specific brain regions (e.g., Ghaziri et al. 2013; Lazar et al. 2005; Takeuchi et al. 2010). Using these techniques, enduring neural changes could be made to the lateral PFC structure and function, which could impact self-control capacity. Such findings could improve social conduct and perhaps aid efforts to understand predispositions toward self-control deficits.

15.6.2 Self-Control for Selfish and Prosocial Impulses

The classic example of self-control in social decision making is that of restraining base, selfish instincts to enact prosocial behaviors. An overarching assumption has been that selfish impulses are automatic first reactions, whereas prosocial motives are second, requiring self-control to implement, as demonstrated by the bulk of the research reviewed above. However, certain studies cast doubt on this assumption. For example, one fMRI study demonstrated that accepting, and not rejecting, unfair offers involves the lateral PFC (Tabibnia et al. 2008). Similarly, another fMRI study found that choosing to not cooperate with an untrustworthy partner (a selfish behavior) activates the right lateral PFC (Suzuki et al. 2011). In these studies, the lateral PFC appeared to implement self-control to mute prosocial impulses to enact more egoistic choices. In a recent review of these studies and the broader self-control literature, Zaki and Mitchell (in press) concluded that such divergent evidence suggests that we should explore not only whether prosocial impulses can be prepotent but also the situational factors that shift prosocial/selfish impulses into prepotency.

In line with this recommendation, we would suggest (as others have, see Declerck et al. 2013; Frith and Singer 2008; Zaki and Mitchell in press) that in self-control in social decision making, there is no one impulse that is universally prepotent or “default.” Rather, what determines a person’s prepotent impulse is personality and the environment. Such a view adheres to classic ideas in social and personality psychology (e.g., Lewin 1946) and can parsimoniously reconcile the divergent and sometimes contradictory findings explored above without the need to posit some universal impulse. For example, recall that Knoch et al. (2006) found that right lateral PFC *disruption* caused increased acceptance of unfair offers, whereas Tabibnia et al. (2008) found that right lateral PFC *activation* was associated with increased acceptance of unfair offers. Rather than claim that one study involved self-control and the other did not, one could argue that self-control was differentially employed due to individual or situational differences.

We propose that preferences may determine prepotency. Thus, people who require the most self-control in social decision making are those who have strong preferences that conflict with the more focal goal. Conversely, people will not need self-control to enact a goal that coincides with a strong preference. For example, a person with strong prosocial preferences should not need self-control to act in a prosocial way, whereas a strongly egoistic individual should need self-control to act in a prosocial way. If individual differences in preferences are critical in determining whether self-control is involved in certain social decisions, then effective measurement of such preferences seems equally critical. Examples of measures that may capture selfish and prosocial preferences include measures of social value orientation (Van Lange et al. 1997) and the Honesty–Humility subscale of the HEXACO personality inventory (Ashton and Lee 2007).

Importantly, preferences are not immutable. The contours of the situation can shift and augment personal preferences, even at implicit levels (Bargh and Chartrand 1999). People become more selfish in a competitive environment and more compassionate in a cooperative environment (Bargh et al. 2001). For example, merely displaying images of money or presenting symbols associated with money can make people significantly more egoistic (Vohs et al. 2006). On the other hand, basic representations of facial features elicit more cooperative behavior in the DG (Rigdon et al. 2009). Given this, it is plausible that mere differences in study design, context, or sample could shift the prepotency of a given impulse (e.g., did the instructions emphasize winning/making money or social, cooperative concerns? Is the sample drawn from a hypercompetitive business school or a progressive arts school?). Future research should thus take into account the baseline preferences and situational affordances in order to determine which impulse is prepotent for whom and thereby determine what behaviors require self-control.

Preliminary neuroscience evidence for this view of self-control can be found. Based on our contention that whether self-control is required or not is (partially) determined by individual preferences, one might hypothesize that if an action opposes a dominant preference, regardless of what that preference is, then the individual should require more self-control to engage in that act. Rilling et al. (2007) conducted a study in which brain activity was measured as participants played a trust game. Participants were grouped into high and low scoring on a psychopathy measure. Results showed that those low in psychopathy tended to cooperate, whereas those high in psychopathy tended to defect. Critically, trials were also examined in which participants acted against their preferred tendency. When low psychopathy people defected and when high psychopathy people cooperated, greater lateral PFC activation was elicited. This is consistent with the idea that acting against prepotent impulses, regardless of the impulse type, required increased self-control.

15.6.3 Other Brain Regions

We are careful to note that the lateral PFC is not only involved in self-control and has been related to a number of different processes. Additionally, brain areas do not act in isolation. This should be particularly true in the case of self-control in social decision making because of the presumably complex and abstract processes involved. A neural network should be engaged. Research does suggest additional brain regions. For example, whereas the preponderance of evidence suggests the right lateral PFC is the integral structure in self-control, in some of the studies above, the left was coactive with the right lateral PFC or appeared more involved in self-control than the right (Steinbeis et al. 2012). In addition to the lateral PFC, response-inhibition activation (NoGo vs. Go) has been related to activation in the dorsomedial PFC and the anterior cingulate cortex (Brass and Haggard 2007; Fallgatter et al. 2002; Kuhn et al. 2009).

Future research could examine how modulated brain activity implements changes in a neural network to cause the behavior of interest. The aforementioned Baumgartner et al. (2011) study is a prime demonstration. In this study, it was found that the right lateral PFC and the ventromedial PFC showed increased activation and connectivity after participants received an unfair offer, though TMS over the right lateral PFC disrupted this neural network. Because the ventromedial PFC encodes the value of choice options (Chib et al. 2009), the authors suggested that the right lateral PFC implements self-control by increasing the value of the normative decision to reject unfair offers, which is processed in the ventromedial PFC. These findings demonstrate that the combination of correlational (fMRI) and causal (TMS) neuroscience methods is capable of precisely determining causal neural networks of self-control in social decision making.

Conclusion

Historically, the study of self-control has been most heavily researched in nonsocial domains, including motor-response inhibition, memory and thought suppression, and emotion regulation (Aron and Poldrack 2005; Cohen and Lieberman 2010). Yet, social dilemmas confront us daily and self-control is critically involved in deciding between options that benefit ourselves and options that benefit others. In this chapter, we reported research in which neuroscience methods combined with social interaction paradigms reveal the neural mechanisms of self-control in social contexts. Moreover, it was revealed that self-control in social decision making reliably involves the lateral PFC, the same region involved in a host of other nonsocial forms of control. Such research highlights the potential for making long-lasting changes to lateral PFC structure and function, which could in turn change self-control capacity and help researchers better understand predispositions toward self-control problems in social conduct. Future research can turn to researching how individual differences and situational affordances interact to impact self-control in social decision making.

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References

Aron, A. R., & Poldrack, R. A. (2005). The cognitive neuroscience of response inhibition: Relevance for genetic research in attention-deficit/hyperactivity disorder. *Biological Psychiatry, 57,* 1285–1292. doi:10.1016/j.biopsych.2004.10.026.

Ashton, M. C., & Lee, K. (2007). Empirical, theoretical, and practical advantages of the HEXACO model of personality structure. *Personality and Social Psychology Review, 11,* 150–166. doi:10.1177/1088868306294907.

Bargh, J. A., & Chartrand, T. L. (1999). The unbearable automaticity of being. *American Psychologist, 54,* 462–479. doi:10.1037/0003-066X.54.7.462.

Bargh, J. A., Gollwitzer, P. M., Lee-Chai, A., Barndollar, K., & Trötschel, R. (2001). The automated will: Nonconscious activation and pursuit of behavioral goals. *Journal of Personality and Social Psychology, 81,* 1014–1027. doi:10.1037//0022-3514.81.6.1014.

Baumgartner, T., Knoch, D., Hotz, P., Eisenegger, C., & Fehr, E. (2011). Dorsolateral and ventromedial prefrontal cortex orchestrate normative choice. *Nature Neuroscience, 14,* 1468-1474. doi:10.1038/nn.2933.

Beck, R. C., & Triplett, M. F. (2009). Test-retest reliability of a group-administered paper-pencil measure of delay discounting. *Experimental and Clinical Psychopharmacology, 17,* 345–355. doi:10.1037/a0017078.

Benenson, J. F., Pascoe, J., & Radmore, N. (2007). Children's altruistic behavior in the dictator game. *Evolution and Human Behavior, 28,* 168–175. doi:10.1016/j.evolhumbehav.2006.10.003.

Berkman, E. T., Burklund, L., & Lieberman, M. D. (2009). Inhibitory spillover: Intentional motor inhibition produces incidental limbic inhibition via right inferior frontal cortex. *NeuroImage, 47,* 705. doi:10.1016/j.neuroimage.2009.04.084.

Berkman, E. T., Falk, E. B., & Lieberman, M. D. (2011). In the trenches of real-world self-control: Neural correlates of breaking the link between craving and smoking. *Psychological Science, 22,* 498–506. doi:10.1177/0956797611400918.

Boettiger, C. A., Mitchell, J. M., Tavares, V. C., Robertson, M., Joslyn, G., D'esposito, M., & Fields, H. L. (2007). Immediate reward bias in humans: Fronto-parietal networks and a role for the catechol-O-methyltransferase 158(Val/Val) genotype. *Journal* *of Neuroscience, 27,* 14383–14391. doi:10.1523/JNEUROSCI.2551-UROSCI.2.

Boyd, R., Gintis, H., Bowles, S., & Richerson, P. J. (2003). The evolution of altruistic punishment. *Proceedings of the National Academy of Sciences United States of America, 100,* 3531–3535. doi:10.1073/pnas.0630443100.

Brass, M., & Haggard, P. (2007). To do or not to do: The neural signature of self-control. *Journal of Neuroscience, 27,* 9141–9145. doi:10.1523/JNEUROSCI.0924-07.2007.

Casey, B. J., Somerville, L. H., Gotlib, I. H., Ayduk, O., Franklin, N. T., Askren, M. K., Jonides, J., et al. (2011). Behavioral and neural correlates of delay of gratification 40 years later. *Proceedings of the National Academy of Sciences United States of America, 108,* 14988–15003. doi:10.1073/pnas.1108561108.

Chib, V. S., Rangel, A., Shimojo, S., & O'Doherty, J. P. (2009). Evidence for a common representation of decision values for dissimilar goods in human ventromedial prefrontal cortex. *Journal of Neuroscience, 29,*12315–12320. doi:10.1523/JNEUROSCI.2575-09.2009.

Clark, L., Manes, F., Antoun, N., Sahakian, B. J., & Robbins, T. W. (2003). The contributions of lesion laterality and lesion volume to decision-making impairment following frontal lobe damage. *Neuropsychologia, 41,* 1474–1483. doi:10.1016/S0028-3932(03)00081-2.

Cohen, J. R., & Lieberman, M. D. (2010). The common neural basis of exerting self-control in multiple domains. In R. R. Hassin, K. N. Ochsner, & Y. Trope (Eds.), *Self control in society, mind, and brain. Oxford series in social cognition and social neuroscience* (pp. 141–160). New York: Oxford University Press. doi:10.1093/acprof:oso/9780195391381003.0008.

Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society B: Biological Sciences, 351,* 1413–1420. doi:10.1098/rstb.1996.0125.

Declerck, C. H., Boone, C., & Emonds, G. (2013). When do people cooperate? The neuroeconomics of prosocial decision making. *Brain and Cognition, 81,* 95–117. doi:10.1016/j.bandc.2012.09.009.

Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, 12, 45–75. doi:10.1016/0273-2297(92)90003-K.

Dunki, R. M., Schmid, G. B., & Stassen, H. H. (2000). Intraindividual specificity and stability of human EEG: Comparing a linear vs a nonlinear approach. *Methods of Information in Medicine-Methodik der Information in der Medizin, 39*(1), 78.

Fallgatter, A. J., & Strik, W. K. (1999). The NoGo-anteriorization as a neurophysiological standard-index for cognitive response control. *International Journal of Psychophysiology, 32,* 233–238. doi:10.1016/S0167-8760(99)00018-5.

Fallgatter, A. J., Bartsch, A. J., & Herrmann, M. J. (2002). Electrophysiological measurements of anterior cingulate function. *Journal of Neural Transmission, 109,* 977–988. doi:10.1007/s007020200080.

Fehr, E., & Gächter, S. (2002). Altruistic punishment in humans. *Nature, 415,* 137–140. doi:10.1038/415137a.

Fehr, E., Bernhard, H., & Rockenbach, B. (2008). Egalitarianism in young children. *Nature, 454,* 1079–1083. doi:10.1038/nature07155.

Friedman, T. L. (2006). *The world is flat: A brief history of the twenty-first century updated and expanded*. New York: Farrar, Straus and Giroux.

Frith, C. D., & Singer, T. (2008). The role of social cognition in decision making. *Philosophical Transactions of the Royal Society B: Biological Sciences, 363,* 3875–3886. doi:10.1098/rstb.2008.0156.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin, 134,* 31–60. doi:10.1037/0033-2909.134.1.31.

Ghaziri, J., Tucholka, A., Larue, V., Blanchette-Sylvestre, M., Reyburn, G., Gilbert, G., et al. (2013). Neurofeedback training induces changes in white and gray matter. *Clinical EEG and Neuroscience*. Advance online publication. doi:10.1177/1550059413476031.

Gianotti, L. R., Figner, B., Ebstein, R. P., & Knoch, D. (2012). Why some people discount more than others: Baseline activation in the dorsal PFC mediates the link between COMT genotype and impatient choice. *Frontiers in Neuroscience, 6,* 1–12. doi:10.3389/fnins.2012.00054.

Gottesman, I. I., & Gould, T. D. (2003). The endophenotype concept in psychiatry: Etymology and strategic intentions. *American Journal of Psychiatry,* 160, 636–645. doi:10.1176/appi.ajp. 160.4.636.

Green, A. E., Munafò, M. R., DeYoung, C. G., Fossella, J. A., Fan, J., & Gray, J. R. (2008). Using genetic data in cognitive neuroscience: From growing pains to genuine insights. *Nature Reviews Neuroscience, 9,* 710–720. doi:10.1038/nrn2461.

Heatherton, T. F. (2011). Neuroscience of self and self-regulation. *Annual Review of Psychology, 62,* 363–390. doi:10.1146/annurev.psych.121208.131616.

Heatherton, T. F., & Wagner, D. D. (2011). Cognitive neuroscience of self-regulation failure. *Trends in Cognitive Sciences, 15,* 132–139. doi:10.1016/j.tics.2010.12.005.

Houben, K., & Jansen, A. (2011). Training inhibitory control: Recipe for resisting sweet temptations. *Appetite, 56,* 345–349. doi:10.1016/j.appet.2010.12.017.

Kanai, R., & Rees, G. (2011). The structural basis of inter-individual differences in human behaviour and cognition. *Nature Reviews Neuroscience, 12,* 231–242. doi:10.1038/nrn3000.

Karayanidis, F., Robaey, P., Bourassa, M., De Koning, D., Geoffroy, G., & Pelletier, G. (2000). ERP differences in visual attention processing between attention-deficit hyperactivity disorder and control boys in the absence of performance differences. *Psychophysiology, 37,* 319–333. doi:10.1111/1469-8986.3730319.

Kemner, C., Verbaten, M. N., Koelega, H. S., Buitelaar, J. K., van der Gaag, R. J., Camfferman, G., & van Engeland, H. (1996). Event-related brain potentials in children with attention-deficit and hyperactivity disorder: Effects of stimulus deviancy and task relevance in the visual and auditory modality. *Biological Psychiatry, 40,* 522–534. doi:10.1016/0006-3223(95)00429- 7.

Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences, 14,* 317–324. doi:10.1016/j.tics.2010.05.002.

Knoch, D., Pascual-Leone, A., Meyer, K., Treyer, V., & Fehr, E. (2006). Diminishing reciprocal fairness by disrupting the right prefrontal cortex. *Science, 314,* 829–832. doi:10.1126/science.1129156.

Knoch, D., Nitsche, M. A., Fischbacher, U., Eisenegger, C., Pascual-Leone, A., & Fehr, E. (2008). Studying the neurobiology of social interaction with transcranial direct current stimulation-the example of punishing unfairness. *Cerebral Cortex, 18,* 1987–1990. doi:10.1093/cercor/bhm237.

Knoch, D., Schneider, F., Schunk, D., Hohmann, M., & Fehr, E. (2009). Disrupting the prefrontal cortex diminishes the human ability to build a good reputation. *Proceedings of the National Academy of Sciences United States of America, 106,* 20895–20899. doi:10.1073/pnas.0911619106.

Knoch, D., Gianotti, L. R. R., Baumgartner, T., & Fehr, E. (2010). A neural marker of costly punishment behavior. *Psychological Science, 21,* 337–342. doi:10.1177/0956797609360750.

Kuhn, S., Haggard, P., & Brass, M. (2009). Intentional inhibition: How the "veto-area" exerts control. *Human Brain Mapping, 30,* 2834–2843. doi:10.1002/hbm.20711.

Kuhnen, C. M., & Chiao, J. Y. (2009). Genetic determinants of financial risk taking. *PLoS One, 4,* e4362. doi:10.1371/journal.pone.0004362..

Kurzban, R., & Leary, M. R. (2001). Evolutionary origins of stigmatization: The functions of social exclusion. *Psychological Bulletin, 127,* 187–208. doi:10.1037//0033-2909.127.2.187.

Lazar, S. W., Kerr, C. E., Wasserman, R. H., Gray, J. R., Greve, D. N., Treadway, M. T., et al. (2005). Meditation experience is associated with increased cortical thickness. *NeuroReport, 16,* 1893–1897. doi:10.1097/01.wnr.0000186598.66243.19.

Lewin, K. (1946). Behavior as a function of total situation. In D. Cartwright (Ed.), *Field theory in social science: Selected theoretical papers* (pp. 238–304). New York: Harper & Row. doi:10.1037/10756-016.

Lopez, R. B., Vohs, K., Wagner, D. D., & Heatherton, T. F. (2014). Self-regulatory strength: Neural mechanisms and implications for training. In G.H.E. Gendolla, S. Koole, & M. Tops (Eds.), *Handbook of Biobehavioral Foundations of Self-Regulation.* New York: Springer.

Meyer-Lindenberg, A., & Weinberger, D. R. (2006). Intermediate phenotypes and genetic mechanisms of psychiatric disorders. *Nature Reviews Neuroscience, 7,* 818–827. doi:10.1038/nrn1993.

Mischel, W., Ayduk, O., Berman, M. G., Casey, B. J., Gotlib, I. H., Jonides, J., et al. (2011). 'Willpower' over the life span: Decomposing self-regulation. *Social Cognitive and Affective Neuroscience, 6,* 252–256. doi:10.1093/scan/nsq081.

Muraven, M., & Baumeister, R. F. (2000). Self-regulation and depletion of limited resources: Does self-control resemble a muscle? *Psychological Bulletin, 126,* 247–259. doi:10.1037//0033-2909.126.2.247.

Näpflin, M., Wildi, M., & Sarnthein, J. (2007). Test-retest reliability of resting EEG spectra validates a statistical signature of persons. *Clinical Neurophysiology, 118,* 2519–2524. doi:10.1016/j.clinph.2007.07.022.

Nash, K., & Knoch, D. (in press). Individual differences in decision-making: A neural trait approach to study sources of behavioral heterogeneity. In M. Reuter & C. Montag (Eds.), *Neuroeconomics*. Berlin: Springer. Manuscript submitted for publication.

Nash, K., Schiller, B., Gianotti, L. R. R., Baumgartner, T., & Knoch, D. (2013). Integrating executive function and social decision-making: Response inhibition predicts self-control in a social context. *PLoS One*. Manuscript submitted for publication.

Paloyelis, Y., Asherson, P., Mehta, M. A., Faraone, S. V., & Kuntsi, J. (2010). DAT1 and COMT effects on delay discounting and trait impulsivity in male adolescents with attention deficit/hyperactivity disorder and healthy controls. *Neuropsychopharmacology: Official Publication of the American College of Neuropsychopharmacology, 35,* 2414–2426. doi:10.1038/npp. 2010.124.

Reimers, S., Maylor, E. A., Stewart, N., & Chater, N. (2009). Associations between a one-shot delay discounting measure and age, income, education and real-world impulsive behavior. *Personality and Individual Differences, 47,* 973–978. doi:10.1016/j.paid.2009.07.026.

Rigdon, M., Ishii, K., Watabe, M., & Kitayama, S. (2009). Minimal social cues in the dictator game. *Journal of Economic Psychology, 30,* 358–367. doi:10.1016/j.joep. 2009.02.002.

Rilling, J. K., & Sanfey, A. G. (2011). The neuroscience of social decision-making. *Annual Review of Psychology, 62,* 23–48. doi:10.1146/annurev.psych.121208.131647.

Rilling, J. K., Glenn, A. L., Jairam, M. R., Pagnoni, G., Goldsmith, D. R., Elfenbein, H. A., & Lilienfeld, S. O. (2007). Neural correlates of social cooperation and non-cooperation as a function of psychopathy. *Biological Psychiatry, 61,* 1260–1271. doi:10.1016/j.biopsych.2006.07.021.

Robbins, T. W., Gillan, C. M., Smith, D. G., de Wit, S., & Ersche, K. D. (2012). Neurocognitive endophenotypes of impulsivity and compulsivity: Towards dimensional psychiatry. *Trends in Cognitive Sciences, 16,* 81–91. doi:10.1016/j.tics.2011.11.009.

Robertson, E. M., Theoret, H., & Pascual-Leone, A. (2003). Studies in cognition: The problems solved and created by transcranial magnetic stimulation. *Journal of Cognitive Neuroscience, 15,* 948–960. doi:10.1162/089892903770007344.

Rorden, C., & Karnath, H. O. (2004). Using human brain lesions to infer function: A relic from a past era in the fMRI age? *Nature Reviews Neuroscience, 5,* 812–819. doi:10.1038/nrn1521.

Sanfey, A. G., Rilling, J. K., Aronson, J. A., Nystrom, L. E., & Cohen, J. D. (2003). The neural basis of economic decision-making in the ultimatum game. *Science, 300,* 1755–1758. doi:10.1126/science.1082976.

Shallice, T. I. M., & Burgess, P. W. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain: A Journal of Neurology, 114,* 727–741. doi:10.1093/brain/114.2.727.

Sharp, D. J., Scott, S. K., Mehta, M. A., & Wise, R. J. (2006). The neural correlates of declining performance with age: Evidence for age-related changes in cognitive control. *Cerebral Cortex, 16,* 1739–1749. doi:10.1093/cercor/bhj109.

Spitzer, M., Fischbacher, U., Herrnberger, B., Grön, G., & Fehr, E. (2007). The neural signature of social norm compliance. *Neuron, 56,* 185–196. doi:10.1016/j.neuron.2007.09.011.

Steinbeis, N., Bernhardt, B. C., & Singer, T. (2012). Impulse control and underlying functions of the left dorsolateral PFC mediate age-related and age-independent individual differences in strategic social behavior. *Neuron, 73,* 1040–1051. doi:10.1016/j.neuron.2011.12.027.

Steinberg, L. (2009). Adolescent development and juvenile justice. *Annual Review of Clinical Psychology, 5,* 459–485. doi:10.1146/annurev.clinpsy.032408.153603.

Stuss, D. T., & Benson, D. F. (1986). *The frontal lobes*. New York: Raven.

Suzuki, S., Niki, K., Fujisaki, S., & Akiyama, E. (2011). Neural basis of conditional cooperation. *Social Cognitive and Affective Neuroscience, 6,* 338–347. doi:10.1093/scan/nsq042.

Tabibnia, G., Satpute, A. B., & Lieberman, M. D. (2008). The sunny side of fairness preference for fairness activates reward circuitry (and disregarding unfairness activates self-control circuitry). *Psychological Science, 19,* 339–347. doi:10.1111/j.1467-9280.2008.02091.x.

Tabibnia, G., Monterosso, J. R., Baicy, K., Aron, A. R., Poldrack, R. A., Chakrapani, S., et al. (2011). Different forms of self-control share a neurocognitive substrate. *Journal of Neuroscience, 31,* 4805–4810. doi:10.1523/JNEUROSCI.2859 − 10.2011.

Takeuchi, H., Sekiguchi, A., Taki, Y., Yokoyama, S., Yomogida, Y., Komuro, N., & Kawashima, R. (2010). Training of working memory impacts structural connectivity. *Journal of Neuroscience, 30,* 3297–3303. doi:10.1523/JNEUROSCI.4611- 09.2010.

Tassy, S., Oullier, O., Duclos, Y., Coulon, O., Mancini, J., Deruelle, C., & Wicker, B. (2012). Disrupting the right prefrontal cortex alters moral judgement. *Social Cognitive and Affective Neuroscience, 7,* 282–288. doi:10.1093/scan/nsr008.

Thaler, R. H., & Shefrin, H. M. (1981). An economic theory of self-control. *Journal of Political Economy, 89,* 392–406. doi:10.1086/260971.

Tranel, D., Bechara, A., & Denburg, N. L. (2002). Asymmetric functional roles of right and left ventromedial prefrontal cortices in social conduct, decision-making, and emotional processing. *Cortex; A Journal Devoted to the Study of the Nervous System and Behavior*, 38, 589–612. doi:10.1016/S0010-9452(08)70024-8.

van 't Wout, M., Kahn, R. S., Sanfey, A. G., & Aleman, A. (2005). Repetitive transcranial magnetic stimulation over the right dorsolateral prefrontal cortex affects strategic decision-making. *NeuroReport, 16,* 1849–1852. doi:10.1097/01.wnr.0000183907.08149.14.

van den Bos, W., van Dijk, E., Westenberg, M., Rombouts, S. A., & Crone, E. A. (2011). Changing brains, changing perspectives: The neurocognitive development of reciprocity. *Psychological Science, 22,* 60–70. doi:10.1177/0956797610391102.

Van Lange, P. A., De Bruin, E., Otten, W., & Joireman, J. A. (1997). Development of prosocial, individualistic, and competitive orientations: Theory and preliminary evidence. *Journal of Personality and Social Psychology, 73,* 733–746. doi:10.1037/0022-3514.73.4.733.

Vohs, K. D., Mead, N. L., & Goode, M. R. (2006). The psychological consequences of money. *Science, 314,* 1154–1156. doi:10.1126/science.1132491.

von Hippel, W. (2007). Aging, executive functioning, and social control. *Current Directions in Psychological Science, 16,* 240–244. doi:10.1111/j.1467-8721.2007.00512.x.

Zaki, J., & Mitchell, J. (2013). Intuitive prosociality. *Current Directions in Psychological Science, 22,* 466–470. doi: 10.1177/0963721413492764.