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Frames, decisions, and cardiac–autonomic control

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The "framing effect" (FE) describes the phenomenon whereby human choices are susceptible to the way they are presented rather than objective information. The present study extends common decision-making paradigms with frame variation by including inhibitory control, operationalized as vagally mediated heart rate variability (HRV) at rest and motor response inhibition during a stop-signal task (SST). We hypothesized that inhibitory control is inversely associated with susceptibility to framing effects. Forty adult volunteers performed a risky-choice framing task in which identical information about wins and losses was presented using loss or gain frames. As predicted, there was an inverse association between HRV and framing effects, accounting for 23% of the variance in framing effects. Inhibitory control as indexed by performance in the SST was not associated with framing effects. These results are discussed in terms of the role of inhibitory processes (as indicated by vagal activity) for decision-making processes.

Keywords: Framing effect; Decision-making; Heart-rate variability; Frontal inhibition.

INTRODUCTION

Research into the psychological processes underlying decision-making originated several decades ago. Given its ubiquitous importance for psychological models of social interactions in general, and—to name but a few examples in applied areas—consumer behavior (Sprotles & Kendall, 1986), health behaviors (Marx, Karlsson, & Woo, 2009), and behavior of individuals in organizations in particular (Peterson, 2009), it comes as no surprise that this area of research has recently received renewed attention, notably in relation to its underlying neuronal processes (Kable & Glimcher, 2009). Among these neuronal processes, inhibitory control is now acknowledged to be a key element where rational decision-making is challenged by cognitive and affective biases evoked by situational cues or events.

Inspired by Tversky and Kahneman's (1974, 1981) prospect theory, the behavior-regulating effect of such situational cues has been termed "framing effect," and this is often conceived as a homogeneous class of effects, affecting decision-making behavior in risk-taking paradigms. More recently Levin, Schneider, and Gaeth (1998) have provided a fine-grained typology of framing effects and suggest the term "risky-choice framing" for the framing paradigm we apply in the present study.

Generally speaking, framing effects contradict the general notion that decisions are solely guided by the pragmatic information provided, independent of the way it is presented (referred to in the literature as extensionality or invariance). Framing effects can indicate irrationality in decision-making. In the risky-choice paradigm they illustrate that linguistically different descriptions of equivalent options lead to

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inconsistent choices. Proneness to framing effects can be understood as a "side-effect" of humans' ability to make use of simplifying heuristics in complex situations where rules of thumb enable an individual to decide quickly and effectively. Such situations can be characterized by any or all of the following: (a) the required information processing exceeds an individual's cognitive capacity, (b) the available information is incomplete, and/or (c) a potentially dangerous situation requires immediate action rather than intensive time-consuming reflection (Tversky & Kahneman, 1974).

Frames can guide decision-making by activating associations linked to elements embedded in the frame, evoking associated affective meanings. For example, frame-inducing keywords implying the risk of a loss will evoke "loss-aversion" and increase the probability to choose the alternative "sure" option in a gambling task. Cues such as "win" or "keep" in the context of a risky situation signal positive consequences of a choice and are more likely to initiate approach behavior. This effect can be observed in situations where the pragmatic information (e.g., the win/loss ratio) remains identical, which is the case in the risky-choice framing task applied in the present study (Levin, Schneider, & Gaeth, 1998), where "win" and "loss" frames were induced by, for example, "Keep €40" or "Lose €60", respectively, out of €100.

In the risky-choice framing task the decision in favor of the sure or the gambling option is biased by affective keywords displayed in the sure option, making alternative options more or less attractive. The keywords are the only variation of frame conditions. Consequently, the bias in decision-making between two options can solely be explained by the way the information is presented, i.e., the choice of words used to present identical information. In the current study we hypothesized that an individual's vulnerability to this framing effect induced by pragmatically irrelevant emotional words resembles a personality trait insofar as this vulnerability is linked to the capacity to inhibit the affective biases evoked by frames. This inhibitory capacity can be measured and quantified by physiological markers of inhibition (e.g., heart rate variability, HRV) and behavioral motor response inhibition, which both rely on prefrontally initiated processes (Li, Huang, Constable, & Sinha, 2006; Napadow et al., 2008) and are considered traits.

De Martino, Kumaran, Seymour, and Dolan (2006) reported results from an fMRI study in which subjects were requested to choose between a sure option and a gamble option presented in the context of two different frames signaling either loss (loss frame) or gain (gain frame) evoked in an identical task. Frames had a significant impact on participants' behavior: risk-averse in the gain frame, while risk-seeking in the loss frame. In terms of neuroanatomical structures involved, amygdala activation was associated with a stronger bias or framing effect. Most importantly, however, activation of several prefrontal cortical areas including the orbital, medial, and dorsolateral and the anterior cingulate cortex (ACC) was inversely correlated with the magnitude of the framing effect, indicating a relationship between prefrontal inhibitory processes and susceptibility to framing effects.

These results suggest an important role of prefrontal inhibitory processes for framing effects, which may be reflected in peripheral physiological markers of a person's inhibitory capacity and self-regulation. The neuroanatomical structures reported in De Martino et al.'s (2006) fMRI study provide a blueprint for current models of neurovisceral integration as described in the central autonomic network (CAN) theory (Benarroch, 1993). In this theory, prefrontal modulation of parasympathetic activity reflects the CNS's inhibitory influence on autonomic processes in order to effectively adapt interior physiological processes such as cardiovascular functions to changing external requirements. Thayer and colleagues have outlined a model of neurovisceral integration, which relates emotional, cognitive and behavioral regulation with HRV in a dynamical systems framework (Thayer & Brosschot, 2005; Thayer & Lane, 2000). Within this model the CAN, consisting of prefrontal and limbic structures, is postulated as the functional unit through which the brain controls cognitive, behavioral, and physiological responses to regulate emotional states by inhibiting other potential responses. Such inhibition is presumed to be mediated synaptically in the brain and through the vagus nerve in the periphery (Thayer & Siegle, 2002). Reciprocal cortico-cardiac interactions are a key feature of the CAN, and these are indicated by the sympathetic–parasympathetic interplay expressed in HRV. Autonomic nervous system related measures such as HRV or baroreceptor sensitivity can be conceived of as a proxy for sympatho-vagal balance. Due to their neuroanatomic relation to the prefrontal cortex (PFC), HRV and baroreceptor sensitivity have been used as measures of an individual's self-regulatory capacity (Knoch & Fehr, 2007; Segerstrom & Solberg Nes, 2007), including frontal inhibitory processes. Furthermore, HRV has been linked to attention allocation (selecting meaningful information from the sensory environment) and emotional responses to that information (Appelhans & Luecken, 2006), which are assumed to be induced by affective cues. Heart rate variability

can, therefore, be considered a proxy for the CAN's ability to regulate behavioral, cognitive and emotional responses through inhibition in accordance with contextual factors (Thayer & Lane, 2009). In this context we propose that individual differences in HRV as a proxy of self-regulatory capacity play an essential role in paradigms assessing cognitive and affective influences on decision-making, i.e. those involving framing effects.

An alternative measure of inhibitory control can be derived from motor response paradigms such as the stop-signal task (SST) (Kindlon, Mezzacappa, & Earls, 1995; Logan, 1994; Logan & Cowan, 1984; Logan, Schachar, & Tannock, 1997). The SST assesses an individual's ability to inhibit a pre-potent motor response. It provides an estimate of stop-signal reaction time (SSRT), which is interpreted as a trait-like feature of inhibitory control (Logan et al., 1997). More efficient response inhibition is reflected in shorter SSRT and is associated with greater activation of inhibitory motor areas such as the superior medial and precentral frontal cortices (Li et al., 2006). Furthermore, inhibitory motor areas have also been shown to be involved in non-motor, cognitive functions requiring inhibitory control such as reappraisal (Ray et al., 2005) and set shifting (Konishi, Kyoichi, & Idai, 1999; Konishi, Nakajima, & Idai, 1998), some of which may also be involved in framing effects.

The framing task assesses outcomes of decision-making processes in which individual traits are displayed on a dimension of rationality. In this context rationality describes the resilience to "wrapping" linguistic variations irrelevant for the underlying pragmatic information. These linguistic variations convey keywords inducing "loss aversion" or "approach tendencies" as responses to potential wins or losses. De Martino et al. (2006) define "rationality" as the inverse of the framing effect, FE (rationality index: 1 – FE), i.e., the robustness toward irrelevant emotional cues conveyed in frame-inducing keywords. If the capacity to inhibit biasing cognitive and affective processes is a precursor of a behavioral tendency or trait (Konishi et al., 1998, 1999), the magnitude of the observed framing effect should be inversely associated with measures of inhibitory control.

In the present study we employed two measures of inhibitory capacity, i.e. HRV at rest and motor response inhibition during a stop-signal task. We hypothesized that higher self-regulatory capacity, i.e., higher HRV, or better performance in the motor-response inhibition task, would be associated with more effective inhibition of the affective biases evoked by the framing keywords "lose" or "keep" and thus, lower susceptibility to framing effects.

METHOD

Participants

Participants were 40 adults (15 male) between the ages of 18 and 34 years (M = 23.0; SD = .73). Of these, 25 were undergraduate students and 15 were recruited outside the university via advertisements. Exclusion criteria were current and previous psychiatric, neurological, or cardiovascular diagnoses, and medication affecting the central nervous or cardiovascular system. Participants received either credit points for participation or a compensation of €10. The ethics committee of the Medical Faculty, University of Würzburg, approved the study protocol, which was in accordance with the Helsinki Declaration of 1975 (as revised in 1983).

Materials and experimental tasks

Framing task

Framing effects were induced by a behavioral task identical to the gambling task described by De Martino et al. (2006). Participants were asked to decide between a "sure" and a "gambling" option. The framing effect was implemented by comparing the individual probabilities to choose the "sure" option, which was presented in two ways, resembling a "loss" frame and a "gain" frame (see Figure 1). After the presentation of a fixation cross for 3 s, participants were informed about the amount of money they "receive." The information was displayed for 2 s (e.g., "You receive €100"). Subsequently, participants had to choose between a "sure" option presented on the left half and a "gamble" option on the right half of the screen. The two options were presented simultaneously for 4 s. The "gamble" option included a two-colored pie graph indicating the probabilities to "lose" or to "keep" the complete amount that was previously announced, whereas the "sure" option was presented in the context of two frames (e.g., "Keep €40" vs. "Lose €60"), indicating that a certain amount out of the total sum would be lost (loss frame) or could be kept (gain frame). The keep/loss ratio and, thus, the pragmatic information conveyed were identical (e.g., losing €40 or keeping €60 out of €100 both represent a 2/3 keep/loss ratio) for loss and gain frames. Furthermore, the win/loss ratio of the "sure" option equaled the statistical expectancy value of the "gamble" option's probabilities.

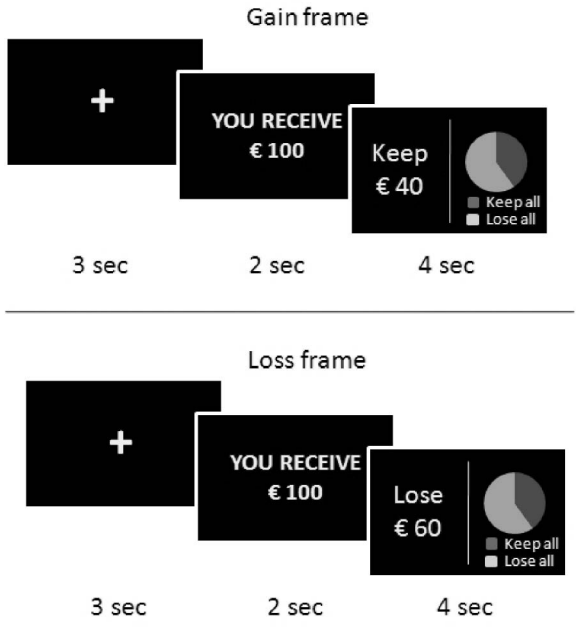

Figure 1. Risky-choice paradigm.

Most importantly, the "gamble" option itself was identical in both frames, thus providing the possibility to compare the risk taking probability between both frames in order to measure individuals' susceptibility to the framing effect induced in the "sure" option. The paradigm consisted of 32 trials in the loss frame, 32 trials in the gain frame and 32 "catch" trials (see below), i.e., a total of 96 randomly presented trials, lasting about 17 min per participant. Four different starting amounts of €25, €50, €75, and €100 were used with the same frequency (eight trials each). The chance to keep the whole starting amount in the "gamble" option was equally balanced between four different probabilities (20%, 40%, 60%, 80%). Thus, 16 different combinations of the starting amount and the chance to win/lose were presented twice (once in each framing condition). After verbal and visual instructions were provided, participants were asked to repeat and rephrase them in their own words. A practice phase of 15 trials was used to familiarize participants with the task and the required decisions. Participants were informed that no feedback concerning the outcomes of their decisions would be given. This was designed to avoid carry-over effects on subsequent behavior caused by erroneous assumptions and expectations about the consequences of the decisions made.

To ensure a high intuition-led framing effect, time pressure had to be maintained (4 s for decision-making process and its execution; see De Martino et al., 2006), creating a considerable load on perceptual speed, motivation, and compliance. "Catch" trials served as controls for compliance and participants' ability to follow instructions and grasp all information given in the slides. Furthermore, catch trials served as a "manipulation check" for the implementation of framing conditions and to ensure that participants were actively engaged in the task for the whole duration of the experiment. Catch trials (one third of the total trials) were markedly unbalanced, i.e., expectancy values of sure and gamble option differed clearly, making one of the two options highly preferable. In "gain-weighted" catch trials participants were required to choose between keeping/losing 50% of the initial starting amount and having only a 5% chance to win it all, or a 95% risk to lose it all, respectively. Similarly, "loss-weighted" catch trials conveyed clear information making the risk option the preferable option (95% chance to win the whole sum).

Stop-signal task (SST)

The "GO" stimuli consisted of the letters "S" or "B," presented on a 19-inch computer display using E-Prime software (v2.0, Psychology Software Tools, Pittsburgh, PA, 2007). Stimuli were presented in black on white background, and the viewing distance from the screen was 80–90 cm. Stimuli covered an angle of approximately 3.5° × 2° of the visual field. "GO" stimuli were presented for 500 ms, followed by an intertrial interval (ITI) of 1500 ms. The total number of trials was 600; in 150 trials (25%) the "GO" stimulus was followed by an auditory signal (1000 Hz, 500 ms). Stimulus onset asynchrony (SOA) between GO and STOP signal was 100 ms, 200 ms, or 300 ms, as determined by a performance-related staircase-tracking algorithm (Boecker, Buecheler, Schroeter, & Gauggel, 2007). Correct "no" responses led to an increase of SOA by 100 ms up to a maximum of 300 ms; false reactions in stop trials led to a decrease of SOA by 100 ms down to a minimum of 100 ms, thus ensuring a similar level of subjective difficulty for all participants.

Physiological assessment

Electrocardiogram (ECG) was monitored using the Einthoven lead I configuration with disposable electrodes attached to the left and right wrists. Piloting showed a significant decrease in probability of movement artifacts and regular breathing cycles in closed-eyes condition compared to open eyes in an environment rich in visual stimulation such as a physiological laboratory. Participants were, therefore,

instructed to relax and close their eyes while monitoring ensued for a period of 10 min. ECG raw data were recorded using a g.USBamp amplifier (sampling rate 500 Hz; g.tec, Graz, Austria).

Experimental protocol

Upon arrival at the laboratory participants were seated in a comfortable chair. After describing the procedure in detail, participants gave written informed consent and were given the opportunity to ask questions. Then electrodes were attached, and after an initial rest period of 5 min designed to help acclimatization ECG was monitored for 10 min while participants were asked to sit quietly with eyes closed and relax. Then electrodes were removed and the framing task and the SST presented in counterbalanced order. After the experiment participants were debriefed and thanked for participation.

Data reduction, exclusion criteria and statistical analyses

Framing task

The difference between probabilities of sure or gambling options in the two frame conditions was taken as a measure of vulnerability to FE, its complement (1 – FE) was interpreted as "rationality index" (RI), following the definitions of De Martino et al. (2006). To ensure the internal validity of the framing paradigm we excluded data of individuals whose behavioral patterns indicated insufficient processing of task-relevant information, i.e. by setting a cut-off value of 15% of erroneous decisions in the clearly marked catch trials. Decisions by participants were made via two response keys, each corresponding to one of the two behavioral options according to their placement on the screen. Analysis of catch trials revealed that 18 out of 39 participants did not fulfill the criterion of an error rate <15% and were thus excluded from further analysis. Framing task data of one participant was lost due to equipment failure. The final sample included in the analyses of the framing task, therefore, comprised 20 participants. Framing effects were quantified as the differences of choices in favor of the sure option in Gain vs. Loss frame.

Stop-signal task

SSRT and percentage of correctly suppressed reactions in STOP trials were assessed for three SOAs and averaged. SSRTs were calculated for those SOA conditions containing at least 15 trials, following the recommendations made by Logan (1994; Logan & Cowan, 1984). Participants with go-trial reaction times exceeding 450 ms were excluded from analysis (n = 11).

HRV

Offline analyses included the extraction of QRS complexes and interbeat intervals (IBIs) from ECG recordings. Artifacts were deleted and real values estimated via interpolation of neighboring IBIs. The last 5 min of the 10-min recording session was chosen for HRV analysis in order to ensure that data reflected resting conditions. Statistical parameters of HRV (Allen, Chambers & Towers, 2007; Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996) were calculated using Kubios HRV Analysis 2.0 software (Niskanen, Tarvainen, Ranta-aho, & Karjalainen, 2004). Time domain measures (for an overview, see Task Force, 1996) included mean heart rate, RMSSD (square root of the mean squared differences of successive NN intervals) and pNN50 (the proportion derived by dividing NN50 by the total number of NN intervals—elapsed time between subsequent ECG-R-peaks in milliseconds). Spectral frequency measures were derived using fast Fourier transformation (FFT). Frequency bands were labeled as recommended by the Task Force (1996) as high-frequency (HF, 0.15–0.4 Hz) and low-frequency (LF, 0.04–0.15 Hz) and expressed in power (ms^2) and normalized units (n.u.). Spectral frequency measures and time domain measures were used as indicators for cardiac–vagal tone and thus as physiological markers of inhibitory capacity. LF/HF was interpreted as a measure for autonomic balance, whereby lower values indicate higher autonomic flexibility. HRV measures (Table 1) were tested for normality and log-transformed (ln) if the assumption of normality was violated. This was the case for LF/HF and HF (ms^2).

TABLE 1
Time and frequency domain measures of HRV and their Pearson's product-moment correlations with FE

	Minimum	*Maximum*	*Mean*	*SD*	*r*	*p*
RMSSD	18.29	81.34	44.18	15.83	–.342	.070
pNN50	0.44	60.75	25.20	16.04	–.408	<.05
HF (ms^2)	90.26	1759.87	669.07	460.11	.121	.306
HF (n.u.)	12.11	75.89	36.35	18.38	–.482	<.05
LF/HF	0.23	6.72	2.28	1.82	.441	<.05

Statistical analyses

Paired sample *t*-tests were calculated to quantify FE. To examine associations between measures of inhibitory control and framing effects, Pearson's correlations were calculated between HRV and SSRT and framing effects.

RESULTS

Framing paradigm

As expected, sure options were more likely to be chosen in the Gain frame condition (M = 68.5, SD = 28.0) than in the Loss frame condition (M = 65.1, SD = 27.6). One-tailed paired-sample *t*-test revealed a main effect for "Frames" (t = 1.744, df = 19, p < .05, d = .12); data were normally distributed (Kolmogorov-Smirnov: Z = .161, df = 19, p = .185). These behavioral results confirm predictions based on prospect theory and previous findings (De Martino et al., 2006) in that participants favored the risky option in the Loss frame (indicating a "loss" aversion) and tended to opt for the sure option in the more positively appearing Gain frame across all conditions and amounts (Figure 2).

HRV and framing effect

Correlation analyses between framing effects and measures of inhibitory control (pNN50, HF (n.u.), LF/HF) revealed significant negative associations of medium effect size. For RMSSD, marginally significant correlations of moderate effect size (r = –.342, df =19, p = .07) were obtained. The strongest correlation between framing effects and inhibitory control emerged for HF (n.u.) (r = –.482, df = 19, p < .05), explaining 23.2% of the variance in framing effects (Figure 3).

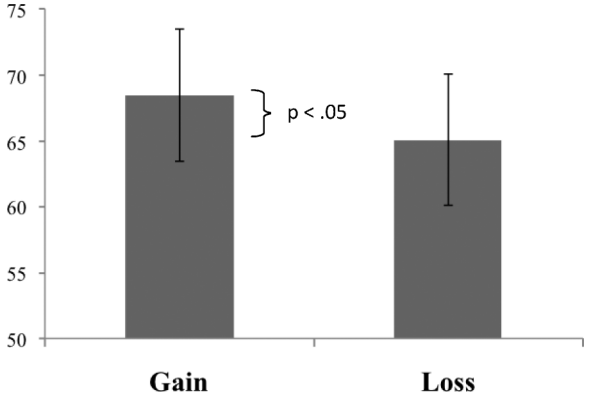

Figure 2. Mean percentages (and standard errors of the mean) of sure option choices in the risky-choices paradigm.

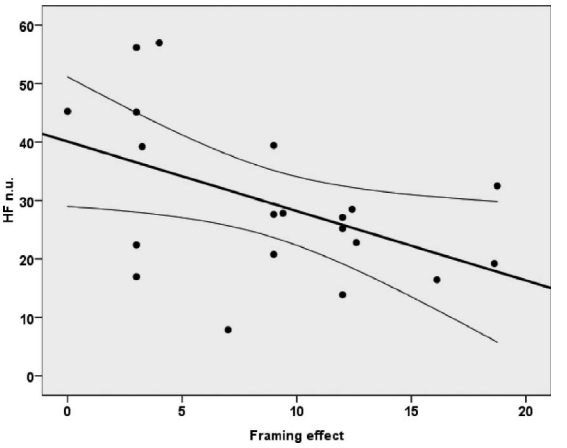

Figure 3. Scatter-plot of correlation coefficients between HF (n.u.) and FE.

Stop-signal reaction time and framing effect

Inhibitory control as indexed by performance in the SST was not associated with framing effects. SSRT was normally distributed (Kolmogorov-Smirnov, Z = .128, df = 31, p > .200) and was weakly, but not significantly associated with FE (r = –.190, df = *19*, p = .199). Percentage of correctly inhibited stop trials was normally distributed (KS, Z =. 750, df = 28, p = .626) and not correlated with FE (r = –.062, df = 19, p = .377).

DISCUSSION

The current study investigated the relationship between inhibitory capacity and susceptibility to framing effects in a risky-choice paradigm. Two measures of inhibition were used to examine prefrontally mediated inhibitory capacity at a trait level (for traits characteristic of SST and HRV, see Avila and Parcet, 2001; Singh, Larson, O'Donnell, & Levy, 2001). Motor response inhibition in an SST revealed no association with framing effects in the risky-choice task. In contrast, parasympathetically mediated HRV was inversely related to FEs, predicting a substantial percentage of the variance in affect-driven biases in the decision-making process.

FEs were established by keywords signaling loss or gain. According to prospect theory, affective words are likely to induce loss-aversion or approach tendencies,

depending on their valence. Furthermore, affective words evoke valence-dependent cortical effects and enhance activity in the visual processing system (Herbert et al., 2009; Herbert, Junghofer, & Kissler, 2008; Kissler, Herbert, Peyk, & Junghofer, 2007). Manipulation of emotional frames does not change the underlying pragmatic information, but induces affective associations with potential losses or gains. We hypothesized that the magnitude to which this irrelevant context-driven impulse can be excluded from the decision-making process depends on an individual's capacity of inhibition and self-regulation. The current results showed parasympathetically mediated HRV to be related to susceptibility to framing effects in that larger HRV (i.e. higher parasympathetic activity) was significantly correlated with lower framing susceptibility in a risky-choice decision-making task. This suggests that HRV is a sensitive indicator of central autonomic control, thereby also reflecting inhibitory control, a finding that has been confirmed in a variety of studies (for an overview, see Benarroch, 1993; Thayer & Lane, 2009).

Nevertheless, to our knowledge the current study is the first to demonstrate this effect in the context of affective-driven decision-making biases. Central nervous correlates of framing effects have been described previously (e.g., De Martino et al., 2006; Gonzalez, Dana, Koshino & Just, 2005), revealing activation of prefrontal control networks. The current study supports these findings and suggests a role of neurovisceral integration processes in cognitive processes of decision-making.

While the role of sympathetic activation in decision-making has been demonstrated in a number of studies within the context of the somatic marker hypothesis (Damasio, Everitt, & Bishop, 1996), little is known about the inhibitory influence of the parasympathetic system on higher order processes such as decision-making. The demonstrated association of FE susceptibility and HRV in the current study suggests a role for HRV as a marker of inhibitory processes, relevant for decision-making processes.

De Martino et al. (2006) have emphasized the role of the amygdala and hypothesized that "the framing effect is driven by an affect heuristic underwritten by an emotional system" and that their "data extend the role of the amygdala to include processing the type of contextual positive or negative emotional information communicated by the frame in the context of a decision-making task" (p. 686). The authors also suggest a role of the orbital and medial prefrontal cortex (OMPFC) as evaluator and integrator of emotional and cognitive information and report a negative association between activation of dorsolateral prefrontal cortex (DLPFC) and susceptibility to framing effects. The latter association, however, was not interpreted. Regarding the DLPFC's role in inhibitory control (Shackman, McMenamin, Maxwell, Greischar and Davidson, 2009), the application of a physiological marker indicating inhibitory control involving DLPFC in its underlying neuronal networks extends De Martino et al.'s (2006) findings. Their suggestion that "more 'rational' individuals have a better and more refined representation of their own emotional biases that enables them to modify their behavior in appropriate circumstances" (p. 687) might be extended by the notion that this "refined representation" of their own emotional biases requires active inhibition (suppression or reappraisal) of these emotionally driven biases to achieve a rational decision. The nature of these inhibitory processes (cognitive suppression or reappraisal) remains to be investigated.

While HRV showed the expected inverse relationship with susceptibility to framing cues, motor response inhibition as measured by SST revealed no significant association with susceptibility to the FE. The reasons for this discrepancy in the predictive power of the two measures of inhibitory control for the FE are not clear. While these results need to be replicated in future studies with larger samples, we would argue that HRV reflects inhibitory processes that are clearly more relevant for decision-making than parameters based on response motor inhibition. Peripheral physiological processes have been shown to contribute directly to emotion-related decision-making processes, as suggested by the somatic marker hypothesis (Damasio et al., 1996). The somatic marker hypothesis, however, has typically been brought into relation to decision-making processes and sympathetic activation (e.g., electrodermal responses as markers of unconscious biases in decision-making paradigms). The results of the present study suggest that parasympathetic activity can also indicate a peripheral factor of influence on decision-making, where irrelevant affective cues need to be inhibited.

By extension, it could be speculated that the CAN as indexed by vagally mediated inhibition represents a more important neuroanatomical network for the suppression of irrelevant affective cues than the prefrontal cortical areas activated in a motor response inhibition paradigm. Future studies should include neuroimaging techniques to more directly test this hypothesis. Further research is also needed to shed more light on the process of inhibition and its physiological correlates in the context of framing susceptibility, e.g., lateralization effects of self-regulatory efforts to overcome framing effects or the influence of emotional states.

The current study has a number of limitations. Firstly, the study sample was relatively small, and this might have increased the probability of type II error, in particular in relation to the null finding in terms of SSRT. In addition, a considerable number of participants had to be excluded from analyses because of failure to perform correctly in at least 85% of catch trials, indicating a need to simplify the task or increase reaction time windows. Nevertheless, HRV explained a substantial proportion of the FE variance, indicating an appropriate sample size for the detection of inhibitory effects. Secondly, we concentrated on measures of inhibitory control. While inhibition seems an important psychological process for FE, there are other psychological factors (e.g., impulsivity, immediate emotions, anticipatory influences, risk aversion, social factors) that also play an important role in decision-making. Future studies should include a range of theoretically derived factors thought to impact on the FE to contrast their relative contribution to decision-making processes and apply other physiological measures of inhibition (e.g., antisaccades, event-related potentials). Thirdly, we focused on a "risky-choices" paradigm. While this is probably the most frequently used framing concept, it limits the generalizability of the current results to other areas of decision-making. For example, more research is needed with other types of FEs such as "attribute framing" and "goal framing" (Levin et al., 1998). Fourthly, the use of neuroimaging techniques would have allowed for a more direct examination of CNS areas involved.

Despite these limitations, we believe that the current study contributes to the literature on the relationship between decision-making and self-regulatory capacity. To our knowledge it is the first investigation to provide evidence for the notion of parasympathetically mediated HRV to be related to susceptibility to FEs. This suggests that HRV is a sensitive indicator of inhibitory control mechanisms relevant for decision-making.

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