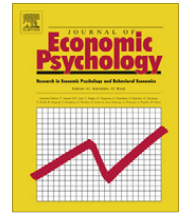




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The somatic marker framework as a neurological theory of decision-making: Review, conceptual comparisons, and future neuroeconomics research

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ABSTRACT

A great deal of contemporary decision research in economics, business, psychology, and neuroscience now accepts the idea that emotions play a significant role in decision-making. Almost 20 years ago, insights from studies on brain lesion patients set the cornerstone for this stream of research and led to the formulation of the somatic marker hypothesis. Despite some debate, the somatic marker framework is still providing a unique neuroanatomical and cognitive framework that helps explain the role of emotion in decision-making. In this article, we review the neurological background, core mechanisms, and critiques of the somatic marker theory, put into perspective conceptually related approaches that link emotion to decision-making, and present an outlook for future neuroeconomics research.

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1. Introduction

The observation that acquired damage to the ventromedial prefrontal cortex often leads to profound alterations in the ability to make advantageous decisions in personal, social, and financial domains has led A.R. Damasio to propose the somatic marker hypothesis (Damasio, 1994, 1996; Damasio, Tranel, & Damasio, 1991). One of the central features of this theory is that emotion-related signals (that is, somatic markers), which are indexed changes in the visceral state, such as changes in heart rate, blood pressure, gut motility, and glandular secretion, assist cognitive processes in implementing decisions. A further aspect of this theory is that these somatic markers can be nonconscious: they can bias behavior even when a person is not really aware of them.

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Changes in the visceral state may be considered a form of anticipation of the bodily impact of objects and events in the world. Visceral responses to biologically relevant stimuli allow an organism to maximize the survival value of situations that may impact the state of the internal milieu. These include events that promote homeostasis, such as an opportunity to feed or engage in social interaction, as well as events that disrupt homeostasis, such as a physical threat or a signal of social rejection. Visceral responses are just one component of a broader emotional response system that also includes changes in the endocrine and skeletomotor systems, as well as changes within the brain that alter the perceptual processing of biologically relevant stimuli (Damasio, 1994).

James (1884) initially proposed that visceral responses to biologically relevant stimuli are a necessary component of the subjective experience of emotion. Specifically, James (1884) proposed that subjective feelings—the hedonic meaning that is attributed to objects and events in the world—arises from the sensory feedback of the visceral responses that are elicited by those objects and events. According to the somatic marker hypothesis (Damasio, 1994, 1996; Damasio et al., 1991), the sensory mapping of visceral responses not only contributes to feelings, but this mapping is also important for the execution of highly complex, goal-oriented behaviors. In this view, visceral responses function to “mark” potential choices as being advantageous or disadvantageous. This process aids in decision-making in which there is a need to weigh positive and negative outcomes that may not be predicted decisively through “cold” rationality alone. Both the Jamesian view and the somatic marker hypothesis hold that the brain must contain a system that translates the sensory properties of external stimuli into changes in the visceral state that reflect their biological relevance. The somatic marker hypothesis argues that this is the essential function of the ventromedial prefrontal cortex—a function that ties control of the visceral state to decision-making and affect.

Despite the fact that the original studies on somatic markers and their impact on the decision-making field (Bechara & Damasio, 2005; Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, Tranel, & Damasio, 1997) have inspired many subsequent studies, and at least in part, may have driven the emergence of the new fields of neuroeconomics, decision neuroscience, and consumer neuroscience (Hansen & Christensen, 2007; Kenning & Plassmann, 2005; Shiv et al., 2005a), some views have critiqued the concept of somatic markers and questioned its utility as an explanatory framework for decision-making (Maia & McClelland, 2004, 2005). While the somatic marker framework incorporates the roles of many different brain structures relevant to decision-making, whose neuroanatomical arrangement has been validated by a multitude of lesion and functional neuroimaging studies (Dunn, Dalgleish, & Lawrence, 2006), most of the critiques have been leveled on only one specific component of the somatic marker neural circuitry, namely the role of peripheral body signals in decision-making. Although the somatic marker framework postulates an “as-if-body loop”, which bypasses the peripheral route altogether, most criticism is often about the role of these body signals in decision-making. However, the fact remains that there are no currently available neurological theories that provide an alternative to the somatic marker theory. Most often, the somatic marker theory is critiqued and contrasted to models that are not neurological in perspective. More specifically, seemingly competing frameworks and models—mostly psychological, cognitive, or behavioral—derive their critique from the viewpoints of their own domains and schools of thought, while the somatic marker theory was established on neurological evidence based on the comparison of decision-making strategies of patients with specific and focal brain lesions to healthy subjects. Because of the theoretical origin of the different approaches—neurology and neuroscience for the somatic marker theory and psychology, cognitive science, and behaviorism for other models of decision-making—a conceptual comparison simply leads to a comparison of “apples and oranges” and, therefore, does not yield meaningful insights.

The somatic marker framework is a neurological theory of decision-making, which specifically details the different neural steps that take place inside the brain before the execution of a decision. Certainly, there are currently numerous neuroscientific studies on decision-making that address the role of a whole variety of events such as expectation, conflict monitoring, gains, losses, and error detection in decision-making. However, none of these theories are comprehensive neurological theories, and they rather focus on only one specific process of the more complex phenomenon of decision-making. For example, the dopaminergic system has been implicated in decision-making (D’Ardenne, McClure, Nystrom, & Cohen, 2008; Montague, Dayan, & Sejnowski, 1996; Schultz, 1998) and is clearly considered a neuroscientific approach to decision-making. Yet, the dopamine story is very specific and constrained, and does not explain decision-making and its influence by emotions in a comprehensive manner as somatic marker theory does. Moreover, the somatic marker model is inclusive of the role of dopamine in decision-making (Bechara & Damasio, 2005). Therefore, the dopamine link to reward, error prediction, and decision-making (Bayer & Glimcher, 2005; Bayer, Lau, & Glimcher, 2007; Pessiglione, Seymour, Flandin, Dolan, & Frith, 2006) is not an alternate view to the somatic marker hypothesis, but rather one specific link in a broader neural model of decision-making described under the somatic marker framework.

The objective of this article is to highlight some of the empirical evidence, from both patients with focal brain lesions and from neuroimaging research, which support predictions from somatic marker theory. Further, we will try to address some of the key criticisms of somatic marker theory (Dunn et al., 2006; Maia & McClelland, 2004, 2005). We will also put somatic marker theory and seemingly related frameworks—specifically, concepts of risk-as-feeling, anticipatory affect, and net emotional response strength—in perspective by highlighting some differences and commonalities. Finally, we will derive potential avenues for further research in neuroeconomics, decision neuroscience, and consumer neuroscience.

2. Somatic marker theory

2.1. Background

Previous research has studied patients with lesions (that is, injuries) of the frontal lobes of their brains. Although many of these patients maintained a normal intellect (that is, an average intelligence quotient of around 100), they demonstrated impairments in decision-making (Bechara, Damasio, Tranel, & Anderson, 1998; Damasio, Tranel, & Damasio, 1990; Eslinger & Damasio, 1985). This body of research was originally inspired by the case of Phineas Gage, a railroad worker of the 19th century. While surviving an accident in railroad construction that led to serious brain injury in his frontal lobes, Phineas Gage's personality, social conduct, judgment, and decision-making changed due to the accident (Harlow, 1848, 1868).

Damasio, Grabowski, Frank, Galaburda, and Damasio (1994) remeasured Gage's skull and utilized neuroimaging techniques in order to reconstruct the accident and determine the likely location of the brain lesion. They found that the damage included left and right prefrontal cortices and caused a defect in rational decision-making and emotional processing. Contemporary counterparts of Phineas Gage support this notion. Often, choices made by these contemporaries significantly differ from decisions they would have made before the brain damage. These choices also deviate from their best interest (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; Bechara et al., 1998; Eslinger & Damasio, 1985).

More specifically, patients with damage in a specific area of the frontal lobes (that is, the ventromedial prefrontal cortex) have severe difficulties in planning their workday and choosing friends, partners, and activities (Bechara & Damasio, 2005). Moreover, patients repeatedly engage in decisions that lead to negative consequences without learning (Anderson et al., 1999; Bechara et al., 1998). Their decisions, thus, often lead to a variety of losses including financial losses, losses in social standing, or losses of family and friends.

2.2. Core mechanisms

At the core of somatic marker theory lays the insight that decision-makers encode the consequences of alternative choices affectively. Bechara's (1994) development of what became known as the Iowa Gambling Task has enabled researchers, for the first time, to detect the decision-making impairment characteristic of patients with ventromedial prefrontal cortex lesions and investigate its possible causes. Such work using the Iowa Gambling Task has provided the key empirical support for the proposal that somatic markers significantly influence decision-making (Bechara & Damasio, 2005). Extant research—largely based on the Iowa Gambling Task as a behavioral measure of decision-making (Bechara, Damasio, Damasio, & Anderson, 1995; Bechara et al., 1994, 1997)—identified several important brain areas, which support somatic marker theory (because of the widespread use of the Iowa Gambling Task, Table 1 summarizes a selection of key empirical studies analyzing lesion patients and neuroimaging).

Several neural structures have been shown to be key components of the neural circuitry underlying somatic state activation. The amygdala as well as the medial orbitofrontal cortex/ventromedial prefrontal cortex region are critical structures for triggering somatic states, but the amygdala seems more important for triggering somatic states from emotional events that occur in the environment (that is, primary inducers), whereas the medial orbitofrontal cortex/ventromedial prefrontal cortex region seems more vital for triggering somatic states from memories, knowledge, and cognition (that is, secondary inducers) (Bechara & Damasio, 2005). Decision-making is a complex process that relies on the integrity of at least two sets of neural systems: (1) one set is important for memory (e.g., the hippocampus), and especially working memory (e.g., the dorsolateral prefrontal cortex), in order to bring online knowledge and information used during the deliberation of a decision; (2) another set is important for triggering emotional responses. This set includes effector structures such as the hypothalamus and autonomic brainstem nuclei that produce changes in internal milieu and visceral structures along with other effector structures such as the ventral striatum, periaqueductal gray, and other brainstem nuclei, which produce changes in facial expression

Table 1

Selected empirical studies supporting the somatic marker theory.

Author(s) (chronologically sorted)	Task	Method	Relevant brain area(s)
Bechara et al. (1994, 1995)	Iowa Gambling Task	Study of lesion patients	Ventromedial prefrontal cortex
Bechara et al. (1997)	Iowa Gambling Task	Study of lesion patients	Ventromedial prefrontal cortex
Bechara, Damasio, Damasio, and Lee (1999)	Iowa Gambling Task	Study of lesion patients	Ventromedial prefrontal cortex, amygdala
Ernst et al. (2002)	Iowa Gambling Task	PET	Ventromedial prefrontal cortex, dorsolateral prefrontal cortex, medial orbitofrontal cortex
Manes et al. (2002)	Iowa Gambling Task	Study of lesion patients	Dorsolateral prefrontal cortex, orbitofrontal cortex,
Fellows and Farah (2005)	Iowa Gambling Task	Study of lesion patients	Ventromedial prefrontal cortex, dorsolateral prefrontal cortex
Northoff et al. (2006)	Iowa Gambling Task	fMRI	Ventromedial prefrontal cortex
Windmann et al. (2006)	Iowa Gambling Task	fMRI	Medial orbitofrontal cortex
Tanabe et al. (2007)	Iowa Gambling Task	fMRI	Ventromedial prefrontal cortex, dorsolateral prefrontal cortex
Frangou et al. (2008)	Iowa Gambling Task	fMRI	Ventral prefrontal cortex, dorsal prefrontal cortex
Lawrence et al. (2009)	Iowa Gambling Task	fMRI	Ventral prefrontal cortex, dorsal prefrontal cortex

and specific approach or withdrawal behaviors. It also includes cortical structures that receive afferent input from the viscera and internal milieu, such as the insular cortex and the posterior cingulate gyrus, retrosplenial cortex, and cuneus region (that is, medial area of the parietal cortex).

During the process of pondering decisions, the immediate prospects of an option may be driven by more subcortical mechanisms (e.g., via the amygdala) that do not require a prefrontal cortex. However, weighing the future consequences requires a prefrontal cortex for triggering somatic responses about possible future consequences. Specifically, when pondering the decision, the immediate and future prospects of an option may trigger numerous somatic responses that conflict with each other (that is, positive and negative somatic responses). The end result, though, is that an overall positive or negative signal emerges (a “go” or “stop” signal). There is a debate as to where this overall somatic state may be computed. We have argued that this computation occurs in the body proper (via the so-called body loop), but it can also occur in the brain itself, in areas that represent “body” states such as the dorsal tegmentum of the midbrain, or areas such as the insula and posterior cingulate (via the so-called as-if-body loop). The controversy has largely been in relation to the body loop, with certain investigators arguing that decision-making is not necessarily dependent on “somatic markers” expressed in the body (e.g., [Maia & McClelland, 2004](#)). Counterarguments have been brought forward in the literature ([Bechara, Damasio, Tranel, & Damasio, 2005](#); [Persaud, McLeod, & Cowey, 2007](#)). Irrespective of whether this computation occurs in the body itself or within the brain, we have proposed that the emergence of this overall somatic state is consistent with the principles of natural selection. In other words, numerous and conflicting signals may be triggered simultaneously, but stronger ones gain selective advantage over weaker ones, until a “winner-takes-all” emerges that consequently biases the decision ([Bechara et al., 2005](#)).

In order for somatic signals to influence cognition and behavior, they must act on the appropriate neural systems. One target of somatic state action is the striatum. A large number of channels convey body information (that is, somatic signals) to the central nervous system (e.g., spinal cord, vagus nerve, and humoral signals). Evidence suggests that the vagal route is especially critical for relaying somatic signals ([Martin, Denburg, Tranel, Granner, & Bechara, 2004](#)). Further, it was proposed that the next link in this body-brain channel involves neurotransmitter systems ([Bechara & Damasio, 2005](#); [Damasio, 1994, 1996](#)). Indeed, the cell bodies of the neurotransmitter dopamine, serotonin, noradrenaline, and acetylcholine are located in the brainstem; the axon terminals of these neurotransmitter neurons synapse on cells and/or terminals all over the cortex and striatum ([Blessing, 1997](#)). When somatic state signals are transmitted to the cell bodies of dopamine or serotonin neurons, for example, the signaling influences the pattern of dopamine or serotonin release at the terminals. In turn, changes in dopamine or serotonin release will modulate synaptic activities of neurons subserving behavior and cognition within the cortex. This chain of neural mechanisms provides a way for somatic states to exert a biasing effect on decisions. At the cellular, and more recently the functional neuroimaging level, the pioneering work of [Schultz, Dayan, and Montague \(1997\)](#) on the role of dopamine in reward processing and error prediction provide a strong validity for the proposed neural framework. Thus, all the work related to dopamine and the ventral striatum is consistent with the somatic marker framework. The key difference is that the dopamine mechanism addresses only one specific component of a larger neural network that is important for implementing decisions. The somatic marker hypothesis is a neural framework that incorporates all the different neural steps involved in decision-making, including the dopamine link, such as the one initially studied by [Schultz et al. \(1997\)](#).

We note that one of the clear predictions of the somatic marker hypothesis is that working memory is a key process in decision-making. Consequently, damage to neural structures that impair working memory, such as the dorsolateral prefrontal cortex, also lead to impaired decision-making. Nonetheless, some criticisms of the theory were made on the basis that deficits in decision-making as measured by the Iowa Gambling Task may not be specific to the ventromedial prefrontal cortex ([Manes et al., 2002](#)) or it may be explained by deficits in other processes such as reversal learning ([Fellows & Farah, 2003](#)). However, research has demonstrated that the relationship between decision-making on the one hand and working memory or reversal learning on the other hand are asymmetrical in nature (e.g., [Bechara, 2004](#); [Bechara et al., 2005](#)). In other words, working memory and/or reversal learning are not dependent on the intactness of decision-making (that is, subjects can have normal working memory and normal reversal learning in the presence or absence of deficits in decision-making). Some patients with ventromedial prefrontal cortex lesions who were severely impaired in decision-making (that is, abnormal in the Iowa Gambling Task) had superior working memory, and are perfectly normal on simple reversal learning tasks. In contrast, decision-making seems to be influenced by the intactness or impairment of working memory and/or reversal learning (that is, decision-making is worse in the presence of abnormal working memory and/or poor reversal learning). Patients with right dorsolateral prefrontal cortex lesions and severe working memory impairments showed low normal results in the Iowa Gambling Task ([Bechara et al., 1998](#)). Patients with damage to the more posterior sector of the ventromedial prefrontal cortex (which includes the basal forebrain), such as the patients who were included in the study by [Fellows and Farah \(2003\)](#), showed impairments on reversal learning tasks, but similar patients with similar lesions also showed poor performance on the Iowa Gambling Task ([Bechara et al., 1998](#)).

2.3. Replication

Several studies that have looked at neural activation while participants performed the Iowa Gambling Task, largely replicating results from lesion studies. One study had individuals perform the Iowa Gambling Task while situated in a positron emission tomography (PET) scanner ([Ernst et al., 2002](#)). The control task in this experiment involved the examiner signaling the participant to select cards from the four decks in a specified order, instead of allowing the participant to actually select

decks. A predominantly right-sided network of prefrontal and posterior cortical regions was activated, which included the medial orbitofrontal cortex/ventromedial prefrontal cortex region, adjacent anterior cingulate cortex, dorsolateral prefrontal cortex, insula, and adjacent inferior parietal cortex (Ernst et al., 2002). This neural network overlaps considerably with that known from lesion studies to interfere with Iowa Gambling Task performance, as outlined earlier. Abnormal activity in this neural circuitry affecting Iowa Gambling Task performance was revealed in a subsequent PET study, using the same Iowa Gambling Task protocol, on cocaine users, who showed impaired performance on the Iowa Gambling Task (Bolla et al., 2003). Cocaine use was associated with increased activation in the right medial orbitofrontal cortex and decreased activation in the right dorsolateral prefrontal cortex, relative to the performance of healthy participants. In a different study, which involved patients in a more acute phase of cocaine abstinence, Iowa Gambling Task performance was negatively correlated with activity in the anterior cingulate gyrus, which is a part of the medial orbitofrontal cortex/ventromedial prefrontal cortex region; and the middle frontal gyrus, medial frontal gyrus, and superior frontal gyrus, all of which are parts of the dorsolateral prefrontal cortex (Tucker et al., 2004).

Similar neural correlates underlying Iowa Gambling Task performance were revealed using functional magnetic resonance imaging (fMRI). Fifteen healthy volunteers performed the Iowa Gambling Task while having their brain activity scanned using event-related fMRI (Fukui, Murai, Fukuyama, Hayashi, & Hanakawa, 2005). When the neural activity occurring during selections from the advantageous decks was compared with the neural activity occurring during selections from the disadvantageous decks, it was found that activity during the anticipatory period (that is, the time spent pondering which deck to choose) engaged the superior part of the anterior cingulate and the neighboring medial frontal gyrus. This activity occurred in an area that is relatively superior to the medial orbitofrontal cortex/ventromedial prefrontal cortex area, though it still lies within the overall region known for housing decision-making impairments in patients with prefrontal cortex lesions. It is unclear whether the medial orbitofrontal cortex/ventromedial prefrontal cortex area was precluded in this fMRI study because of signal dropout due to distortion artifacts. Northoff et al. (2006) analyzed the relationship between the ventromedial prefrontal cortex, emotionally accentuated affective judgment (that is, unexpected), cognitively accentuated affective judgment (that is, expected), and performance on the Iowa Gambling Task. Neuronal activity in the ventromedial prefrontal cortex during unexpected affective judgment significantly correlated with Iowa Gambling Task performance. The authors posit that the degree to which subjects recruit the ventromedial prefrontal cortex during affective judgments is related to beneficial performance on the Iowa Gambling Task (Northoff et al., 2006). These findings support the claim of somatic marker theory that not only cognitive but also affective mechanisms are crucial for decision-making. Since affective judgments require an interaction between affective and cognitive components, it might be considered a key process in decision-making that has been linked to neural activity in the ventromedial prefrontal cortex. Another study in different groups of substance-dependent individuals and in pathological gamblers using fMRI showed, relative to controls, reductions in the ventromedial prefrontal region activity, and in the right frontopolar and superior frontal cortex regions (these areas are part of the dorsolateral prefrontal cortex) during performance of the Iowa Gambling Task (Tanabe et al., 2007). Research by Windmann et al. (2006) used the original and inverted versions of the Iowa Gambling Task in healthy controls and suggested that the tendency to choose from the bad decks for longer in the original, relative to the inverted, task activated the medial orbitofrontal cortex more, which is consistent with the notion that the medial orbitofrontal cortex is involved in maintaining a behavioral strategy. Conversely, the inverted task activated more the lateral orbitofrontal cortex subregions, consistent with the notion that the ability to shift from the initially preferred choice option to alternative options is the relevant variable determining lateral orbitofrontal cortex activation, as well as performance on the Iowa Gambling Task, and not the ability to look into the future. Furthermore, Frangou, Kington, Raymont, and Shergill (2008) had patients with bipolar disorder (that is, a manic-depressive illness, which results in alterations in mood, energy and activity levels, as well as the capability to perform everyday tasks) and a healthy control group perform the Iowa Gambling Task inside an fMRI scanner. The authors found that while healthy controls showed significant activation in both the ventral and dorsal prefrontal cortex; this activation was attenuated in bipolar disorder patients. Instead, bipolar disorder patients showed increased activation in both lateral temporal and polar regions. These results suggest that trait abnormalities in dorsal and ventral prefrontal cortex function in bipolar disorder patients exist (Frangou et al., 2008). Additionally, Lawrence, Jollant, O'Daly, Zelaya, and Phillips (2009) utilized the Iowa Gambling Task to analyze decision-making under initially ambiguous circumstances. Using a version of the Iowa Gambling Task that was modified for event-related fMRI, the authors find involvement of several prefrontal cortical regions in task performance. Decision-making in healthy subjects resulted in ventromedial prefrontal cortex activation. The findings of this study not only replicate but also add to prior research in that they disclose that deciding advantageously under initially ambiguous circumstances may require both continuous and dynamic processes involving the ventral and dorsal prefrontal cortex (Lawrence et al., 2009). As such, this research adds more validity to the Iowa Gambling Task in terms of eliciting dorsal and ventral prefrontal cortex activation.

In summary, the ventromedial prefrontal cortex, the dorsolateral prefrontal cortex, the medial orbitofrontal cortex, and the amygdala emerge as key brain areas related to emotion and decision-making from the aforementioned research and, as such, form the neuroanatomical basis of the somatic marker framework. Fig. 1 illustrates these brain areas.

2.4. Criticism and justification

Recent studies argued that impaired performance on the Iowa Gambling Task could be owed to impairments in reversal learning, working memory, attentional shift, and related high-level cognitive processes (Dunn et al., 2006; Maia &

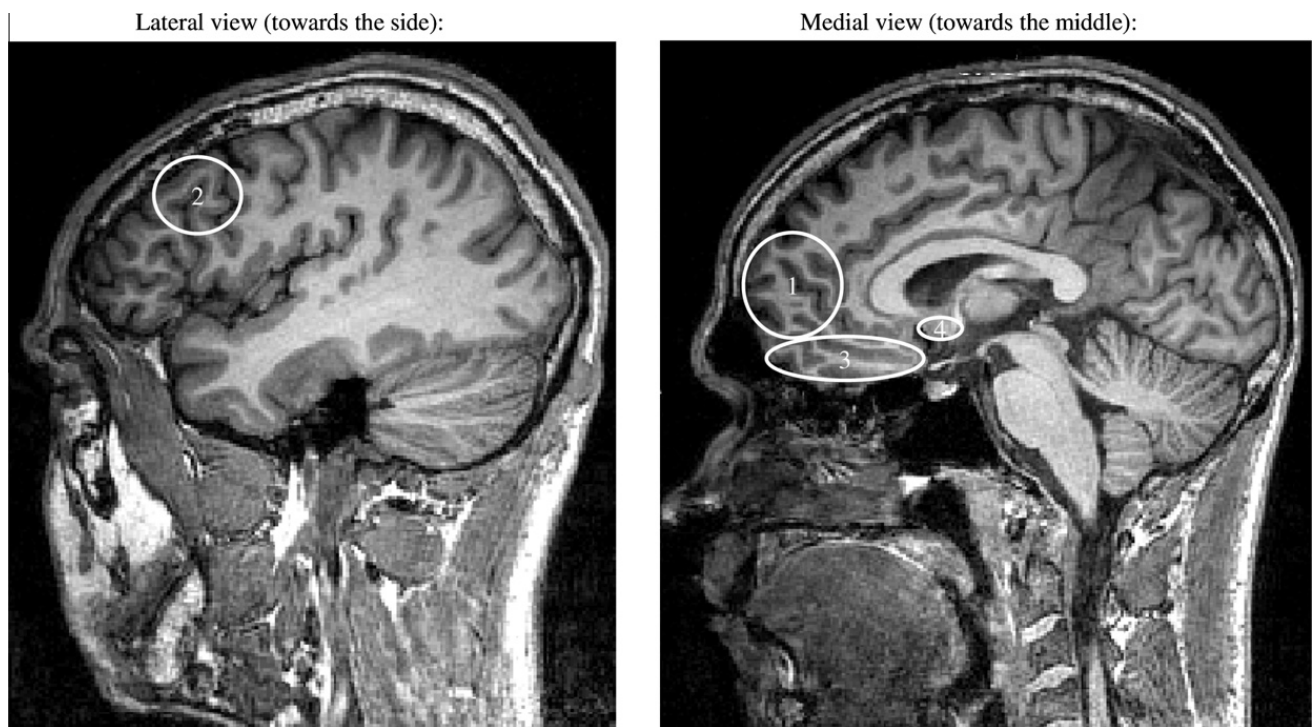


Fig. 1. Relevant brain areas in somatic marker theory. *Note*– Approximate locations of relevant brain areas in somatic marker theory: (1) Ventromedial prefrontal cortex, (2) dorsolateral prefrontal cortex, (3) medial orbitofrontal cortex, (4) amygdala.

McClelland, 2004, 2005). However, as we discussed earlier, this possibility is not always true. Specifically, we have shown that deficits in reversal learning and working memory can lead to poor decision-making. However, impaired decision-making can still occur independent of any working memory or reversal learning deficit, thus suggesting that the two mechanisms have an asymmetrical relationship.

Another criticism has been made by Maia and McClelland (2004) in that somatic markers are not really needed for decision-making. At a time when Bechara et al. (1997) posited that somatic markers were guiding decisions before any conceptual knowledge about the task has formed, Maia and McClelland (2004) argued that participants had more knowledge about the game (that is, the Iowa Gambling Task) at a much earlier stage in the game than previously thought; thus, suggesting that knowledge, and not somatic markers, could be the guide for advantageous decisions. To make their argument, Maia and McClelland (2004) relied on the use of a very probing and inquisitive procedure to measure knowledge, which we believe has the adverse effect of construing knowledge and leading the subject to the correct response. Indeed, this is what was revealed subsequently by a study conducted by Persaud et al. (2007). In this study, the investigators tested the decision-making behavior of a sample of subjects in three different ways: (1) no interruption in the task at all; (2) there were interruptions but the questions were very open and identical to the procedure of Bechara et al. (1997); and (3) there were interruptions but the questions were detailed and identical to the procedure of Maia and McClelland (2004). More importantly, Persaud et al. (2007) used a clever procedure for assessing conceptual knowledge, which is wagering, a behavioral method that is thought to independently measure the level of knowledge and confidence about one's decision. The results clearly revealed that the no-question method as well as the open question method of Bechara et al. (1997) were very similar, and both methods showed that subjects began to choose advantageously at a time much earlier than when they began to increase their wagering about their choices (that is, reflecting the level of their knowledge). In contrast, the detailed question method resulted in a shift to the left in the wagering curve, suggesting that subjects began to acquire knowledge about the task much earlier on, which is likely the result of using a more probing questioning procedure that inadvertently leads to the introduction of knowledge.

In another critical study, Dunn et al. (2006) posit that the interpretation of somatic marker theory are undermined by potential cognitive penetrability of a reward versus punishment schedule, ambiguity regarding the interpretation of psychophysiological data presented in earlier research as well as a shortage of causal support on the link between peripheral feedback to performance on the Iowa Gambling Task. The authors conclude that while somatic marker theory provides an framework of the impact of emotions on decision-making, it requires additional empirical support (Dunn et al., 2006). Nonetheless, the key criticism of Dunn et al. (2006) to the somatic marker theory is primarily related to the peripheral nervous system link (or the body loop) of the neural circuitry, which admittedly remains the most controversial and the weakest link in the whole theory. However, Dunn et al.'s (2006) review also acknowledges the strength of the somatic marker theory in terms of its neuroanatomical basis, and the fact that the theory receives a considerable empirical support for its neuroanatomical structure from a variety of approaches, including functional neuroimaging.

In summary, criticisms of the somatic marker theory seem to arise from two common sources. One source is contrasting the somatic marker theory with other available affect-based theories of decision-making, the majority of which are psychological or behavioral in perspective; such examples include the use of behavioral constructs such as reversal learning to explain the decision-making impairment of brain lesion patients, or the use of other cognitive constructs (e.g., [Maia & McClelland, 2004](#)) to eliminate the need for somatic markers. Another source of criticism is primarily directed against the body link in the theory, which argues that somatic states can be triggered in the body itself before exerting an influence on brain systems involved in decision-making. This peripheral link remains the weakest link in the theory because of the impossibility of getting patients that have a complete disconnection between their body and their brain. No matter which neurological condition involves the peripheral nervous system (e.g., spinal cord transection or peripheral neuropathies), the condition never provides a complete disconnection between the body and brain—there will always be spared routes for the body to provide neural signaling to the brain. The only condition that leads to almost complete disconnection is a lesion in the dorsal tegmentum of the brainstem, but unfortunately such damage leads to a coma or it is incompatible with life. For these practical reasons, the tests of the hypothesis that body signals influence decision-making have remained inconclusive. Regardless, the somatic marker theory is not contingent on this peripheral link, and its description of the various roles that many other different brain regions play in emotional processing and decision-making have been tested over time and have received robust support from numerous studies (e.g., see [Dunn et al., 2006](#) for a review). Thus, the somatic marker theory remains the only neurological theory of decision-making.

3. Related approaches to emotion and decision-making

Although this article focuses on the somatic marker theory that provides a comprehensive description of the neural events that take place during decision-making all the way from perception to the execution of a motor response, there are several other emotion-based theories of decision-making. One such a prominent theory is (1) the risk-as-feeling concept, which originates in the judgment and decision-making research community and stems from economic and psychological thought. We will also stress (2) the anticipatory affect concept that is largely based on psychological thinking with strong conceptual links to neuroscience. Both views yield conceptual similarities between them in that they try to shed light on the important role of emotions in decision-making. Finally, we will elaborate on (3) the concept of net emotional response strength, which plays an important role in consumer choice research.

3.1. Concept of risk-as-feeling

[Loewenstein, Weber, Hsee, and Welch \(2001\)](#) proposed a concept of ‘risk-as-feeling’, which suggests that responses to risky situations, including decision-making, result partly from direct (that is, not cortically mediated) emotional influences. These influences comprise feelings such as worry, fear, dread, and anxiety. According to the model, risk evaluation takes place at a cognitive level. While these evaluations are based largely on the probability and desirability of associated consequences, they also have affective consequences, which have a reciprocal influence on cognitive evaluations ([Loewenstein et al., 2001](#)). As such, the model claims that emotional reactions to risky situations often diverge from cognitive assessments of those risks. When such divergence occurs, emotional reactions often drive decision-making. Taking this perspective, the risk-as-feeling concept is in contrast to the bulk of current theories of decision-making in the classical judgment and decision-making domain, which are cognitive and consequentialist in nature. That is, these theories assume that decision-makers assess the desirability and likelihood of possible choice outcomes and integrate this information through expectation-based calculus to arrive at a decision ([Loewenstein et al., 2001](#)).

The risk-as-feelings concept is conceptually similar to somatic marker theory, in that it highlights the important role played by emotions in decision-making. However, unlike the somatic marker framework, the risk-as-feeling concept does not go into detailing the different roles played by diverse brain regions during decision-making, and therefore, the concept is purely psychological. Aside from this obvious difference, there may also be some conceptual distinctions. In contrast to somatic marker theory, [Loewenstein et al. \(2001\)](#) note that the lack of an emotional response may not automatically lead to a poor decision. [Loewenstein et al. \(2001\)](#) claim that it is the special design of the Iowa Gambling Task that leads patients with prefrontal damage into bankruptcy. These authors also suggested that an alternative experiment could be designed with an expected value of the high-risk deck that is actually higher than that of the low-risk deck. In this case, [Loewenstein et al. \(2001\)](#) predicted that patients with prefrontal cortex lesions would do better in the long run than the healthy subjects because fear among the healthy subjects deters them from choosing the risky but higher expected value deck. In fact, such an experiment was conducted and it confirmed [Loewenstein et al.’s \(2001\)](#) prediction in that patients with damage to brain areas that are critical for processing emotions demonstrated more rational and better decisions, relative to healthy individuals, on a laboratory investment task designed to simulate the phenomenon of myopic loss aversion ([Shiv, Loewenstein, Bechara, Damasio, & Damasio, 2005b](#)). Although most of the previous work in connection with somatic marker theory argued for the beneficial role of emotions in decision-making, unquestionably there are conditions under which emotions can be disruptive to decision-making. The key point is that emotions play a key role in influencing decision-making. Specifically, emotions play a major role in the interaction between environmental conditions and human decision processes, with neural systems carrying emotional signals, providing valuable implicit or explicit knowledge for making fast and often advantageous decisions. But sometimes, these emotional signals interfere with rational decisions. Thus, it is not a simple issue of

trusting biases and emotions as the necessary arbiter of good and bad decisions. It is a matter of discovering the circumstances in which biases and emotions can be useful or disruptive. The somatic marker theory does not predict the difference between those circumstances. Therefore, further research aimed at uncovering and determining the conditions under which emotions (or somatic markers) are helpful, so that one can enhance them, and the circumstances under which they are disruptive (so that one can control them) would be of tremendous practical significance.

3.2. *Concept of anticipatory affect*

Another approach to the relationship between emotions and decision-making has been coined ‘anticipatory affect’ (Kuhnen & Knutson, 2005). Current research on anticipatory affect is based on the notion that affect happens before the outcome—that is, during anticipation of an outcome. More specifically, anticipatory affect is defined as emotional states that are experienced while anticipating significant outcomes, e.g., pertaining to a decision (Knutson & Greer, 2008). As such, it is not clear how the anticipatory affect framework would be conceptually different from that of somatic marker theory, and, therefore, the two concepts are in fact similar. Recent research under the umbrella term of anticipatory affect has investigated affect anticipation, for example, before engaging in financial risks (Knutson, Adams, Fong, & Hommer, 2001; Knutson, Wimmer, Kuhnen, & Winkielman, 2008a; Kuhnen & Knutson, 2005) and before buying or selling products (Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007; Knutson et al., 2008b). These studies confirmed an experience of emotional states while anticipating significant outcomes and, as such, provide strong empirical support for the claims of somatic marker theory. One stance from this body of work is that all anticipatory affect depends on a chain of physiological events that occur entirely within the brain. However, the work of Knutson and colleagues never involved any manipulations of the peripheral nervous system, and therefore ruling out these mechanisms cannot be confirmed on the basis of the functional neuroimaging work that was conducted alone. Moreover, the criticism of the peripheral (body loop) link is not a first; as indicated earlier, this peripheral mechanism remains the most difficult to prove or disprove.

3.3. *Concept of net emotional response strength*

Another concept that has been introduced and that emphasizes the important role of affect and emotions in decision-making comes from the domain of consumer choice (Hansen, 2005; Hansen & Christensen, 2007). Hansen and Christensen (2007) recognized the insufficiency of the available models of consumer choice in explaining consumer behavior and argued for the importance of incorporating affect when studying consumer choice. Further, Hansen and Christensen (2007) developed the concept of net emotional response strength. When applying this concept, subjects are given a variety of brands and are asked to rate how they feel about the brand, using a list of positive and negative feelings. For each brand, a number of positive versus negative factors are extracted, and the net emotional response strength is the difference between the two (which is positive or negative). Presumably, this net emotional response strength is a predictor of whether individuals would choose this brand or not (Hansen & Christensen, 2007). This concept is highly consistent with the somatic marker framework in that it reduces choice to a competition between positive and negative emotional responses, and then the net result is what may play a key role in influencing consumer choice. One issue that remains to be addressed is how this computation may occur. As indicated earlier, the somatic marker framework proposes that the computation takes a Darwinian form (that is, the “winner-takes-all”), whereas the net emotional response strength uses an algebraic sum of the positive and negative emotions.

4. *Outlook for future neuroeconomics research*

Somatic marker theory provides at least three avenues for future research in the areas of neuroeconomics, decision neuroscience, and consumer neuroscience: (1) localization versus differentiation, (2) prediction, and (3) theory testing.

4.1. *Localization versus differentiation*

Future neuroeconomics research may utilize somatic marker theory because it provides a systems-level neuroanatomical and cognitive framework for decision-making and its impact by emotion (Bechara & Damasio, 2005). A core issue in prior and current neuroeconomics research—specifically in its applied branches of decision neuroscience and consumer neuroscience—has been the “localization versus differentiation” debate (a roundtable discussion on the future of consumer neuroscience held at the *Association for Consumer Research Annual Conference* in San Francisco, California on October 25, 2008 highlighted this issue among other topics). While in early neuroeconomics research, single facets of decision-making (e.g., choice or preference) have been linked to single brain areas (and, thus, focused largely on localization), contemporary research calls for a more holistic analysis (that is, incorporating a multitude of the most relevant brain areas). Furthermore, future research in neuroeconomics should require a differentiated analysis of the relative impact of a particular brain area and its network on decision-making. As such, future studies should differentiate brain areas’ impact in addition to their localization. Here, we suggest that through its integration of several brain areas, somatic marker theory might be particularly suited as a holistic framework for neuroeconomics research.

4.2. Prediction

Furthermore, somatic marker theory can be used to make hypothetical predictions of the activation of certain brain areas. Extant neuroeconomics research has greatly relied on fMRI as methodology to study brain activation. Yet, prior research has often been exploratory in nature and has not been based on a thorough development of neural hypotheses. Yet, only analyzing “what lights up in the brain” without incorporating neuroanatomical insight might not yield meaningful results and maybe difficult to replicate. Therefore, somatic marker theory may support future neuroeconomic research—specifically at the interface of emotion and decision-making—in becoming more confirmatory in nature and, thus, improving the reliability and validity of research results.

4.3. Theory testing

Finally, somatic marker theory maybe used to confirm or disconfirm existing theories of decision-making. Since the Iowa Gambling Task, which was used to verify the somatic marker hypothesis, has been independently replicated in numerous brain lesion and neuroimaging studies (including PET and fMRI), it may serve as useful task for future decision-making studies that try to test specific theories stemming from economics thought or business issues.

5. Conclusion

This article examined somatic marker theory and its underlying neuroanatomical and cognitive framework that helps explain the role of emotion in decision-making. After almost 20 years of research, somatic marker theory is still providing important insight for decision research—and its contemporary off-springs neuroeconomics, decision neuroscience, and consumer neuroscience. Reviewing previous applications of one important measure used in research on the somatic marker hypothesis—the Iowa Gambling Task—we elaborated on a number of brain areas involved in decision-making. Furthermore, we put somatic marker theory in perspective to alternative explanations of emotion and decision-making, which are largely rooted in psychology, cognitive science, and behaviorism. We hope that this review will inspire future empirical work in economics, business, psychology, and neuroscience.

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References

- Anderson, S. W., Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1999). Impairment of social and moral behavior related to early damage in human prefrontal cortex. *Nature Neuroscience*, 2, 1032–1037.
- Bayer, H. M., & Glimcher, P. W. (2005). Midbrain dopamine neurons encode a quantitative reward prediction error signal. *Neuron*, 47, 129–141.
- Bayer, H. M., Lau, B., & Glimcher, P. W. (2007). Statistics of midbrain dopamine neuron spike trains in the awake primate. *Journal of Neurophysiology*, 98, 1428–1439.
- Bechara, A. (2004). The role of emotion in decision-making: Evidence from neurological patients with orbitofrontal damage. *Brain and Cognition*, 55, 30–40.
- Bechara, A., & Damasio, A. R. (2005). The somatic marker hypothesis: A neural theory of economic decision. *Games and Economic Behavior*, 52, 336–372.
- Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, 50, 7–15.
- Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1995). Insensitivity to future consequences following damage to human prefrontal cortex. In J. Mehler & S. Franck (Eds.), *Cognition on cognition* (pp. 1–11). Cambridge, MA: MIT Press.
- Bechara, A., Damasio, H., Damasio, A. R., & Lee, G. P. (1999). Different contributions of the human amygdala and ventromedial prefrontal cortex to decision-making. *Journal of Neuroscience*, 19, 5473–5481.
- Bechara, A., Damasio, H., Tranel, D., & Anderson, S. W. (1998). Dissociation of working memory from decision making within the human prefrontal cortex. *Journal of Neuroscience*, 18, 428–437.
- Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science*, 275, 1293–1295.
- Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (2005). The Iowa gambling task and the somatic marker hypothesis: Some questions and answers. *Trends in Cognitive Sciences*, 9, 159–162.
- Blessing, W. W. (1997). Anatomy of the lower brainstem. In W. W. Blessing (Ed.), *The lower brainstem and bodily homeostasis* (pp. 29–99). New York, NY: Oxford University Press.
- Bolla, K. I., Eldreth, D. A., London, E. D., Kiehl, K. A., Mouratidis, M., Contoreggi, C. S., et al (2003). Orbitofrontal cortex dysfunction in abstinent cocaine abusers performing a decision-making task. *Neuroimage*, 19, 1085–1094.
- Damasio, A. R. (1994). *Descartes' error: Emotion reason, and the human brain*. New York, NY: Putnam.
- 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.
- Damasio, H., Grabowski, T., Frank, R., Galaburda, A. M., & Damasio, A. R. (1994). The return of Phineas Gage: Clues about the brain from the skull of a famous patient. *Science*, 264, 1102–1105.
- Damasio, A. R., Tranel, D., & Damasio, H. (1990). Individuals with sociopathic behavior caused by frontal damage fail to respond autonomically to social stimuli. *Behavioural Brain Research*, 41, 81–94.
- Damasio, A. R., Tranel, D., & Damasio, H. (1991). Somatic markers and the guidance of behavior: Theory and preliminary testing. In H. S. Levin, H. M. Eisenberg, & A. L. Benton (Eds.), *Frontal lobe function and dysfunction* (pp. 217–229). New York, NY: Oxford University Press.
- D'Ardenne, K., McClure, S. M., Nystrom, L. E., & Cohen, J. D. (2008). Bold responses reflecting dopaminergic signals in the human ventral tegmental area. *Science*, 319, 1264–1267.

- Dunn, B. D., Dalgleish, T., & Lawrence, A. D. (2006). The somatic marker hypothesis: A critical evaluation. *Neuroscience and Biobehavioral Reviews*, 30, 239–271.
- Ernst, M., Bolla, K., Mouratidis, M., Contoreggi, C., Matochik, J. A., Kurian, V., et al (2002). Decision-making in a risk-taking task: A pet study. *Neuropsychopharmacology*, 26, 682–691.
- Eslinger, P. J., & Damasio, A. R. (1985). Severe disturbance of higher cognition after bilateral frontal lobe ablation: Patient EVR. *Neurology*, 35, 1731–1741.
- Fellows, L. K., & Farah, M. J. (2003). Ventromedial frontal cortex mediates affective shifting in humans: Evidence from a reversal learning paradigm. *Brain*, 126, 1830–1837.
- Fellows, L. K., & Farah, M. J. (2005). Different underlying impairments in decision-making following ventromedial and dorsolateral frontal lobe damage in humans. *Cerebral Cortex*, 15, 58–63.
- Frangou, S., Kington, J., Raymont, V., & Shergill, S. S. (2008). Examining ventral and dorsal prefrontal function in bipolar disorder: A functional magnetic resonance imaging study. *European Psychiatry*, 23, 300–308.
- Fukui, H., Murai, T., Fukuyama, H., Hayashi, T., & Hanakawa, T. (2005). Functional activity related to risk anticipation during performance of the Iowa gambling task. *Neuroimage*, 24, 253–259.
- Hansen, F. (2005). Distinguishing between feelings and emotions in understanding communication effects. *Journal of Business Research*, 58, 1426–1436.
- Hansen, F., & Christensen, S. R. (2007). *Emotions advertising and consumer choice*. Copenhagen, Denmark: Copenhagen Business School Press.
- Harlow, J. M. (1848). Passage of an iron rod through the head. *Boston Medical and Surgical Journal*, 39, 389–393.
- Harlow, J. M. (1868). Recovery from the passage of an iron bar through the head. *Publications of the Massachusetts Medical Society*, 2, 327–347.
- James, W. (1884). What is an emotion? *Mind*, 9, 188–205.
- Kenning, P., & Plassmann, H. (2005). Neuroeconomics: An overview from an economic perspective. *Brain Research Bulletin*, 67, 343–354.
- Knutson, B., Adams, C. M., Fong, G. W., & Hommer, D. (2001). Anticipation of increasing monetary reward selectively recruits nucleus accumbens. *Journal of Neuroscience*, 21, 159–164.
- Knutson, B., & Greer, S. M. (2008). Anticipatory affect: Neural correlates and consequences for choice. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363, 3771–3786.
- Knutson, B., Rick, S., Wimmer, G. E., Prelec, D., & Loewenstein, G. (2007). Neural predictors of purchases. *Neuron*, 53, 147–156.
- Knutson, B., Wimmer, G. E., Kuhnen, C. M., & Winkielman, P. (2008a). Nucleus accumbens activation mediates the influence of reward cues on financial risk taking. *NeuroReport*, 19, 509–513.
- Knutson, B., Wimmer, G. E., Rick, S., Hollon, N. G., Prelec, D., & Loewenstein, G. (2008b). Neural antecedents of the endowment effect. *Neuron*, 58, 814–822.
- Kuhnen, C. M., & Knutson, B. (2005). The neural basis of financial risk taking. *Neuron*, 47, 763–770.
- Lawrence, N. S., Jollant, F., O'Daly, O., Zelaya, F., & Phillips, M. L. (2009). Distinct roles of prefrontal cortical subregions in the Iowa gambling task. *Cerebral Cortex*, 19, 1134–1143.
- Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as feelings. *Psychological Bulletin*, 127, 267–286.
- Maia, T. V., & McClelland, J. L. (2004). A reexamination of the evidence for the somatic marker hypothesis: What participants really know in the Iowa gambling task. *Proceedings of the National Academy of Sciences*, 101, 16075–16080.
- Maia, T. V., & McClelland, J. L. (2005). The somatic marker hypothesis: Still many questions but no answers. Response to Bechara et al. *Trends in Cognitive Sciences*, 9, 162–164.
- Manes, F., Sahakian, B., Clark, L., Rogers, R., Antoun, N., Aitken, M., et al (2002). Decision-making processes following damage to the prefrontal cortex. *Brain*, 125, 624–639.
- Martin, C., Denburg, N., Tranel, D., Granner, M., & Bechara, A. (2004). The effects of vagal nerve stimulation on decision-making. *Cortex*, 40, 1–8.
- Montague, P. R., Dayan, P., & Sejnowski, T. J. (1996). A framework for mesencephalic dopamine systems based on predictive Hebbian learning. *Journal of Neuroscience*, 16, 1936–1947.
- Northoff, G., Grimm, S., Boeker, H., Schmidt, C., Bermppohl, F., Heinzel, A., et al (2006). Affective judgment and beneficial decision making: Ventromedial prefrontal activity correlates with performance in the Iowa gambling task. *Human brain mapping*, 27, 572–587.
- Persaud, N., McLeod, P., & Cowey, A. (2007). Post-decision wagering objectively measures awareness. *Nature Neuroscience*, 10, 257–261.
- Pessiglione, M., Seymour, B., Flandin, G., Dolan, R. J., & Frith, C. D. (2006). Dopamine-dependent prediction errors underpin reward-seeking behaviour in humans. *Nature*, 442, 1042–1045.
- Schultz, W. (1998). Predictive reward signal of dopamine neurons. *Journal of Neurophysiology*, 80, 1–27.
- Schultz, W., Dayan, P., & Montague, P. R. (1997). A neural substrate of prediction and reward. *Science*, 275, 1593–1599.
- Shiv, B., Bechara, A., Levin, I., Alba, J., Bettman, J., Dube, L., et al (2005a). Decision neuroscience. *Marketing Letters*, 16, 375–386.
- Shiv, B., Loewenstein, G., Bechara, A., Damasio, H., & Damasio, A. R. (2005b). Investment behavior and the negative side of emotion. *Psychological Science*, 16, 435–439.
- Tanabe, J., Thompson, L., Claus, E., Dalwani, M., Hutchison, K., & Banich, M. T. (2007). Prefrontal cortex activity is reduced in gambling and nongambling substance users during decision-making. *Human Brain Mapping*, 28, 1276–1287.
- Tucker, K. A., Potenza, M. N., Beauvais, J. E., Brownndyke, J. N., Gottschalk, P. C., & Kosten, T. R. (2004). Perfusion abnormalities and decision making in cocaine dependence. *Biological Psychiatry*, 56, 527–530.
- Windmann, S., Kirsch, P., Mier, D., Stark, R., Walter, B., Gunturkun, O., et al (2006). On framing effects in decision making: Linking lateral versus medial orbitofrontal cortex activation to choice outcome processing. *Journal of Cognitive Neuroscience*, 18, 1198–1211.