NeuroImage 84 (2014) 833–842

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Comparison of functional near-infrared spectroscopy and electrodermal activity in assessing objective versus subjective risk during risky financial decisions

Lisa Holper [a,*], Martin Wolf [a], Philippe N. Tobler [b]

[a] Biomedical Optics Research Laboratory (BORL), Division of Neonatology, University Hospital Zurich, Frauenklinikstrasse 10, 8091 Zurich, Switzerland
[b] Laboratory for Social and Neural Systems Research, Department of Economics, University of Zurich, Blümlisalpstrasse 10, 8006 Zurich, Switzerland

ARTICLE INFO

Article history:
Accepted 20 September 2013
Available online 1 October 2013

Keywords:
Decision-making
Neuroeconomics
Risk behavior
Lateral prefrontal cortex
Single-trial classification
Coherence analysis

ABSTRACT

Risk is an important factor impacting financial decisions. Risk can be processed objectively, e.g. as variance across possible outcomes of a choice option or subjectively, e.g. as value of that variance to a given individual. The aim of the present study was to test the potential of functional near-infrared spectroscopy (fNIRS) in assessing these different ways of processing risk while subjects decided between either high or low risk financial options or a safe (risk-free) option. For comparison we simultaneously measured electrodermal activity (EDA), a well-established method in decision-making research and a core measure of affective processes. FNIRS showed that lateral prefrontal cortex responses to high risk were enhanced relative to low risk only in risk-seeking individuals but reduced relative to low risk in risk-averse individuals. This is in-line with individual-specific risk processing reflecting the subjective value of risk. By contrast, EDA showed enhanced responses to high risk, independent of individual risk attitude, in-line with the notion of objective risk processing. The dissociation between the two measures arose even though they overall were equally sensitive to detect individual risk-related differences and even though there was an increased, risk attitude-independent, temporal coherence between the two measures during high-risk conditions. Our results suggest that hemodynamic responses in lateral prefrontal cortex as measured by fNIRS reflect the subjective value of risk, whereas EDA may index the objective amount of risk people are presented with. The findings suggest that fNIRS could be a useful method for studying risk behavior in financial decisions.

Introduction

Risk impacts a wide variety of behaviors, including economic, financial and foraging decisions. Within the context of finance theory, risky choice options can be decomposed into statistical moments of the probability distribution of the outcomes, like the mean and the variance (mean-variance approach). The value of a choice option typically increases with the mean. Interestingly, there are substantial individual differences in how risk is processed. In risk-averse individuals, risk reduces the subjective value of a choice option whereas in risk-seeking individuals it increases value. If given a choice between a safe option and a risky option with the same expected value (EV), most people prefer the safe one, i.e. they are risk-averse. For example, when asked to choose between a box containing 10 Dollars for certain or another box with a 50/50 chance of containing 20 Dollars or being empty, most people prefer the safe option (Kahneman and Tversky, 1979). However, some prefer the risky one, i.e. they are risk-seeking. If one systematically changes the safe amount it typically turns out that also the degree of risk aversion and risk seeking varies considerably across individuals.

In the present paper, we compare two different neurophysiological methods to assess four alternatives of how individual differences in risk attitudes can manifest themselves in psychological processes and their physiological correlates. First, risk attitudes may reflect differences in the subjective valuation of risk: the more risk-averse people are, the more diminished is the subjective value of a choice option with higher risk compared to the subjective value of an option with lower risk (resulting in a negative linear relation between risk aversion and subjective value of the high risk minus the low risk option). Second, they could reflect differences in the perception of risk: the more risk-averse people are, the larger they perceive the risk of a riskier option compared to a less risky option (resulting in a positive linear relation between risk aversion and risk perception of the high risk minus the low risk option). Thirdly, they could reflect affective differences: risk-averse people may experience negative affect when exposed to risk, risk-seeking people positive affect. Accordingly, the more extreme the risk attitude, the more pronounced the affect (resulting in a curvilinear relation between risk attitude and affect induced by the high risk minus the low risk option). Lastly, it may well be the case that in order for valuation, perception and affect to be employed and individual differences to manifest

* Corresponding author. Fax: +41 44 255 44 42.
E-mail addresses: holper@ini.phys.ethz.ch (L. Holper), Martin.Wolf@usz.ch (M. Wolf), phil.tobler@econ.uzh.ch (P.N. Tobler).

1053-8119/$ – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.neuroimage.2013.09.047

themselves, risk first needs to be detected and processed in an objective fashion by all individuals alike (resulting in a flat relation between risk attitude and the difference between the high risk and the low risk option).

We have previously used functional magnetic resonance imaging (fMRI) and showed that the hemodynamic activity of the lateral prefrontal cortex reflects the subjective value of risk (first alternative) (Tobler et al., 2009). Specifically, the more risk-averse people are, the more activity in lateral prefrontal cortex is diminished with increasing risk, expressed in a negative linear relation between activity to high versus low risk and individual risk attitude. The first question of the present study was whether another method of measuring hemodynamic activity, i.e. functional near-infrared spectroscopy (fNIRS), could also be used for assessing this individual risk response. If so, fNIRS could then potentially be used in field studies on risky decision-making thanks to its more portable nature. So far, the method has not been widely applied in decision-making research within the laboratory. The few studies that used fNIRS in decision-related task paradigms did either not differentiate cortical signals between typical decision parameters, but reported results over whole task durations (Suhr and Hammers, 2010); or focused on non-risk-related decision aspects such as wins and losses (Cazzell et al., 2012), which do not provide insight into individual risk processing. In the present study, regarding the alternatives stated above, we expected that the hemodynamic activity of the lateral prefrontal cortex to high versus low risk measured with fNIRS shows a similar negative linear relation with risk aversion as the activity previously measured with fMRI. Such a finding would provide face-value for the use of fNIRS in financial and economic decision research.

The second question of the present study was to compare fNIRS during risky decisions with electrodermal activity (EDA). EDA offers a psychophysiological technique of measuring affective reactivity (Boucsein, 1992; Critchley et al., 2000). It has a similar temporal profile as the hemodynamic response measured by fNIRS but found much wider use in decision-making research (Figner and Murphy, 2010). Previous studies using EDA evaluating decision processing with respect to risk showed that EDA can reflect both increasing risk (Bechara et al., 1999; Studer and Clark, 2011; Yen et al., 2012) and increasing expected value (Glöckner et al., 2012; Yen et al., 2012). There are so far few studies that assessed simultaneously the physiological responses of fNIRS and EDA, e.g. (Combe et al., 2010; Kirilina et al., 2012; Matsuo et al., 2003; Solovey et al., 2012; Watanabe et al., 2011; Zimmermann et al., 2013), but not in decision-making research. Moreover, from a methodological point of view, it is entirely unclear whether the two methods have comparable sensitivity in detecting individual risk-related differences.

The third question of the present study was how EDA reflects individual risk attitude. So far previous research did not assess whether EDA reflects risk for example in a similar way as the hemodynamic response measured by fMRI (first alternative), or whether it reflects risk based on one of the other alternatives. In the decision-making literature EDA has typically been associated with the arousal dimension of affect, indexing its intensity (Figner and Murphy, 2010). According to this notion and the above reasoning, one would expect a curvilinear relation between risk attitude and EDA (third alternative). However, EDA has also been shown to reflect the properties of affective stimuli more objectively and irrespective of their positive or negative valence (Fowles, 1986). According to this notion and the above reasoning, one would expect a flat relation between risk attitude and EDA (fourth alternative).

Materials and methods

Subjects

Twenty healthy subjects were investigated (9 females, mean age (± STD) 28.4 ± 3.9). All subjects were right-handed (mean laterality quotient (LQ ± STD) = 83.4 ± 13.9) according to the Edinburgh Handedness Inventory (Oldfield, 1971). Exclusion criteria were any history of visual, neurological or psychiatric disorder or any current medication. All subjects gave written informed consent. The study was approved by the ethics committee of the Canton Zurich and performed in accordance with the Declaration of Helsinki.

Experimental protocol

Each subject completed a previously described risky decision-making task (Christopoulos et al., 2009; Tobler et al., 2009) and a baseline recording. The order of the conditions was counter-balanced between subjects. During the baseline recording (120 s), subjects were asked to fixate their eyes on a fixation cross on a black screen and to remain motionless. The decision task was implemented using the software PsychoPy (Peirce, 2007). None of the present subjects had previously taken part in experiments using this task. In each trial, subjects made choices between options of varying risk and EV displayed on the screen (Fig. 1A). A safe and a risky option appeared for 5.5 s on the right and left side of a fixation cross. The safe option indicated that subjects would receive the given outcome for sure (100%), whereas the risky option indicated that the two possible outcomes were delivered with an even-chance (50%/50%) probability. In particular, two levels of EV were used, CHF (Swiss Francs) 30 and 60. Each of these was presented in an even-chance (50%/50%) low-risk and high-risk version resulting in four risky options (15/45, 10/50, 40/80, 30/90), one of which was randomly presented in each trial, together with a safe option. Thus, at an EV of CHF 30, the low-risk option offered a 50/50 chance of CHF 15 or 45 whereas the high-risk option offered CHF 10 or 50. At the high EV level of CHF 60, the low-risk option offered CHF 40 or 80 and the high-risk CHF 30 or 90. Therefore, within each pair of conditions with the same EV, one was riskier (i.e. had higher variance) than the other. The safe option varied within the range of the risky option it was presented with.

Subjects were asked to choose their preferred option in each trial by considering both the safe and the risky options. Subjects had to indicate their choice between the safe and the risky option during a 2 s presentation of a circle around the fixation cross by pressing the arrows on a keyboard with their right hand. After the circle disappeared, the chosen option was framed for 1 s. No outcome of subjects' choices was shown

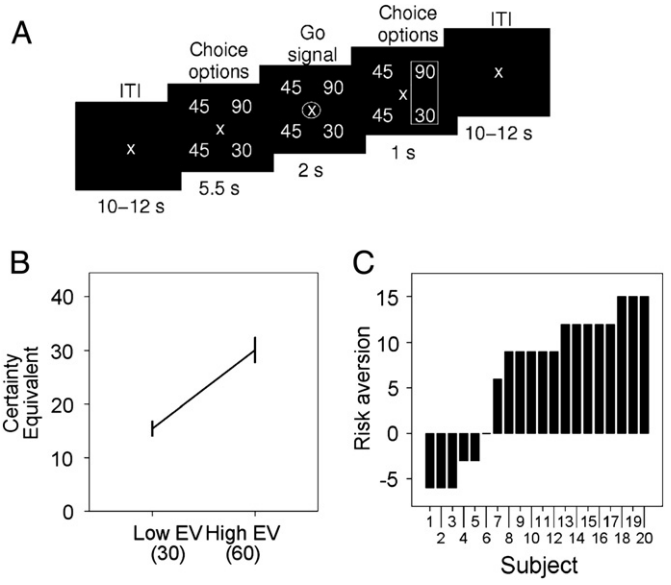

Fig. 1. (A) Experimental design. Shown is the trial structure including option presentation, Go signal, chosen option and inter-trial interval (ITI). (B) Certainty equivalents. Average certainty equivalents (CEs) of low and high expected value (EV) options with same risk; error bars represent standard error of the mean (SEM). (C) Risk aversion. Risk aversion of single subjects as measured by the difference between CEs of low- and high-risk options (CE_{DIFF}) (subjects are ordered based on their CE_{DIFF} and classified as risk-seekingfor CEDIFF ≤ 0 and risk-averse for CEDIFF > 0). The majority (N = 14) of subjects was risk-averse.