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Neural correlates of risk perception as a function of risk level: An approach to the study of risk through a daily life task

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ABSTRACT

We are often required to make decisions that can have safe or risky consequences. Evaluating the risk of each possible alternative is an important step before making our final decision. The main goal of the present research was to explore the neural basis of risk perception in a naturalistic context (driving). Twenty-two drivers evaluated the perceived risk in 72 traffic situations (previously categorized by driving instructors) while brain activity was recorded using fMRI. A neural network involving attentional factors, emotional processing, stimulus-response associations, and risk aversion was related to the perception of risks. Given the nature of our task, a more prominent role was played by emotional factors (evaluation of the consequences) than cognitive factors (e.g. probabilistic calculations). Moreover, activation in the insula, inferior frontal gyrus, precentral/postcentral gyrus, inferior parietal gyrus, and temporal and occipital regions linearly increased as a function of risk level. Our findings provide a new step towards understanding the neural processing underlying risk behavior in daily life tasks, which is particularly relevant given the study context and its important practical implications for our society.

1. Introduction

Often in our daily lives we have to face situations in which several behavioral courses can lead us to either positive (e.g., win a lottery, get home safe after driving) or negative consequences (e.g., money loss, have a traffic accident). In real everyday contexts, unlike financial environments where risk is understood as a complex construct associated with statistical uncertainty models studying variance in both losses and gains (Alós-Ferrer and Strack, 2014; Bouchaud and Potters, 2003), risky behavior refers to the selection of an action than can lead to a certain probability of negative outcomes (Helfinstein et al., 2014; Schonberg, Fox, and Poldrack, 2011; Van Duijvenvoorde, Blankenstein, Crone, and Figner, 2017), such as harming oneself/others. Choosing this action depends, among other factors, on the individual's ability to make a prior evaluation of the situation and predict the rewards and costs associated with the different alternative responses (Rangel, Camerer, and Montague, 2008). In this regard, the evaluation of risk implies three essential, subjective elements: 1) the possibility of losses, 2) the significance of these losses, and 3) the uncertainty associated with these losses (Yates and Stone, 1992).

Neuroimaging studies using risk behavior questionnaires and simple behavioral tasks have identified a brain network related to financial risks, but they show limited validity for predicting real-world risk taking (Krain et al., 2006; Helfinstein et al., 2014). More naturalistic and complex behavioral tasks measuring risk-taking behavior, such as the Iowa Gambling Task (IGT) and Balloon Analogue Risk Task (BART), have shown to be better predictors in real-life environments (Schonberg, 2011). However, a prominent feature of these tasks (both IGT and BART) is that the stimulus itself carries no risk; this emerges after the decision is made, and therefore a deep evaluation of the consequences, but a minimal evaluation of the stimulus is required. This is different from many real-life situations in which the stimulus provides rich information about the probability of having negative outcomes, such as the case in which one wants to overtake a car when a truck is coming in the opposite direction, using a syringe used by someone else, or bungee jumping. In these cases, decisions are made after considering the evidence provided by the stimulus (e.g., distance of the oncoming truck), the objective potential consequences (both rewards and costs), their emotional meaning, and the probability of such consequences occurring (Megías et al., 2014; Loewenstein et al., 2001; Slovic, Finucane et al., 2007).

In the present work, a novel method was employed to gain evidence regarding the neural mechanisms underlying the perception of risk in real-world contexts. In particular, we studied risk processing by using real pictures of traffic scenes, adopting a rapid event-related fMRI design. Driving can be regarded as one of the most common risk behaviors

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worldwide, since almost everyone over a certain age has experience of driving cars or other vehicles. This method represents a departure from other tasks used to study risk in naturalistic environments, such as the IGT or the BART, which are further removed from daily life contexts, and in which aspects such as numeracy or literacy play a more important role in the computation and perception of risks. Moreover, in many of the tasks employed in the literature, risk perception and decision-making processes are commonly intertwined (Vorhold, 2008). Unlike these studies, we focus only on risk perception by placing our participants in an "observer" mental set, in which no consequences occur as a result of their behavioral decisions regarding the riskiness of the situation, that is, they are simply like the observers of a game (Megías et al., 2011, 2015).

Mohr et al. (2010), in a quantitative meta-analysis on neural representations of risk processing, identified a network that encompasses the anterior insula, thalamus, dorsolateral and dorsomedial prefrontal (DLPFC/DMPFC), and parietal cortices. Anterior cingulate cortex (AAC), amygdala, ventromedial prefrontal cortex (VMPFC), inferior frontal gyrus (IFG), and cerebellum have also been commonly associated with risk-taking and risk perception (Christopoulos et al., 2009; Coaster et al., 2011; Ernst et al., 2002; Vorhold et al., 2007). For example, results from another recent meta-analysis and systematic review (Gowin et al., 2013) comparing substance users (risk-takers) and healthy controls using tasks that have been shown to correlate with naturalistic risk taking (i.e.: IGT, BART) indicated that altered risk-related processing in substance users is associated with differences in activation of the ventral striatum, ventromedial prefrontal and orbitofrontal cortex, anterior cingulate, insula, amygdala, and primary somatosensory cortex.

Reviewing this literature, we can observe that many of these areas belong to the limbic system or are mainly associated with emotional processing. Activity in anterior insula, amygdala, ACC, and VMPFC is known to be correlated with the emotional value of risky stimuli (Menon and Uddin, 2010; Phan et al., 2002). On the other hand, DLPFC, DMPFC, IFG and parts of the parietal cortex have been implied in more cognitive aspects of risk such as the calculation of summary statistics, stimulus appraisal, control of the risk behavior, or in the preparation and execution of the final decision (Christopoulos et al., 2009; Mohr et al., 2010; Symmonds et al., 2011). These findings show the involvement of a broad neural network in risk processing and indicate the important role that is played by the interaction of cognitive, motivational, and emotional factors in risk perception and decision-making (Coaster et al., 2011; Loewenstein et al., 2001; Knutson and Huettel, 2015).

As pointed out previously, much of the literature on the neural basis of risk behavior has not separated the perception stage from the decision phase. However, decision-making includes additional processes to risk perception, and judgments of risk are not only restricted to the decision-making process (Rangel et al., 2008; Vorhold, 2008). Thus, for a proper understanding of risk perception, this must be studied separately from decision-making. The few studies that have distinguished between neural processes involved in risk perception and risk taking have revealed a greater recruitment of frontal areas in risk taking (Megías et al., 2015; Mohr et al., 2010), but these findings need to be further explored. One of our aims in the present research was to address this gap by assessing brain activation in a purely perceptual naturalistic task in which responses do not have outcomes.

In addition, we were also interested in studying whether the activity of the brain areas involved in risk perception is a linear function of the risk levels of the situation. People usually categorize situations as risky or not risky, but at the cognitive level risk perception is understood as a continuum rather than a dichotomous construct, which may vary along a dimension from no risk at all to very high risk (Sitkin and Pablo, 1992). The linear hypothesis would imply that perceived risk should be reflected in a gradual change in the activation of the brain areas involved in risk information provided by the stimulus, probabilistic calculations (cognitive factors), and the evaluation of the consequences (mostly emotional factors) in risk behavior. However, a non-linear function would imply that the areas of the brain involved in risk processing would be recruited after a certain risk threshold had been reached.

The purpose of the current study can be divided into a main objective and two specific objectives. The main objective was to study the neural basis underlying risk perception in a naturalistic task that more closely resembles real-life situations (in our case, driving). Given that most of the neural evidence related to risk processing has focused on economic contexts, and it is well known that risk behavior is highly dependent on the study domain, previous results may not readily be generalized across domains (Blais, and Weber, 2006). Driving has the particularity that a wrong decision may lead to severe physical harm, or even death. Thus, we hypothesize that the neural activity related to emotional processing should carry greater weight in comparison with other domains previously studied in the literature (e.g. economic contexts and gambling). The two more specific objectives were: a) to study the particular brain areas involved in the process of risk perception, which have often been overshadowed by the study of the entire risk decision-making process; and b) to explore whether activity in these brain areas is graded according to the level of risk (a linear function) or is determined by a risk threshold above which these areas are recruited (a non-linear function).

2. Method

2.1. Participants

A total of twenty-two volunteer participants (13 female, 9 male) from the University of Granada took part in the experiment in exchange for course credits. All of them were within a similar age range (M_{age} = 22.5, SD_{age} = 4.83) and had a driver's license in order to reduce the influence of these factors on risk perception in the driving context (Forsyth et al., 1995; Levy, 1990). The participants had held the driver's license for an average period of 34.68 months. All participants gave their written informed consent and were briefed on their rights according to the Helsinki Declaration (World Medical Association, 2008). The research was approved by the Ethic Committee of the University of Granada.

2.2. Stimulus material

The stimuli used in the experiment consisted of seventy-two pictures showing actual driving situations from the driver's perspective. The pictures were selected from an extensive image database depicting different levels of risky driving situations recorded by members of the Learning, Emotion, and Decision Research Group (University of Granada) on Spanish and Finnish roads. All of these selected situations met a set of criteria with the aim of reducing interpersonal variability in their interpretation. First, perception of the speed at which a vehicle is traveling in a static image is problematic (see Vlakveld, 2011). Forty driving school instructors previously evaluated the subjective perceived speed in each one of the images included in the database. Only images where the standard deviation of the speed perception was lower than 25% of the mean were considered. Second, in the selected risky situations, the risk was always induced by a specific stimulus, e.g., a vehicle crossing an intersection, a pedestrian on the road, or another driver opening the door of his/her car, all of which blocked the way. Less specific risk agents such as extreme weather conditions or lack of visibility were dismissed to gain more exhaustive control of the brain response to risk stimuli. Finally, in addition to the experts' evaluation, 40 drivers with a standard driving license evaluated the level of risk of the images (not participants of the present study) using a Likert scale questionnaire (where 0 = no risk, and 7 = high risk). The final set of images used in the experiment included 24 pictures depicting high risk