Investigating the Neural Correlates of the Affect Heuristic
Using Functional Magnetic Resonance Imaging

Kenny Skagerlund¹, Mikael Skagenholt¹, Paul J. Hamilton¹, Paul Slovic²,³, and Daniel Västfjäll¹,²

Abstract

This study investigated the neural correlates of the so-called “affect heuristic,” which refers to the phenomenon whereby individuals tend to rely on affective states rather than rational deliberation of utility and probabilities during judgments of risk and utility of a given event or scenario. The study sought to explore whether there are shared regional activations during both judgments of relative risk and relative benefit of various scenarios, thus being a potential candidate of the affect heuristic. Using functional magnetic resonance imaging, we developed a novel risk perception task, based on a preexisting behavioral task assessing the affect heuristic. A whole-brain voxel-wise analysis of a sample of participants (n = 42) during the risk and benefit conditions revealed overlapping clusters in the left insula, left inferior frontal gyrus, and left medial frontal gyrus across conditions. Extraction of parameter estimates of these clusters revealed that activity of these regions during both tasks was inversely correlated with a behavioral measure assessing the inclination to use the affect heuristic. More activity in these areas during risk judgments reflects individuals’ ability to disregard momentary affective impulses. The insula may be involved in integrating visceromotor sensory information and forming a representation of the current emotional state of the body, whereas activity in the left inferior frontal gyrus and medial frontal gyrus indicates that executive processes may be involved in inhibiting the impulse of making judgments in favor of deliberate risk evaluations.

INTRODUCTION

The evaluation and perception of risk permeates mental life and encompasses both personal activities, such as whether to apply for a bank loan or invest in stocks, and more societal and existential issues, such as whether to expand a nuclear energy program. Initial models of human risk perception, and decision-making more generally, emphasized rational, cognitive processing where the probability and utility of each alternative are clearly and exhaustively calculated. Empirical work, however, indicates that human risk perception seems to be guided by affective information rather than explicit deliberation (e.g., Slovic & Peters, 2006). There is now a general consensus that affective states play an important role in decision-making more broadly, a role that has been neglected historically (Västfjäll et al., 2016; Loewenstein, Weber, Hsee, & Welch, 2001). Indeed, dual-process theories of decision-making (e.g., Stanovich & West, 2000; Sloman, 1996) that incorporate affect in decision-making models have been shown to have increased explanatory power (e.g., Bernheim & Rangel, 2004). An influential neurocognitive framework of affective contributions to decision-making was proposed by Bechara and Damasio (2005). This framework outlines how affective states, or “somatic markers,” become associated with stimuli and choices and, therefore, guide future behavior, especially when situations are too complex or uncertain to evaluate using explicit cognitive processing. It is generally agreed that using affective processes as sources of information is a more efficient way to navigate a complex world of uncertainty (Schwarz & Clore, 1988). In fact, some have proposed that affect plays a primary role in decision-making (Loewenstein & Lerner, 2003; Damasio, 1994).

One domain of decision-making in humans, risk judgment, appears to be driven more by affective states than rational deliberation of utility and probabilities (risk-as-feelings; Slovic & Peters, 2006; Loewenstein et al., 2001). Indeed, human beings rely on the so called “affect heuristic” (Slovic, Finucane, Peters, & MacGregor, 2002) ubiquitously in judgment and decision-making. The affect heuristic denotes that people make judgments based on affectively tagged representations of objects or events. By consulting the affective impression that something is tagged with, instead of doing laborious calculations and utility maximizations, one can efficiently achieve satisfactory decisions (Slovic, Finucane, Peters, & MacGregor, 2004, 2007). Consistent with this formulation, Alhakami and Slovic (1994) found an inverse relationship between judgments of risks and benefits of certain activities that respondents were asked to make. The consistency in this relationship was initially puzzling given that risk and benefits of activities and events in the world often should
be independent of one another or even positively correlated (Slovic, 1987). For example, nuclear power technology could be regarded as both having a high risk and potentially being highly beneficial. However, it suggests, nonetheless, that what people “feel” about an activity is what drives judgment. Finucane, Alhakami, Slovic, and Johnson (2000) noted that that the inverse relationship between perceived risk and perceived benefit of an activity (e.g., using pesticides) was linked to the strength of positive or negative affect associated with that activity as measured by rating the activity on bipolar scales such as good/bad, nice/awful, and so forth. This finding implies that people judge a risk not only by what they think about it but also by how they feel about it. If their feelings toward an activity are favorable, they tend to judge the risks as low and the benefits as high; if their feelings toward the activity are unfavorable, they tend to make the opposite judgment—high risk and low benefit (Finucane et al., 2000). Thus, there is abundant behavioral research supporting the affect heuristic, but very little is known about the neural processes that subserve this heuristic. The primary purpose of the current study is to unveil the neural correlates of risk and benefit judgments using functional magnetic resonance imaging (fMRI), where participants will be asked to judge the level of risk and benefit of various verbally presented activities and scenarios. The assumption is that the affect heuristic constitutes a common psychological mechanism that underlies both risk and benefit judgments, and we therefore assume that this psychological mechanism can be traced to common neural activation responsible for judgments of both risks and benefits of a given scenario or activity.

Although the affect heuristic has not been explicitly investigated using functional neuroimaging, a number of studies investigating the neurocognitive correlates of risk perception using a variety of paradigms have identified candidate brain regions. For example, Preuschoff, Quartz, and Bossaerts (2008) utilized a gambling task and found that anterior insula was activated during risk monitoring. In a combined event-related potential and fMRI paradigm, Qin and Han (2009) found that posterior parietal cortex and insula were involved during evaluation of personal health and environmental risks. In a recent article, Vogel et al. (2016) investigated health-risk perception in healthy adults and found activations in the right precuneus and insula during risk judgments. A recurring finding, therefore, is the involvement of the insula in risk judgments. Moreover, some recent findings indicate that posterior insula, together with the amygdala, shows a more pronounced role in the processing of potential losses relative to potential gains (e.g., Markett, Heeren, Montag, Weber, & Reuter, 2016; Canessa et al., 2013). For example, Markett et al. (2016) conducted a morphometric study of gray matter volume of the posterior insula and found that gray matter volume in this region was associated with loss aversion. More generally, posterior insula has been postulated to play a central role in processing viscero-somatosensory information, given that it receives visceral afferent projections conveying interoceptive information from all parts of the body (Pugnaghi et al., 2013). In addition, research has found that the posterior insula keeps track of the physiological state of the body (Pugnaghi et al., 2013), and Craig (2009) proposed that salient interoceptive and environmental factors are coded moment-to-moment to represent a phenomenological “now,” providing a basis for self-awareness. Moreover, Craig (2009) suggested that there is a posterior-to-anterior progression of integration of information in the insula, such that visceral information is processed in the posterior insula, which is then subsequently integrated in the anterior insula for further processing and abstraction. In this framework, it is possible that the insula is involved in risk perception and the affect heuristic in several ways. When an individual is facing a risky decision or professing an attitude toward an issue, it is likely that the posterior insula is involved in processing viscero-somatosensory information that provides a momentary affective information of the prospective decision or issue currently under consideration. Per Craig’s (2009) formulation, this information may then be integrated in anterior portions of the insula for further processing and evaluation. We therefore hypothesize that posterior and anterior insula act in concert in subserving the affect heuristic, by feeding information from a viscero-somatosensory system about the “goodness” of any given stimulus, such as a risky decision or other representation, to the anterior insula that integrates this information in combination with other cognitive processes.

Although an fMRI study by Fukunaga, Brown, and Bogg (2012) found that insula, indeed, did activate during loss aversion in a gambling task, they also found that ventromedial portions of the prefrontal cortex (vPFC) were involved in “reward seeking.” They also suggested that the inferior frontal gyrus (IFG), adjacent to the anterior insula, is involved in decisions under risk. It has been proposed that IFG activity reflects a subjective risk rating based on feelings processed by the insula (Christopolous, Tobler, Bossaerts, Dolan, & Schultz, 2009). Teasing out the role of the IFG in risk perception is challenging given its involvement in various processes, such as executive functions (Skagerlund et al., 2019; Dajani & Uddin, 2015) and processing of abstract concepts (Della Rosa, Catricalà, Canini, Vigliocco, & Cappa, 2018). Within the realm of decision-making, Reckless et al. (2014) found that the left IFG was responsible for adjusting response bias when making decisions. As such, the IFG may be involved in making decisions under risk by taking input from other regions involved in prior steps in the risk processing chain, such as the amygdala or the insula, after which the IFG is responsible for flexible adaptation and implementing behavior.

The role of the amygdala in emotionally charged decision-making is well established. A seminal study investigated a similar process to the affect heuristic called the “framing effect” that is also believed to rely on both
affective processes and deliberate cognitive judgments and then observed activation in prefrontal areas and the amygdala (De Martino, Kumaran, Seymour, & Dolan, 2006). Activity in medial portions of the pFC has been interpreted in terms of evaluating and integrating emotional and cognitive information received from the amygdala (De Martino et al., 2006). Other neuroimaging studies have found that the amygdala is activated in risky decision-making (e.g., Cohen, Elger, & Weber, 2008; Ji et al., 2010), and it has been suggested that the amygdala triggers emotions of fear regarding potential losses (e.g., Levin et al., 2012). This is consistent with lesion studies showing that damage to the amygdala is associated with impairments on gambling tasks (Weller, Levin, Shiv, & Bechara, 2007). In terms of our current investigation of the affect heuristic, we do not hypothesize that the amygdala will be active in both risk and benefit judgments. During benefit judgments, it is unlikely that the amygdala would signal potential losses or fear responses, whereas this could be the case during risk judgments. Such a dissociation is plausible but would however not be a common denominator that drives the affect heuristic, which is expected to be in play regardless of process valence.

Most research on risk perception and decision-making involves studying how people make choices during a gambling task, such as the balloon analogue risk task (e.g., Schonberg et al., 2012) or the monetary incentive delay task (Knutson, Westdorp, Kaiser, & Hommer, 2000), which contain monetary gambles that capture neural correlates of rewards, punishments, probabilities, and risks. These tasks have yielded great insight into the mechanisms of reward and loss, especially by mapping the dopaminergic reward system in the brain (e.g., Rao, Korczykowski, Pluta, Hoang, & Detre, 2008; Tom, Fox, Trepel, & Poldrack, 2007; De Martino et al., 2006). For example, an extensive distributed neurocognitive network is consistently found in gambling tasks, including the insula, ventromedial pFC, striatum, posterior parietal cortex, amygdala, and anterior cingulate cortex (ACC; cf. Smith et al., 2009). A caveat, however, is that those tasks are complex in terms of the neurocognitive requirements (they involve visual perception, number decoding, risk magnitude, reward magnitude, subjective risk taking, punishment magnitude, gains/losses, etc.), which makes it difficult to isolate and understand the role of specific areas and mechanisms (Schonberg, Fox, & Poldrack, 2011). It has been suggested, therefore, that the research community ought to develop carefully designed and targeted tasks that allow for fine-grained analyses of specific mechanisms involved in decision-making under risk (Schonberg et al., 2011). Echoing the work by Vorhold et al. (2007), it is important to note that risk perception in the context of evaluative judgments, devoid of explicit probabilities and rewards presented during gambling tasks, plays a central role in everyday decision-making. Making judgments about mortgage plans, choosing a romantic partner, or dealing with looming environmental disasters all require risk judgments about uncertain outcomes with uncertain consequences. Therefore, we need to develop our understanding of human risk perception beyond artificial gambling situations.

In the current study, we attempt to address this gap in our knowledge by investigating where in the brain both risk and benefit judgments are mapped. To this end, we have developed a novel risk perception task that reflects risk perception processes that call on the affect heuristic. Specifically, we have developed a novel and simple risk perception task—based on previous behavioral studies—for measuring judgments of relative risk and benefit of various activities. This task has the advantage of being devoid of complex monetary gambles that are contaminated with number processing and reward/punishment mechanisms. Thus, our primary aim is to investigate common activations associated with risk and benefit judgments to reveal neural mechanisms that may drive the affect heuristic. A secondary aim is to determine whether the conjunction of risk and benefit neural correlates is itself, correlated with individual propensity for using the affect heuristic. Although the affect heuristic is typically assessed at the group level, where the relative strength of the inverse correlation signifies the existence of the affect, one can also investigate the slope of the risk–benefit correlation at the individual level. This reveals the propensity with which one uses the affect heuristic, or whether tends to dissociate risk and benefit judgments in a more deliberative manner, which would result in a weaker correlation coefficient (cf. Skagerlund, Forsblad, Slovic, & Västfjäll, 2020).

We propose the following predictions of our whole-brain voxel-wise analysis.

i) A conjunction analysis will reveal common activations in the insula, indicating this region’s role as a central neural hub of the affect heuristic.

ii) The amygdala will be more active in the risk perception task than in the benefit task because of possible perceived elements of potential loss.

iii) Medial portions of the pFC will be more active in the benefit task because of possible perceived elements of reward.

METHODS

Participants

Fifty-four right-handed volunteers (ages 20–33 years) were recruited from Linköping University. The sample consisted of healthy adults enrolled as students at the university. None of the participants reported any history of drug abuse or neurological illness. All participants had normal or corrected-to-normal vision. Written informed consent was obtained from each participant, and the study was approved by the Swedish Central Ethical Review Board (study approval number: Dnr 2017/103-31). Seven participants were excluded from further analyses because of...
were aware of whether the upcoming task was concerned of the nature of the upcoming task, so that the participants Before each block presentation, a brief instruction screen [1500 msec]) and resulted in a block duration of 56 sec. presented for 4000 msec (including fixation cue [500 msec], consisted 14 trials of one of the tasks, each of which was over six blocks in an alternating block design. Each block an overview of the tasks). These tasks were administered to benefit judgments, and one control task (see Figure 1 for one pertaining to risk judgments and the other pertaining using the affect heuristic. A large negative correlation means with risk judgments or benefit judgments. Between each block, a resting period of 12 sec was implemented to let the hemodynamic response signal return to baseline. SuperLab 5 (Cedrus Corporation) was used to administer all tasks and was used to record reaction time (RT) data for each participant. The participants responded by using an fMRI-compatible Lumina response pad (Cedrus Corporation). Participants were instructed to use buttons beneath their right-hand index and middle fingers to select their response, corresponding to the left- and right-lateralized risk scenarios presented on the screen. The stimuli were presented using a pair of VisuaStimDigital video goggles (Resonance Technology Inc.).

**Behavioral Measure of the Affect Heuristic**

To measure the affect heuristic, we used a questionnaire containing 64 items comprising various activities and scenarios in different domains (cf. Skagerlund et al., 2020). The activities and domains were adapted from previous research that has investigated attitudes toward risk and risky behavior (Weber, Blais, & Betz, 2002; Bradley & Lang, 1999; Slovic, 1987). The domains that the activities were taken from included the sensation-seeking domain (e.g., “Skydiving”), the social domain (e.g., “Speaking before an audience”), the health domain (e.g., “Vaccination”), and the economic domain (e.g., “Buying stocks”). The participants were asked to rate each scenario, based on his or her subjective attitude, from 1 (not at all risky) to 7 (extremely risky). The participants were given two versions of the same questionnaire. In the first condition, the participants were asked to estimate the subjective level of risk, as described above. In the second version of the questionnaire, the participants were asked to judge the subjective level of benefit of each activity instead. The order in which the participants filled out the questionnaires was counterbalanced. Individual risk–benefit correlations were then calculated. Our previous work has shown that there is a negative correlation between estimations of risk and benefit using this protocol (Skagerlund et al., 2020). The individual risk–benefit correlation is a measure of an individual’s propensity for using the affect heuristic. A large negative correlation means that judgments are based on common mechanisms, whereas an absence of an anti-correlation signifies that an individual dissociates judgments of risk and benefits. The individual risk–benefit correlation was then used to investigate whether we could find associations with the neural data. The same activities and scenarios of the questionnaire were then used to the task fMRI paradigm.

**Design and Experimental Tasks**

The fMRI paradigm consisted of two experimental tasks, one pertaining to risk judgments and the other pertaining to benefit judgments, and one control task (see Figure 1 for an overview of the tasks). These tasks were administered over six blocks in an alternating block design. Each block consisted 14 trials of one of the tasks, each of which was presented for 4000 msec (including fixation cue [500 msec], stimulus presentation [2000 msec], and response window [1500 msec]) and resulted in a block duration of 56 sec. Before each block presentation, a brief instruction screen was presented for 2000 msec to remind the participants of the nature of the upcoming task, so that the participants were aware of whether the upcoming task was concerned

![Figure 1. Overview of the risk and benefit perception tasks, which are identical in their design and thus depicted in the figure. The control task was administered to elicit and control for motor processes and lexical processes.](image)
For example, a participant might have rated “Bowling” as a “1” and “Bungy jumping” as a “6” outside the scanner regarding the estimated risk involved. In the scanner, this particular trial would yield a difference score of “5” (6 – 1). We calculated the mean difference score for each block to see whether they actually differed between “Difficult” blocks and “Easy” blocks across all participants. The harder trials of both risk (M = 1.24, SD = 0.29) and benefit (M = 1.43, SD = 0.37) conditions showed lower difference scores than the easier trials (M = 2.45, SD = 0.50, and M = 2.14, SD = 0.47, respectively), which yielded significant differences, t(41) = −15.72, p < .001, and t(41) = −7.81, p < .001, respectively.

Control Task

Similar to Vorhold et al. (2007), we used a letter processing control task to contrast against risk/benefit processing from letter processing that poses similar perceptual and motor demands. A letter-case discrimination task was used as baseline control task for the experimental conditions, featured at the end of each cycle of blocks. Two letters were presented horizontally, where one was printed in uppercase and the other was printed in lowercase (e.g., “A” vs. “F”). Participants were requested to select the uppercase letter in each of the 14 trials in a block, meaning that the control task followed the same presentation format and response requirements as the experimental tasks. A fixation cross was presented for 500 msec at the onset of each trial, followed by a stimulus presentation of 2000 msec. Each trial ended with a response screen lasting 1500 msec. Participants responded by pressing the corresponding right- or left-lateralized button on the response pad and received no feedback regarding their response.

fMRI Data Acquisition

The fMRI data were collected at the Center for Medical Imaging and Visualization, Linköping University. A 3-T Siemens Magnetom Prisma MRI scanner, fitted with a 20-channel head coil, was used for data acquisition. High-resolution structural scans were acquired using a T1-weighted pulse sequence (repetition time = 2300.0 msec, echo time = 2.36 msec, flip = 8°, slice thickness = 0.90 × 0.90 × 0.90 mm, number of slices = 208) for each participant before the acquisition of functional scans, to assist localization and coregistration during data preprocessing. A blood oxygen level dependent-sensitive T2*-weighted ascending echo planar imaging pulse sequence was used to acquire whole-brain functional scans (repetition time = 1340.0 msec, echo time = 30.0 msec, flip = 69°). Forty-eight 3.0-mm-thick slices with an in-plane resolution of 3.0 mm and no gap were used.

fMRI Data Analysis

Preprocessing and general linear model analysis was performed using SPM12 (Wellcome Department of Cognitive Neurology). Functional images were motion corrected by realignment and by reference to the mean functional image. Coregistration was performed with the segmented anatomical image. Images were smoothed using a Gaussian kernel of 8 × 8 × 8 mm full width half maximum and normalized using the default gray matter probability template in Montreal Neurological Institute (MNI) space. After motion correction and realignment, six motion regressors were included in the first-level design matrix for each individual. A whole-brain voxel-wise blood oxygen level dependent analysis was performed for each participant and task, where each experimental condition was contrasted with the control condition (e.g., Risk > Control) as well as condition-specific parametric levels (e.g., Risk_Difficult > Risk_Easy; Benefit_Difficult > Benefit_Easy). Participant-level beta maps were then entered into a second-level random effects analysis with a family-wise error (FWE) correction threshold of p = .05 was performed to report group-level results. To investigate overlapping activations across both experimental tasks, we performed a conjunction null analysis (Nichols, Brett, Wager, & Poline, 2005) over the two contrasts [Risk > Control] ∩ [Benefit > Control].

RESULTS

Behavioral Results

Initial analyses of the risk and benefit ratings completed outside the scanner were done to estimate individuals’ use of the affect heuristic. All the scenarios and participants’ mean ratings can be found in Table 1 below. On the basis of these mean ratings, we investigated whether there was a significant inverse correlation between risk and benefit ratings. There was indeed a strong negative correlation, r = −.77, p < .001, between group-level estimations of risk and benefit, which can be seen in Figure 1 below. After establishing this association, we calculated coefficients for each individual, which yields an individual “Risk–Benefit Index” (RBI). Participant-level RBI showed a mean correlation coefficient of r = −.55 (SD = .15) that ranged between r = −.84 and r = −.12.

Behavioral results from the risk and benefit task in the scanner showed that mean RTs for the risk condition was 564 msec (SD = 99 msec), whereas the means for the benefit condition and control condition were 565 msec (SD = 97 msec) and 461 msec (SD = 75 msec), respectively. One-way repeated-measures analysis of variance revealed that there was a main effect of task, F(2, 80) = 91.07, p < .001, partial η² = .70. Post hoc analyses using Sidak tests showed that there was no difference between the risk and benefit conditions (p = 1.00), whereas the control condition differed from both risk and benefit conditions (ps < .001). Potential parametric effects were also investigated and showed that difficult risk trials (M = 610 msec, SD = 111 msec) yielded slower RTs than easy trials (M = 519 msec, SD = 102 msec), t(41) = 7.26, p < .001, and...
difficult benefit trials ($M = 585\text{ msec}$, $SD = 111\text{ msec}$) resulted in slower RTs than easier trials ($M = 545\text{ msec}$, $SD = 94\text{ msec}$), $t(41) = 3.42, p = .001$.

### Brain Imaging Results

To report task-related activation, we used the cytoarchitectonic probability maps featured in Anatomy Toolbox (Eickhoff et al., 2005) in SPM12. Contrasting activations during the risk perception task with the control condition revealed activations in the left hemisphere exclusively, with a primary cluster around the left IFG and the left anterior insula (see Table 2 and Figure 2A below). Additional frontal activations could be demonstrated in the left medial frontal gyrus (MFG), whereas parietal activations were limited to a small portion of the left IPS.

#### Table 1. Risk and Benefit Judgments Sorted by Level of Estimated Risk

<table>
<thead>
<tr>
<th>Activity</th>
<th>Risk $M$</th>
<th>Benefit $M$</th>
<th>Activity</th>
<th>Risk $M$</th>
<th>Benefit $M$</th>
<th>Activity</th>
<th>Risk $M$</th>
<th>Benefit $M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take cocaine</td>
<td>6.00</td>
<td>1.45</td>
<td>Have kids</td>
<td>3.15</td>
<td>5.05</td>
<td>Go by train</td>
<td>1.68</td>
<td>5.33</td>
</tr>
<tr>
<td>Take ecstasy</td>
<td>5.78</td>
<td>1.53</td>
<td>Ice skating on lake</td>
<td>3.05</td>
<td>3.60</td>
<td>Donate blood</td>
<td>1.60</td>
<td>5.13</td>
</tr>
<tr>
<td>Smoking</td>
<td>5.18</td>
<td>1.20</td>
<td>Take a bank loan</td>
<td>3.05</td>
<td>4.38</td>
<td>Jogging</td>
<td>1.45</td>
<td>5.65</td>
</tr>
<tr>
<td>Handling guns</td>
<td>4.73</td>
<td>1.93</td>
<td>Get divorced</td>
<td>3.33</td>
<td>3.00</td>
<td>Drink coffee</td>
<td>1.40</td>
<td>4.28</td>
</tr>
<tr>
<td>Cheating on partner</td>
<td>4.60</td>
<td>1.28</td>
<td>Snowboarding</td>
<td>2.83</td>
<td>3.45</td>
<td>Play golf</td>
<td>1.33</td>
<td>2.93</td>
</tr>
<tr>
<td>Shoplifting</td>
<td>4.50</td>
<td>1.20</td>
<td>Skiing</td>
<td>2.75</td>
<td>2.88</td>
<td>Bowling</td>
<td>1.27</td>
<td>3.70</td>
</tr>
<tr>
<td>Mountaineering</td>
<td>4.28</td>
<td>3.48</td>
<td>Buy scratch ticket</td>
<td>2.70</td>
<td>2.35</td>
<td>Take a walk</td>
<td>1.23</td>
<td>5.93</td>
</tr>
<tr>
<td>Speeding with a car</td>
<td>4.28</td>
<td>2.30</td>
<td>Drive a car</td>
<td>2.60</td>
<td>5.13</td>
<td>Eat chocolate</td>
<td>1.20</td>
<td>4.40</td>
</tr>
<tr>
<td>White water rafting</td>
<td>4.20</td>
<td>3.53</td>
<td>Horseback riding</td>
<td>2.53</td>
<td>3.40</td>
<td>Yoga</td>
<td>1.18</td>
<td>4.85</td>
</tr>
<tr>
<td>Skydiving</td>
<td>4.18</td>
<td>3.63</td>
<td>Fly commercially</td>
<td>2.30</td>
<td>4.93</td>
<td>Drink juice</td>
<td>1.18</td>
<td>3.75</td>
</tr>
<tr>
<td>Casino gambling</td>
<td>4.13</td>
<td>1.83</td>
<td>Eat sugar</td>
<td>2.30</td>
<td>3.28</td>
<td>Watch TV</td>
<td>1.15</td>
<td>3.98</td>
</tr>
<tr>
<td>Online casino</td>
<td>4.05</td>
<td>1.80</td>
<td>Eat red meat</td>
<td>2.20</td>
<td>3.55</td>
<td>Play chess</td>
<td>1.13</td>
<td>3.73</td>
</tr>
<tr>
<td>Bungee jumping</td>
<td>4.03</td>
<td>3.25</td>
<td>Take painkillers</td>
<td>2.13</td>
<td>4.33</td>
<td>Eat an apple</td>
<td>1.13</td>
<td>4.78</td>
</tr>
<tr>
<td>Unprotected sex</td>
<td>3.78</td>
<td>2.80</td>
<td>Bicycling</td>
<td>2.13</td>
<td>5.45</td>
<td>Play video games</td>
<td>1.10</td>
<td>3.58</td>
</tr>
<tr>
<td>Drink strong spirits</td>
<td>3.75</td>
<td>2.73</td>
<td>Vaccinating</td>
<td>1.98</td>
<td>5.73</td>
<td>Drink tea</td>
<td>1.08</td>
<td>4.80</td>
</tr>
<tr>
<td>Buy stocks</td>
<td>3.65</td>
<td>3.88</td>
<td>Rollercoaster</td>
<td>1.90</td>
<td>4.35</td>
<td>Play board games</td>
<td>1.05</td>
<td>4.75</td>
</tr>
<tr>
<td>Snuffing tobacco</td>
<td>3.55</td>
<td>1.68</td>
<td>Hold a speech</td>
<td>1.83</td>
<td>4.95</td>
<td>Eat dinner</td>
<td>1.05</td>
<td>6.30</td>
</tr>
<tr>
<td>Drink alcohol</td>
<td>3.45</td>
<td>3.48</td>
<td>Swimming</td>
<td>1.80</td>
<td>4.83</td>
<td>Drink water</td>
<td>1.05</td>
<td>6.85</td>
</tr>
<tr>
<td>Sun tanning (salon)</td>
<td>3.38</td>
<td>1.80</td>
<td>Hold a speech</td>
<td>1.83</td>
<td>4.95</td>
<td>Resting</td>
<td>1.00</td>
<td>6.13</td>
</tr>
<tr>
<td>Get divorced</td>
<td>3.33</td>
<td>3.00</td>
<td>Have an x-ray</td>
<td>1.77</td>
<td>5.10</td>
<td>Reading</td>
<td>1.00</td>
<td>5.95</td>
</tr>
<tr>
<td>Switch career</td>
<td>3.33</td>
<td>4.40</td>
<td>Go by ferry</td>
<td>1.73</td>
<td>4.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave surfing</td>
<td>3.15</td>
<td>3.93</td>
<td>Shopping</td>
<td>1.70</td>
<td>4.15</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Clusters Identified in the Risk > Control Contrast (FWE $p < .05$)

<table>
<thead>
<tr>
<th>Anatomical Region</th>
<th>MNI Coordinates</th>
<th>Cluster Size</th>
<th>$p$</th>
<th>$z$ Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left IFG/insula</td>
<td>$-39, 26, 20$</td>
<td>270</td>
<td>$&lt; .001$</td>
<td>6.60</td>
</tr>
<tr>
<td>Left MFG</td>
<td>$-6, 17, 50$</td>
<td>44</td>
<td>$&lt; .001$</td>
<td>6.02</td>
</tr>
<tr>
<td>Left intraparietal sulcus</td>
<td>$-30, -55, 41$</td>
<td>6</td>
<td>$&lt; .001$</td>
<td>5.01</td>
</tr>
<tr>
<td>Left inferior temporal gyrus</td>
<td>$-42, -46, -13$</td>
<td>3</td>
<td>$&lt; .001$</td>
<td>4.52</td>
</tr>
<tr>
<td>Left middle temporal gyrus</td>
<td>$-48, -43, 2$</td>
<td>2</td>
<td>$&lt; .001$</td>
<td>4.46</td>
</tr>
</tbody>
</table>

Value of cluster size indicates number of voxels. Coordinates indicate peak level activation.
Analysis of the activations during the benefit condition compared to the control condition revealed two clusters in the frontal areas of the brain. Similar to the risk condition, we found one cluster in the left IFG and another in the left MFG (see Table 3 and Figure 2B).

Follow-up analyses of potential parametric effects (i.e., Risk_Difficult > Risk_Easy and Benefit_Difficult > Benefit_Easy) revealed no suprathreshold clusters at FWE > .05. However, liberal thresholding at $p < .001$ (uncorrected) revealed two clusters for the risk condition in the left IPS and the left MFG. However, given the liberal threshold, we only refer to Figure A1 and Table A3 in the Appendix. To account for potential interindividual variability of individual risk ratings outside the scanner that could potentially drive an effect, we also repeated the main analyses (i.e., Risk > Control and Benefit > Control) while including individual risk/benefit differences between comparison stimuli as a second-level covariate. This did not change the results, and these results can also be found in the Appendix (Figure A1 and Tables A1 and A2).

Before performing a conjunction analysis to investigate common activations across both the experimental conditions, we explored whether there were any unique activations pertaining to each condition. By contrasting Risk > Benefit, we found a cluster in the left posterior insula extending into superior temporal gyrus. In addition, this contrast revealed a cluster in the left inferior parietal lobule, right posterior insula, and right middle temporal gyrus. As opposed to the task–control contrasts, the insula activations were posterior rather than anterior. However, when analyzing the Benefit > Risk contrast, we found no suprathreshold clusters when correcting for FWE at $p < .05$.

After initial task-specific analyses of risk and benefit conditions, we performed a conjunction analysis over the contrasts [Risk > Control] ∩ [Benefit > Control] with FWE $p < .05$. This conjunction analysis would inform whether there were overlapping activations during both conditions, which would indicate the neural underpinnings of the affect heuristic. The conjunction (conjunction null) analysis demonstrated overlapping clusters in the left IFG and insula, as well as the left MFG and left middle temporal gyrus (see Table 4 and Figure 3). After

### Table 4. Clusters Identified in the Risk > Benefit Contrast (FWE $p < .05$)

<table>
<thead>
<tr>
<th>Anatomical Region</th>
<th>MNI Coordinates</th>
<th>Cluster Size</th>
<th>$p$</th>
<th>$z$ Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left superior temporal gyrus/insula</td>
<td>$-48, -10, 2$</td>
<td>11</td>
<td>$&lt; .001$</td>
<td>4.74</td>
</tr>
<tr>
<td>Left inferior parietal lobule</td>
<td>$-39, -37, 29$</td>
<td>5</td>
<td>$&lt; .001$</td>
<td>4.52</td>
</tr>
<tr>
<td>Right posterior insula</td>
<td>$39, -13, -1$</td>
<td>5</td>
<td>$&lt; .001$</td>
<td>4.29</td>
</tr>
<tr>
<td>Right middle temporal gyrus</td>
<td>$48, -53, 2$</td>
<td>3</td>
<td>$&lt; .001$</td>
<td>4.28</td>
</tr>
</tbody>
</table>

Value of cluster size indicates number of voxels. Coordinates indicate peak level activation.

Figure 3. An overview of the results from the contrasts between experimental tasks and the control group at FWE$p < .05$. A illustrates the active clusters from the Risk > Control contrast, whereas B illustrates the results from the Benefit > Control contrast. To determine task-specific activations, we also contrasted Risk > Benefit and Benefit > Risk. Only suprathreshold clusters were found for the former contrast, as can be seen in C.
establishing shared activations over both risk and benefit conditions, our hypothesis was that these neural correlates would be positively correlated with the individual RBI. Thus, neural activation strength during risk and benefit estimations would be correlated with better (lower inverse correlation) score on the RBI. To examine whether this was the case, we exported masks based on the conjunction analysis clusters to use in a region-of-interest (ROI) analysis. Using these ROIs, we extracted beta weights during the risk and benefit tasks using MarsBar (Brett, Anton, Valabregue, & Poline, 2002; marsbar.sourceforge.net), which we then correlated with individual RBI. Before running a correlation analysis between RBI and parameter estimates extracted from ROIs, two outliers (scores > 2.5 SDs from the sample mean) were identified and removed from further analysis. The correlation between the activity of the MFG during the risk task was associated with RBI ($r = .28, p = .040$). The results also revealed a correlation between RBI and activation in the left IFG/insula ROI, $r = .31, p = .027$. Similar results were revealed for the benefit task. The beta weights extracted from the same clusters during the benefit task were also correlated with RBI (see Figure 4). Signal from the left IFG/insula ROI correlated with RBI ($r = .44, p = .003$) as did signal from the MFG ($r = .39, p = .007$). The pattern of results augments the interpretation that the activations during these tasks are involved in the affect heuristic (Table 5).

### Table 5. Clusters Identified in the Conjunction Analysis over the Two Contrasts [Risk > Control] ∩ [Benefit > Control] with FWE $p < .05$

<table>
<thead>
<tr>
<th>Anatomical Region</th>
<th>MNI Coordinates</th>
<th>Cluster Size</th>
<th>$p$</th>
<th>$z$ Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left IFG/insula</td>
<td>−36, 17, 29</td>
<td>75</td>
<td>&lt; .001</td>
<td>5.22</td>
</tr>
<tr>
<td>Left MFG</td>
<td>−6, 17, 50</td>
<td>4</td>
<td>&lt; .001</td>
<td>4.79</td>
</tr>
<tr>
<td>Left middle temporal</td>
<td>−48, −40, 2</td>
<td>1</td>
<td>&lt; .001</td>
<td>4.37</td>
</tr>
<tr>
<td>tempgyrus</td>
<td>−30, 23, −1</td>
<td>1</td>
<td>&lt; .001</td>
<td>4.32</td>
</tr>
</tbody>
</table>

Value of cluster size indicates number of voxels. Coordinates indicate peak level activation.

### DISCUSSION

The purpose of the current study was to investigate the neural correlates of the affect heuristic, thus unveiling the neural substrates of what guides human judgments of risk and benefits with respect to various activities and issues. To this end, we developed an fMRI paradigm where individuals had to estimate which of two presented scenarios involved the most risk or benefit. Using a conjunction analysis, we could identify overlapping activations that could constitute neural mechanisms of the affect heuristic. Because this is the first study to investigate this issue, we employed whole-brain voxel-wise analyses. In light of findings from previous studies that have
investigated risk perception using various gambling tasks (e.g., Canessa et al., 2013; Tom et al., 2007), we hypothesized that the insula would be a central hub that would be involved in both risk and benefit judgments. We also hypothesized that the amygdala and medial pFC could be involved in the risk task and the benefit task, respectively.

In line with our first hypothesis, we observed a significant cluster centering on the left IFG extending ventrally into the insula that was common to both risk and benefit judgments. One tentative interpretation is that the left insula is a partial neural substrate of the affect heuristic that integrates viscerosomatic sensory information received from the posterior insula into a coherent representation of the current emotional state of the body. This formulation is supported by findings showing that the anterior insula has bidirectional connections to the amygdala and orbitofrontal cortex.

Previous findings have shown that the IFG is involved in risky decision-making. Reckless et al. (2014) found that the left IFG was involved in adjusting response bias when making decisions. Regarding the role of the IFG in the affect heuristic, the IFG may be involved by taking input from other regions involved in prior steps in the risk processing chain (such as the insula in this case) and implementing flexible adaptation and behavior. However, given the involvement of both the IFG and the insula in various cognitive, social, affective, and visceral processes, it is challenging to disentangle what processes are occurring. This is why we opted to use a behavioral measure—in this case, an affect heuristic measure—to test our interpretations. We hypothesized that common activations revealed by the conjunction analysis would be correlated with individual inclination to rely on the affect heuristic. As we state above, recent findings indicate that individuals differ in the extent to which they rely on the affect heuristic, as measured by calculating individual risk–benefit correlations (RBI). We found that the beta values extracted from the largest clusters in the risk–benefit conjunction analysis were significantly correlated with the RBI. In other words, more activation in the left IFG, insula, and MFG during risk and benefit tasks was associated with a decoupled estimation of risk and benefit judgments. Conversely, lower activity in the MFG, insula, and IFG indicated higher reliance on the affect heuristic. The functional role of the insula in risk and benefit judgments is in line with previous theoretical and empirical work, suggesting its role in tracking physiological states and self-awareness. The anterior insula receives input from the posterior insula, which keeps track of the physiological state of the body (Pugnaghi et al., 2013), and codes salient interoceptive and environmental inputs on a moment-to-moment basis to represent a phenomenological “now,” providing a basis for self-awareness (Craig, 2009). Similarly, interoceptive information is likely the basis underlying the affect heuristic. Interestingly, the posterior insula was more active during risk judgments than during benefit judgments, which tentatively could suggest that risk judgments involved possible elements of loss aversion. Previous work has found that the posterior insula, possibly together with the amygdala, is active during potential losses (Markett et al., 2016; Levin et al., 2012). The more pronounced role of the posterior insula during risk judgments could be taken to suggest that, during benefit judgments, people do not rely on potential losses to the same extent, which is reasonable given the positive framing of the task in question. Nevertheless, posterior insula is likely tracking the internal state of the viscerosomatic sensory state of the body even during benefit judgments, but its role does not seem to be as pertinent as when the utility computations have to keep track of potential harmful information. Therefore, a key neural hub of the affect heuristic seems to be the left anterior insula, a finding that is consistent with several previous findings regarding the neural substrates of risk perception and decision-making (e.g., Harlé, Chang, Wout, & Sanfey, 2012; Preuschoff et al., 2008).

The involvement of the insula was predicted, but the conjunction analysis also revealed a small cluster in the MFG. Moreover, activity of the MFG during risk and benefit tasks was inversely correlated with the inclination to use the affect heuristic. A previous study by Li et al. (2015) investigated the functional and structural connectivity patterns of subregions of the superior frontal gyrus, in which MFG was included. The authors found that the MFG demonstrated strong structural and functional connections with the posterior cingulate cortex, middle cingulate cortex, ACC, and IFG (Li et al., 2013). The authors conclude that the medial portion of the superior frontal gyrus (i.e., MFG) is likely involved in cognitive control, given the strong connection to ACC. Results from earlier work by Talati and Hirsch (2005) corroborate this interpretation. The MFG was found to be involved in go/no-go tasks, which taxes the inhibition component of executive functions. Thus, the most parsimonious interpretation is that the role in the MFG may be related to cognitive control, which allows individuals to inhibit momentary impulses of making judgments of risks and benefits according to the visceral information processed by the insula. This is also corroborated by our parametric contrasts between difficult risk trials and easy trials, but given the liberal threshold required (p < .001, uncorrected), this should be interpreted with caution. In addition to the MFG, the parametric analysis of risk judgments also revealed activation of the IPS, as in the main Risk > Control contrast. This could indicate that the IPS is involved either as a function of effortful cognitive processing, given that it is part of the dorsal attention network, or as a function of magnitude processing. The IPS is consistently found to be involved in representing abstract meaning of numerosity (e.g., Harvey, Klein, Petridou, & Dumoulin, 2013; Ansari, 2008) and other magnitudes (e.g., Walsh, 2003).

Although our primary hypothesis was supported, we did not find support for our second and third hypotheses,
which predicted that amygdala would be more involved in risk perception task than in the benefit task because of possible loss-aversion effects. Interestingly, the posterior insula may have served this functional role instead in the current tasks. The absence of amygdala involvement may be because of the lack of tangible rewards and losses, which could be why the medial portion of the pFC was not more pronounced in the benefit condition either. Although the risk and benefit tasks did involve potentially rewarding and dangerous stimuli, the stimuli did not convey sufficiently substantial consequences as to activate either reward circuitry or fear circuitry.

The current study introduced a novel method, similar in spirit to previous efforts by Vorhold et al. (2007), to assess risk perception and estimation. Previous studies investigating risk perception have mainly used gambling tasks that tap into a complex chain of neural processing pertaining to visual perception, number decoding, risk magnitude, reward magnitude, subjective risk taking, punishment magnitude, gains/losses, and so forth, which makes it hard to isolate and understand the role of specific areas and mechanisms (Schonberg et al., 2011). The tasks in the current experiment paradigm mimic the way in which the phenomenon of the affect heuristic is typically observed and measured—by estimating the risk or benefit of activities and issues presented verbally. Future studies could leverage the findings in the current study but instead employ different presentation formats, such as visual depictions of various scenarios or issues, which could reinforce and extend the current findings.

There are a number of limitations of the current study that should be acknowledged. The nature of the control task contains fewer letters and requires less effort, which is reflected by lower RTs. Therefore, the current findings should be interpreted with that in mind, and follow-up studies should employ a control task of equal information complexity. Another limitation concerns a central assumption about whether common activations are reflective of the affect heuristic. We acknowledge the pleiotropic nature of individual regions and networks of the brain, such that we cannot be absolutely 100% certain that common activations refer to the same phenotypical cognitive process. One might posit that overlapping neural activations during risk and benefit judgments could constitute a necessary but not sufficient criterion of the affect heuristic. However, the correlation between the RBI and parameter estimates during these tasks is the best supportive evidence we can present for a cognitive process (affect heuristic) that is assumed to rely on shared psychological and neural mechanisms.

One might also question whether an observed negative correlation necessarily must be attributed to common psychological and affective mechanisms, insofar as a given participant might instead use separate but complementary pieces of evidence to make each rating that only superficially looks like it could be attributed to common psychological processes engendering both risk and benefit ratings. Other researchers have investigated the mechanisms of this relationship. For example, a causal link between judgments of risk and benefit was shown by Finucane et al. (2000), where they manipulated the amount of information given to the participants about various activities. By providing positive information about a scenario, the positive affective judgment of this particular scenario increased, resulting in lower risk estimations concurrently with higher benefit judgments (Finucane et al., 2000). Similarly, the causal link between judgments of risk and benefits was demonstrated by Keller, Siegrist, and Gutscher (2006) who found that evoking negative affect in participants resulted in higher estimations of risks. Therefore, these causal effects verify that the observed correlation between risk and benefit judgments can be attributed to common affective processes.

Taken together, our findings indicate that the neural correlates of the affect heuristic can be found in a cluster centering on the left insula, left IFG, and left MFG. Activations in these regions were common to both risk and benefit judgments in the scanner. In addition, beta values extracted from these clusters were also associated with individual scores on the affect heuristic instrument (i.e., the RBI) administered outside the scanner. One tentative interpretation is that the left insula is a partial neural substrate of the affect heuristic that integrates viscerosomaticosensory information received from the posterior insula into a coherent representation of the current emotional state of the body. Activity could also be identified in the left MFG, indicating that executive processes may be involved in inhibiting the impulse of making judgments according to momentary visceral information. Together, these areas may be part of a network that underlie risk judgments and evaluations without explicit reward or loss.
Figure A1. An overview of the follow-up analyses of the main analyses. A illustrates the active clusters from the Risk > Control contrast while including individual judgments of risk (FWE $p < .05$). B illustrates the results from the Benefit > Control contrast while including individual judgments of benefit as second-level covariate. C shows a parametric contrast between difficult risk judgments versus easy risk judgments ($p < .001$, uncorrected).

Table A1. Clusters Identified in the Risk > Control Contrast (FWE $p < .05$, with Individual Risk Judgments as Second-Level Covariate)

<table>
<thead>
<tr>
<th>Anatomical Region</th>
<th>MNI Coordinates</th>
<th>Cluster Size</th>
<th>$p$</th>
<th>$z$ Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left IFG/insula</td>
<td>$-39, 26, 20$</td>
<td>273</td>
<td>$&lt; .001$</td>
<td>6.63</td>
</tr>
<tr>
<td>Left MFG</td>
<td>$-6, 17, 50$</td>
<td>48</td>
<td>$&lt; .001$</td>
<td>6.16</td>
</tr>
<tr>
<td>Left intraparietal sulcus</td>
<td>$-30, -55, 41$</td>
<td>8</td>
<td>$&lt; .001$</td>
<td>5.20</td>
</tr>
<tr>
<td>Left inferior temporal gyrus</td>
<td>$-42, -46, -13$</td>
<td>4</td>
<td>$&lt; .001$</td>
<td>4.54</td>
</tr>
<tr>
<td>Left middle temporal gyrus</td>
<td>$-48, -43, 2$</td>
<td>2</td>
<td>$&lt; .001$</td>
<td>4.46</td>
</tr>
<tr>
<td>Right MFG</td>
<td>$42, 26, 23$</td>
<td>1</td>
<td>$&lt; .001$</td>
<td>4.41</td>
</tr>
</tbody>
</table>

Value of cluster size indicates number of voxels. Coordinates indicate peak level activation.
Reprint requests should be sent to Kenny Skagerlund, Department of Behavioural Sciences and Learning, Linköping University, Campus Valla, SE-581 83 Linköping, Sweden, or via e-mail: kenny.skagerlund@liu.se.

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Diversity in Citation Practices

A retrospective analysis of the citations in every article published in this journal from 2010 to 2020 has revealed a persistent pattern of gender imbalance: Although the proportions of authorship teams (categorized by estimated gender identification of first author/last author) publishing in the Journal of Cognitive Neuroscience (JoCN) during this period were M(an)/M = .579, W(oman)/M = .243, M/ W = .102, and W/ W = .076 (Fulvio et al., JoCN, 33:1, pp. 3–7). Consequently, JoCN encourages all authors to consider gender balance explicitly when selecting which articles to cite and gives them the opportunity to report their article’s gender citation balance.

REFERENCES


Table 2. Clusters Identified in the Benefit > Control Contrast (FWE p < .05, with Individual Benefit Judgments as Second-Level Covariate)

<table>
<thead>
<tr>
<th>Anatomical Region</th>
<th>MNI Coordinates</th>
<th>Cluster Size</th>
<th>p</th>
<th>z Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left IFG</td>
<td>−33, 17, 29</td>
<td>88</td>
<td>&lt;.001</td>
<td>5.36</td>
</tr>
<tr>
<td>Left MFG</td>
<td>−6, 17, 50</td>
<td>4</td>
<td>&lt;.001</td>
<td>4.69</td>
</tr>
</tbody>
</table>

Value of cluster size indicates number of voxels. Coordinates indicate peak level activation.

Table 3. Risk_Difficult > Risk_Easy (p < .001, Uncorrected)

<table>
<thead>
<tr>
<th>Anatomical Region</th>
<th>MNI Coordinates</th>
<th>Cluster Size</th>
<th>p</th>
<th>z Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left middle frontal gyrus</td>
<td>−39, −1, 38</td>
<td>20</td>
<td>&lt;.001</td>
<td>3.75</td>
</tr>
<tr>
<td>Left intraparietal sulcus</td>
<td>−27, −52, 44</td>
<td>1</td>
<td>&lt;.001</td>
<td>3.40</td>
</tr>
</tbody>
</table>

Value of cluster size indicates number of voxels. Coordinates indicate peak level activation.


