Chapter 6
Imperfect Decision Making and Risk Taking Are Affected by Personality

Sarah K. Mesrobian, Michel Bader, Lorenz Götte, Alessandro E.P. Villa and Alessandra Lintas

Abstract Classic game theory predicts that individuals should behave as rational agents in order to maximize their gain. In real life situations it is observed that human decision making does not follow this theory. Specific patterns of activity in several brain circuits identified in recent years have been associated with irrational and imperfect decision making. Brain activity modulated by dopamine and serotonin is assumed to be among the main drivers of the expression of personality traits and patients affected by Attention deficit hyperactivity disorder (ADHD) are characterized by altered activity in those neuromodulating circuits. We investigated the effect of fairness and personality traits on neuronal and psychological mechanisms of decision making and risk taking in two sets of experiments based on the Ultimatum Game (UG) and the Investment Game (IG). In the UG we found that Fairness and Conscientiousness were associated with responder's gain and with event-related potentials (ERP) components Feedback-Related Negativity (FRN) and Late Positive component (LPP). In the IG the sum gained during the risky gambling task were presented immediately after half of the trials (condition "high frequency feedback", *HFFB*), while the other half were presented at the end of each block (condition "low frequency feedback", *LFFB*). Conscientiousness, Agreeableness and Sincerity influenced latencies of the negative deflection occurring at around 200 ms (N200)

S.K. Mesrobian · A.E.P. Villa · A. Lintas (✉)
Neuroheuristic Research Group, Faculty of Business and Economics,
University of Lausanne, Lausanne, Switzerland
e-mail: alessandra.lintas@neuroheuristic.org

S.K. Mesrobian
e-mail: sarah.mesrobian@neuroheuristic.org

A.E.P Villa
e-mail: alessandro.villa@neuroheuristic.org

M. Bader
Department of Child and Adolescent Psychiatry (SUPEA), Faculty of Medicine,
University of Lausanne, Lausanne, Switzerland

L. Götte
Department of Economics, Faculty of Business and Economics,
University of Lausanne, Lausanne, Switzerland

T.V. Guy et al. (eds.), *Decision Making: Uncertainty, Imperfection, Deliberation and Scalability*, Studies in Computational Intelligence 538,
DOI 10.1007/978-3-319-15144-1_6

and the positive wave peaking at around 250 ms (P250) components. The contingent negative variation (CNV) component was affected in a different way in controls and participants with ADHD as a function of the feedback frequency (*HFFB* versus *LFFB*). These results clearly show that imperfect decision making and risk taking are affected by personality traits and cannot be accounted by models based on rational computations.

6.1 *Homo Economicus* and *Homo Sociologicus*

Neuroeconomics is an interdisciplinary field whose aims include studying the neural foundations of decision making under risk. Uncertainty can be defined as the psychological state in which a decision maker lacks knowledge about what outcome will follow from what choice. Economists and neuroscientists commonly considering the risk referred to situations with a known distribution of possible outcome [97].

Traditional economic models of decision making found their roots through in the concept of utility referred to as the option leading to the highest outcome that will be chosen by "rational agents" when individuals have the opportunity to choose between different options. Daniel Bernoulli's St Petersburg Paradox demonstrates utility in a tail or head game, where a coin is tossed until the first head appears; the payoff increases at each trial, whereas the probability decreases exponentially, leading to a concave utility function. Hence, individuals are considered as rational agents, referred to as *Homo Economicus*, who are expected to maximize the utility to play a game with a highly skewed payoff distribution [9].

The concept of "maximization" refers to the agents' ability to evaluate each option and its possible outcome. By taking into account the preferences of an agent over different kinds of choices, four axioms of the Expected Utility Theory were defined by assuming the properties of completeness, transitivity, convexity and independence of lotteries [120]. The addition of a psychological dimension to risky behaviors defined the ground of an updated theory referred to as the Prospect Theory [70, 117]. This latter theory allowed to explain how individuals behave when they are faced with probabilistic risky options, namely, to underestimate risks leading to a loss (*risk seeking*), and to overestimate risky behaviors towards gains (*risk aversion*).

The attempt to understand individual differences and similarities towards risk triggered many studies and the development of specific questionnaires and experimental tasks aimed at measuring risky behaviors. General risk taking or sensation seeking is commonly assumed to be motivated to a large extent by the intrinsic value of adventure or sensory experience derived from the risky behavior itself [4]. An example of a simple task aimed at rating risk taking behavior is the Balloon Analogue Risk Task (*BART*) [77]. In this game, individuals have the opportunity to make a balloon grow by introducing air with a pump. Rules are simple, each puff allows the participant to earn money, but in the case of an explosion of the balloon, the participant would loose all money earned so far. Therefore, at each trial a decision has to be taken, either to stop pumping the air and collect the money or to pump more air in the balloon. Referring to individuals' characteristics within usual pattern of behaviors, "Personality is the more or less stable and enduring organization of a person's character, temperament, intellect, and physique, which determines his unique adjustment to the environment" [44].

In the Ultimatum Game (UG), where the participants play a role of proposer and responder sharing a virtual amount of money [59], it is rationale to expect that the proposer offers the smallest possible amount and the responder accepts any amount. On the contrary, a consistent number of UG studies revealed that responders showed a tendency to reject unfair offer, especially for offers below 30 % of the total amount [20, 26, 59]. Social interaction like friendship [21] and moral characteristic of the people [50] influence the maximization target in UG. We showed that perceived emotions associated to background pictures and individual differences associated to the role of proposer and responder significantly affected the amount of money players were keen to share [46]. When individuals were playing the role of proposers, they tended to share a higher amount of money when their choice was made in association with negative emotions, in particular sadness and disgust. When participants were playing the role of responders, they were more likely to accept an offer when their decision was made in association with positive emotions, such as joy and surprise. Positive emotions predicted higher acceptance rate, and negative emotions higher amount of money offered. Furthermore, the participants were more likely to accept an unfair offer when they were introverted, conscientious, and honest [46]. This result is aligned with studies demonstrating that a positive emotional state signals a beneficial outcome and leads individuals to use simple heuristics and not to raise too many questions about the decision to be taken [110].

Offers in bargaining are likely to be guided by the emotions that proposers anticipate when contemplating their offers [83]. Positive offers may be driven by fear and guilt, where fear is more related to the perceived consequences of having one's offer rejected, and guilt is more related to concerns for the opponents' outcomes [83]. All together these observations show that indeed, risky behaviors can be modified as a function of the task [62], and are modulated by emotions and personality traits [126]. Hence, the participant should not be considered any more as a *Homo Economicus* but rather as a *Homo Sociologicus* [88].

This Chapter is organized as follows. In Sect. 6.2 we review the background of the personality traits that have been identified in the past decades, in particular the *HEXACO* model. The main brain areas involved in decision making and risk taking are listed in Sect. 6.3 following the brain imaging studies explained in Sect. 6.4. The electrophysiological techniques used in our studies are explained in Sect. 6.5. The experiment aimed at studying the effect of personality in the Ultimatum Game paradigm is described in Sect. 6.6, while in Sect. 6.7 we present the Investment Game paradigm derived from the Gneezy Potters' task. In the discussion Sect. 6.8 we present the main results for each study and the chapter ends with a general conclusion (Sect. 6.9).

6.2 Personality

Determinants of personality have been studied from different points of view in psychology. One of them important for the referred research has examined the concept of taxonomy, which refers to individuals' characteristics within usual pattern of behaviors, usually called traits or factors. A hierarchical structure based on 16 factors or traits extracted from the English language was presented by Raymond Cattell (1905–1998) [24]. This model included primary traits associated with individual differences, second-order (or global factors) associated with a more theoretical level and third-order factors (also called super factors) representing the most abstract level of personality. Eysenck's (1916–1997) approach of personality defined at first two general traits, called Extraversion and Neuroticism, which are bipolar and independent [43]. Each factor represents a direction allowing secondary factors to have a value on the scale. In latter years Eysenck added another trait, Psychoticism, and settled a revised version of the Eysenck Personality Questionnaire (EPQ-R) of personality [45].

Eysenck's model appeared too limited and in the 1990s the Five Factor Model, known under the name of *OCEAN* or Big Five, has considerably contributed to study basic personality traits along the dimensions characterized by Openness (*O*), Conscientiousness (*C*), Extraversion (*E*), Agreeableness (*A*) and Neuroticism (*OCEAN*) [31, 55]. An alternative model of personality, named *HEXACO*, has been developed from lexical studies of personality structure, namely Honesty-Humility (*H*), Emotionality (*E*), eXtraversion (*X*), Agreeableness (*A*), Conscientiousness (*C*) and Openness to experience (*O*) [3]. Actually, both models appear to have similarities among certain factors, notably with regard to the dimensions of eXtraversion, Conscientiousness and Openness to experience, whereas Big Five Neuroticism and Agreeableness' rotation variations have been found to represent Emotionality and Agreeableness factor within the HEXACO [1]. The sixth factor, Honesty-Humility, has been found to be sparsely linked to the Big Five factors, whilst the Agreeableness facet of the Five Factor Model was strongly correlated to this additional dimension.

The HEXACO dimensions can described as follows [1, 2, 76, 126]:

- *Honesty-Humility*: This factor includes sincerity, fairness, greed-avoidance and modesty. Individuals with low scores on this dimension are perceived as using advantages such as praise or compliments to obtain profits, to care about material benefit and with a strong sentiment of pomposity, characterized by descriptive adjectives such as sly, deceitful, greedy, pretentious, hypocritical, boastful, pompous. High score individuals appear to avoid manipulation to obtain profits and are not attracted by material commodities and do not have feelings such as self-importance, in other words, they are sincere, honest, faithful, loyal, modest/unassuming.
- *Emotionality*: This factor includes fearfulness, anxiety, dependence and sentimentality. Stressful situations are not experienced as a hindrance in persons with low score of emotionality who seem not to be worried by physical damages and do not need to share feelings, i.e. exhibiting brave, tough, independent, self-assured

and stable behaviors. High scores individuals are worried about dangers, feel more anxiety in stressful situations and are commonly characterized by emotional, oversensitive, sentimental, fearful, and vulnerable behaviors.

- *Extraversion*: Social self-esteem, social boldness, sociably and liveliness (engagement in social endeavors) are sub-dimensions of this factor. Individuals with low score of extraversion are shy, passive, withdrawn, introverted, quiet, reserved and thinking that they are unpopular and indifferent to social activities. On the opposite, individuals with high score of extraversion feel confident, have a good self-image, appreciate social interactions and are outgoing, lively, extraverted, talkative and cheerful.
- *Agreeableness*: This factor includes forgiveness, gentleness, flexibility and patience. Individuals with low score of agreeableness are ill-tempered, quarrelsome, stubborn, choleric, resentful, obstinate persons who do not accept other's shortcoming and have difficulties to control themselves. Conversely, individuals with high score of agreeableness tend to show tolerant, peaceful, mild, agreeable, lenient, gentle indulgent, cooperative and patient behaviors.
- *Conscientiousness*: This factor includes organization, diligence, perfectionism and prudence (engagement in task-related endeavors). Individuals with low score of conscientiousness tend to be sloppy, negligent, reckless, lazy, irresponsible, absent-minded, impulsive, disrupted and have a tendency to abandon in front of troubles. Individuals with high scores tend to select safe decisions and show organized, disciplined, diligent, careful, thorough, precise and accurate behaviors.
- *Openness to experience*: This factor includes aesthetic appreciation, inquisitiveness, creativity and unconventionality (engagement in idea-related endeavors). Individuals with low score on this scale tend to be shallow, unimaginative, uninterested about art, innovation or creativity and to avoid extreme ideas to remain rather conventional. Individuals with high score of openness to experience are attracted by art and by various domain of knowledge, being associated with intellectual, creative, unconventional, innovative and ironic behaviors.

The links between personality and risk have been revealed in several studies. In front of a choice between a sure gain or a an uncertain greater gain, or between a sure loss or an uncertain greater loss, results showed that Honesty-Humility was negatively associated to risk in both cases, just like Emotionality [125]. In a study based on a new self-report scale assessing "the tendency to seek and accept great risks, particularly physical risks", called Status-Driven Risk Taking (SDRT) [4], Conscientiousness was also associated to risky behaviors, but only in the gain domain. The nature of the risk appears as an essential factor to determine the decision making. In one case the risky decision task was based on a potential financial loss or gain, and in the other case the risk was conceptualized mainly on a physical basis, measured by a self-report questionnaire. A domain-specific risk-taking scale [123] measures five different dimensions of risk, namely financial (such as Investment and gambling), health/safety (for instance, buying illegal drug for personal use), recreational (relative to the practice of extreme sports), ethical (for example, cheating or stealing) and social (such as approaching one's boss to ask for a salary increase) risky behaviors.

In an attempt to look for the association between the dimensions of the HEXACO personality inventory and the risk taking domains, it appeared that "Emotionality" and "Conscientiousness" were linked to all risk domains, whereas "Openness to experience" was closely related to social and recreational risks and "Honesty/Humility" was negatively correlated to health/safety and ethical risk taking [126].

6.3 Neurobiological Background

Decision making and risk taking reflect one's ability to engage successfully in independent and purposive behaviors associated with the integrity of executive functions. Studies of patients with impaired decision making in risky situations have contributed to a better understanding of the neural circuits involved in these behaviors. Following the discovery of behavioral changes of the notorious Phineas Gage, the study of patients with frontal lesions have been the starting point of Damasio's somatic marker hypothesis [36].

Somatic markers involve different brain areas, most of them illustrated in Fig. 6.1. The anterior cingulate cortex (ACC) is a structure located on the medial surface of the frontal lobes. The dorsal regions of the ACC is considered to correspond to its "cognitive" subdivision, being crucial for error processing [22] and for mediating processes such as response inhibition [19]. Caudo-dorsal regions of ACC share further connections with other neural systems involved in reward processing and decision-making, such as the mesencephalic dopamine system [33] and the orbitofrontal cortex [118]. The rostro-ventral ACC corresponds to its "affective" subdivision, and is connected to the amygdala, periaqueductal gray, nucleus accumbens, hypothalamus, hippocampus, anterior insula and orbitofrontal cortex [38].

Regarding subjects with brain damages, patients with lesions of the ventromedial prefrontal cortex, insular cortex, and orbitofrontal cortex tend to increase their betting compared to controls and to patients with dorsolateral and ventrolateral lesion within the prefrontal cortex [27]. These patients have impaired betting behaviors compared to control individuals in a Gamble Task [81], more specifically, they tend to bet much more than controls, on the contrary to patient with dorsal prefrontal lesions, which are more likely to choose safe options like control participants [28].

Expounding patients' behaviors of inattention were reported since the 17th century [32]. Disorders of the cognitive control are well characterized by attention deficit [7, 114, 127] and hyperactive-impulsive behavior [7, 84, 87] that have been recognized to be part of the core symptoms of children with Attention Deficit/Hyperactivity Disorder (*ADHD*) [7]. Links between ADHD and executive functions associated with response inhibition, vigilance, working memory and planning have been established in children [10, 92, 95, 108, 127] and have been found to be stable into young adult age [11, 63]. Adults with ADHD are well characterized also by taking more risks in the everyday life conduct, for instance in risky driving [116], risky sexual behaviors [48], alcohol consumption [122], as well as in experimental conditions such as in the Balloon Analogue Risk Task [82].

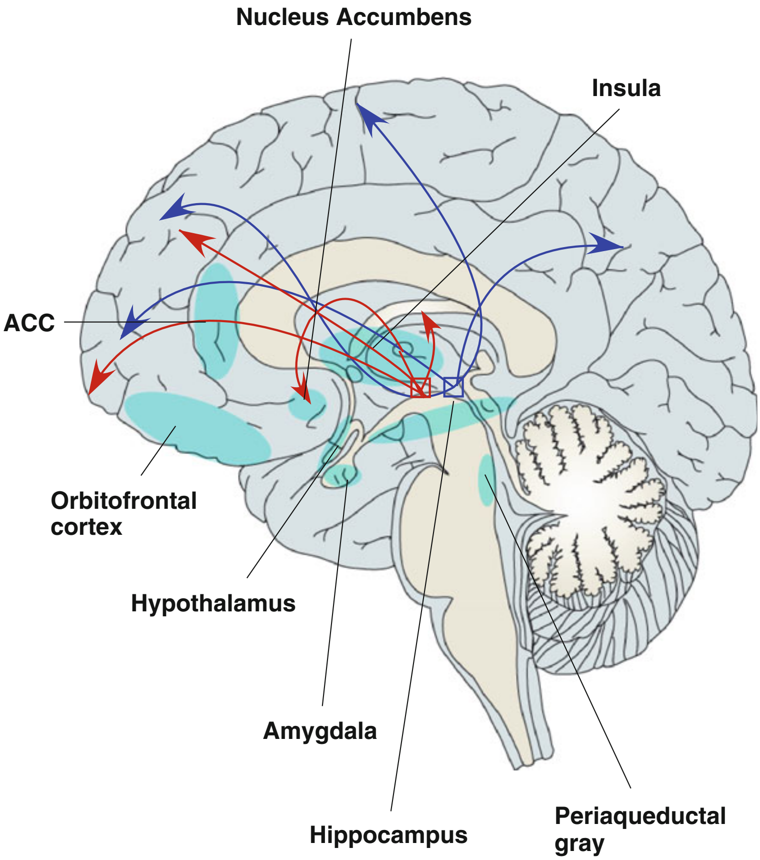

Fig. 6.1 Human brain illustration of medial surface of the left cerebral hemisphere (modified from [46]). The principal areas involved in decision-making are labeled in turquoise. The *blue arrows* show the main modulatory projections of the nuclei using the serotonin transmitter to cortical areas. The major dopaminergic pathways are indicated by the *red arrows*

Numerous studies have investigated the relationship between personality and the major monoamine neurotransmitters particularly serotonin and dopamine [18] (Fig. 6.1). Pathological gamblers [16] as well as subjects identified as stimulant users are more likely to take risk than non-stimulant users [78]. It has been demonstrated that methamphetamine consumers displayed an increased activation of the right insula, rise which is growing according to the risk, whereas activation of ACC was decreased compared to control participants [56]. Furthermore, activation of the ventromedial part of the caudate nucleus has been found to be reduced in pathological gamblers during the process of anticipation of gains and losses in a gambling task, while anticipation of losses was only characterized by a reduced activation of the anterior insula in the same population [25].

6.4 Brain Imaging Studies

Until the 18th Century the correlation between specific brain areas and their functions was a matter of study by neuroanatomists who described post-mortem anatomical inspection of the brain. Since the 19th Century the progress in microscopy led the investigators to consider cellular features by means of histological analysis. With the progress of electronics and nuclear physics, five major imaging methods are currently employed for studying the neural mechanisms underpinning risky decision making, more specifically, functional magnetic resonance imaging (*fMRI*), positron emission topography (*PET*), transcranial magnetic stimulation (*TMS*), and electroencephalography (*EEG*). Each device has its own advantages and disadvantages, and sometimes the combination of several methods allows to investigate different stages within the decision making process under risk, for instance, sensory processing of the environment, state evaluation, rule identification and outcome evaluation [6]. We do not consider here the studies based on genomic analysis and molecular biology.

The fMRI is a technique for measuring and mapping brain activity based on the fact that the nucleus of a hydrogen atom behaves like a small magnet [90]. The application of a radio frequency magnetic pulse at a certain frequency provokes the generation of a faint signal by the hydrogen nuclei detected by the magnetic coils of the device. The topographic distribution of the excitable hydrogen nuclei generate an image and the changes in their distribution as a function of an external event generates a functional image. Changes in neural activity are associated with changes in oxygen consumption and blood flow. Hemoglobin binds oxygen in blood and oxygen-rich blood and oxygen-poor blood have different magnetic properties related to hydrogen nuclei in water and their surroundings. An activated brain area consumes more oxygen and blood flow to the active area must be increased to meet this demand. Hence, during a specific mental process fMRI can be used to produce activation maps showing the areas of the brain that are involved [90].

The insula (part of the brain illustrated in Fig. 6.1) was associated with the selection of risky options [94]. The activation of its anterior part appeared prior to the selection of riskless choices following the selection of a risky option and to “risk-aversion mistakes”, that are mistakes describing errors of judgment when individuals should in theory take risk [74]. The insular cortex and the dorsomedial prefrontal cortex were found to play a role in response to prior risk experience trials and the insular activation was emphasized after those trials when participants had decided not to gamble and in association with the personality trait of urgency [132]. The perception of unfairness evoked also specific patterns of activation. In the Ultimatum Game, the bilateral anterior insula, the dorsolateral prefrontal cortex and the anterior cingulate cortex (*ACC*) were involved in processing unfair offers from human proposers [106]. Patients with ventromedial prefrontal damage showed prominent sensitivity to the fair condition in the UG and were much more likely to reject unfair offers if the proposer could have proposed an equitable offer [111].

The existence of different circuits within the brain was found by assessing tasks with various types of risk. For instance, in a study by Knutson and Kuhnen, the nucleus accumbens was found to be activated prior to risky choices following two types of situations, the selection of a safe option, and trials where individuals took risks despite the fact that this is not the best strategy [74]. The activation of the nucleus accumbens has been linked to the prediction of individuals' intention to shift toward a high-risk option [73]. The existence of an evaluating system related to uncertainty was supported by finding activated areas associated to risk which included the dorsal striatum (caudate nucleus) peaking significantly later than regions associated to ambiguity (differing from uncertainty in so far as the probabilities remain unknown), independently of individuals' choices [67].

Altogether these results are thought to be consistent with the hypothesis of a reward-anticipation system within the striatum which is "further downstream", compared to rapid vigilance/evaluation system in the amygdala.

Brain activity can also be measured with the PET technique. This technique uses trace amounts of short-lived positron-emitting radionuclides (tracers) injected into the body on a biologically active molecule. The physical principle is that as the tracer undergoes positron emission decay (also known as positive beta decay), it emits a positron. The encounters of the positrons and the electrons belonging to the local tissue annihilate both particles and produce pairs of gamma rays going approximately into opposite directions. Gamma rays arriving in temporal pairs from opposite directions are detected by specific devices and a map of radioactivities can be constructed showing the locations in which the molecular tracer was concentrated. Based on a principle similar to fMRI, the tracer Oxygen-15 is used to measure indirectly the blood flow to different parts of the brain. The localization of energy intake in a given region being associated with glucose consumption and cerebral activity can be measured by the injection of a tracer such as Fluorine-18. This radionuclide is generally used to label fluorodeoxyglucose (also called FDG or fludeoxyglucose) that is a glucose analogue that produces intense radio-labeling of tissues with high glucose uptake. Carbon-11 is a radionuclide generally used to label ligands for specific neuroreceptors thus allowing the visualization of neuroreceptor pools associated with psychological processes or disorders and brain activity.

During the risky decision making task, PET neuroimaging was used to show the activation of several brain regions, corresponding to bilateral orbitofrontal cortices followed by the right side of the dorsolateral prefrontal cortex, the anterior cingulate cortex and the inferior parietal cortex and the last regions being the thalamus, the anterior insula and the lateral cerebellum, all activated bilaterally [42]. However, PET neuroimaging requires a tracer injection and its application remains limited compared with fMRI.

Yet, another tool has proven itself in the research field, the transcranial magnetic stimulation (TMS). By applying a featured magnetic stimulus to a specific part of the cortex, TMS has become an attractive instrument, eliciting a reversible and controlled perturbation within the brain [35]. The principle of this technique is to use electromagnetic induction to induce weak electric currents in the brain using a rapidly changing magnetic field [101]. A magnetic coil placed near a selected cortical area generates short electromagnetic pulses that pass through the skull and provoke electrical currents that cause depolarization or hyperpolarization in the neurons of the targeted area. Single or paired pulses or repetitive pulses at specific frequencies may provoke very different effects when applied to the same cortical area [47]. This technique was applied in studying a risk taking task. The results suggested that the dorsolateral prefrontal cortex was not involved in changing the probability of selecting risky options on the opposite of the role of the right dorsolateral prefrontal cortex in the suppression of superficially seductive options and exhibiting riskier prospects [72].

Despite the remarkable advances brought by the advent of imaging techniques related to nuclear medicine, EEG recording remains the most widely used method to record human brain activity with high temporal resolution (1 ms time scale) in a non-invasive way from the human scalp by means of external electrodes placed over many standard locations determined by skull landmarks. Transient electric potentials associated in time with a response to internal or external events are termed event-related potentials (*ERPs*) [96]. The ERP is extracted from the ongoing EEG by means of signal filtering and averaged over many responses to a triggering event associated with cognitive activity involved in stimulus processing and/or action preparation. Although ERPs can be evaluated in both frequency and time domains, we focus the interest of this study on ERPs recorded in the time domain, i.e. the curves obtained by averaging electric potential shifts as a function of time over several trials and across participants. In the temporal domain "early" and "late" components of ERPs have been extensively studied and recognized in the vast majority of experimental paradigms, with each "peak" or component named after its lag from the triggering event, for instance P200 meaning a waveform with a positive deflection near 200 ms.

Three main stages of processing,defined as choice evaluation, response selection and evaluation of feedback, have been suggested for the analysis of decision making behavior [34]. A component associated with feedback processing, the third stage, is called Medial Frontal Negativity (*MFN*) or Feedback Related Negativity (*FRN*). This wave is associated with the activity in the medial frontal cortex and, more specifically, in the anterior cingulate cortex, at around 250–350 ms post stimulus presentation [52, 99, 130]. In a risk taking task, FRN was affected by the nature of the outcome with a weak, if any, effect of the reward magnitude and a stronger effect for losses [13, 34, 52, 61, 99]. In addition, the FRN was found to be sensitive to unexpected rewards [130] and affected by probabilities, only for gains not for losses [29]. The amplitude of FRN and ACC activation were more pronounced upon receiving unfair low offers in the Ultimatum Game, i.e. the occurrence of outcomes that are not as good as expected, and this was accentuated for participants with high concern of fairness [14, 65]. In UG, advantageous unequal offers elicited MFN responses with larger amplitudes than responses elicited by equal or disadvantageous unequal offers [103, 129].

At latencies similar to MFN another component characterized by a positive deflection along the midline, referred to as P300 or P3, showed larger positive deflection in response to feedback for larger actual and expected outcomes [104, 105]. It is interesting to notice that larger P300 were also elicited by fair offers in the UG [103].

Another ERP component associated with the outcome evaluation in decision making under risk is measured within 500–600 ms from the triggering event. In a blackjack game N500 was measured following the appearance of the two initial cards, hence with the option to ask for another card or not. This N500 wave is characterized with a larger amplitude over the frontal areas for losses compared to gains [99]. Trials with a high conflict versus trials with a low conflict, that is risky decisions versus "conservative" responses, elicited also larger negative amplitudes for N500 [133]. In UG task a late ERP component called the late positive potential (LPP) was observed at a latency of 450–650 ms [131]. The amplitude of LPP was larger for moderately unequal offers than for highly unequal offers in an upward social comparison. The large amplitude of LPP is generally obtained for high reports of affective experience like emotional compared to neutral pictures [109].

6.5 Methods: Electrophysiological Recordings

Continuous EEG was recorded using 64 scalp Ag/AgCl active electrodes (ActiveTwo MARK II Biosemi EEG System, BioSemi B.V., Amsterdam, The Netherlands) mounted on a headcap (10/20 layout, NeuroSpec Quick Cap) and referenced to the linked earlobes. Electrophysiological signals were sampled at 1024 Hz with lower cutoff at 0.05 Hz and upper cut-off at 200 Hz, 24 bit resolution (DC amplifiers and software by Biosemi, USA). Electrode impedances were kept below 5 KΩ for all recordings. Vertical and horizontal ocular movements were also recorded using two pairs of bipolar electrodes. Event-Related Potentials were analyzed with BrainVision Analyzer 2.0.4 (Brain Products, Gilching, Germany). Raw data were preprocessed, ocular artifacts were corrected using Infomax Independent Component Analysis (*ICA*) [80]. Blink, saccade and eyelid artifact components were set to zero, based on their respective shape and topography [98]. Markers were used off-line to segment the continuous EEG data into epochs time-locked to events. The epochs were further scanned for contamination by muscular or electrode artifacts and the remaining trials were inspected visually to control for residual minor artifacts. ERP analyses were performed on the artifact-free trials, band-pass filtered between 0.1 and 30 Hz (-12 dB/octave). Trials were then corrected to baseline 500 ms prior to event onset and ERPs were obtained by averaging the EEG signal on an analysis window corresponding to time intervals lasting 2000 ms. All free-artifact epochs were kept and averaged in order to analyze ERPs on AFz, Fz, FCz, Cz, CPz, Pz and POz electrodes.

At the begin of an experimental session we always recorded two minutes of EEG with the participants seating quietly with closed eyes and two minutes with open eyes maintaining their gaze on a central fixation cross on the computer monitor. Participants were asked to restrain their movements, especially concerning eye movements and blinks during the entire duration of the recording.

6.6 STUDY 1: Ultimatum Game

The Ultimatum Game task [58] has been widely used to investigate human “irrational” behavior against the “rational” model of game theory, but very few studies have looked at the effect of emotions and personality on players’s economic behavior [106]. All participants were administered a 60 item personality questionnaire, the French version of the HEXACO-60 personality questionnaire derived from lexical studies [2, 76]. In the current study, participants played the UG using a computer interface while abstract images were displayed in the background of the computer monitor. We investigated whether the willingness-to-share was affected by specific personality traits and associated with neurobiological correlates of the decision-making process, extending our previous study [121].

6.6.1 Participants Task 1

Twenty-eight neurological healthy, right-handed participants ($N = 28$ of either sex, age range 18–45, $M = 24.6 \pm 1.11$ yrs.[1]) volunteered to participate in the study and played with virtual money. All had normal or corrected-to-normal vision, none reported a history of sustained head injury, and all were naive to the Ultimate Game. They were informed about the UG test at the beginning of the study and provided written consent for their participation in line with the Declaration of Helsinki [128]. The participants were comfortably seated in a sound- and light-attenuated room, watched a computer-controlled monitor at a distance of 60 cm, and were instructed to maintain their gaze on the center of the monitor throughout the experiment. Contrasting results were reported on the association of performance with a real payoff [54] and in this task participants were only motivated by the challenge to get the best score and contribute to scientific investigation.

6.6.2 Behavioral Task 1

In the original version [58] the Ultimatum Game is an anonymous, single-shot two-player game, in which a “proposer” offers to share a certain sum of money to a “responder”. If the responder accepts the proposal, the share is done accordingly, but if the responder rejects the offer, both players end up with nothing. In the current implementation of the task (with E-Prime software by Psychology Software Tools, Inc., Sharpsburg, PA 15215-2821, USA), each participant played the role of proposer and responder in 3 alternated blocks of 30 trials each. Participants were told to play the UG trying to maximize their gain as much as possible. Each UG trial involved

[1] M± SEM, Mean ± Standard Error of the Mean.

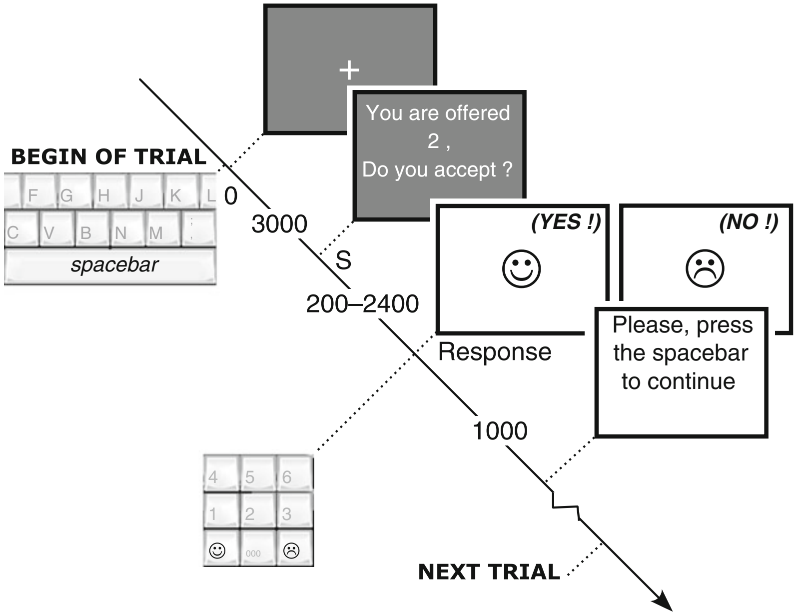

Fig. 6.2 Illustration of the Ultimatum Game task with the participants acting as responders. Event (S) indicate the stimulus onset

a take-it-or-leave-it integer split of a virtual sum of 10 Swiss francs. Participants performed all UG trials while EEG data were recorded.

Each "responder" trial started with the pressure of the spacebar of the computer keyboard (event at time 0, Fig. 6.2). The proposer is a virtual player, a computer program implementing a strategy such that offers occurred randomly with an equal frequency of 14.28 % each for values in the range 3–7 and with an equal frequency of 7.15 % each for values 1, 2, 8, or 9.

After maintaining the gaze on the central fixation cross for 3,000 ms the message "You are offered x. Do you accept ?", corresponding to event S, appeared on the center of the monitor. The responder's decision (event HR, human player response, Fig. 6.2) was conveyed by pressing the bottom left key (YES), labeled with a smiled face smiley, of the numerical keypad in case of acceptance and by pressing the bottom right key (NO), labeled with a frowned face smiley, in case of rejection of the offer. An additional 1,000 ms interval followed until the message "Please press the spacebar to continue" appeared on the center of the monitor. By pressing the spacebar a new responder trial started. All the results presented here are related with the responder condition (see Fig. 6.2). If the participants asked whether the experimenter was playing the opponent party, the experimenter replied that the other party was a virtual player programmed to play according to observed human strategies. The overall experiment lasted about 30 min.

6.6.3 Results Task 1

6.6.3.1 Subjects' Strategy

In order to investigate the effect of personality traits on responder's decision-making in the UG, we calculated all correlations between the personality traits and the participant's gain, the opponent's gain (i.e., here is the virtual proposer's gain) and the average value of the accepted offer. Concerning the correlations between personality traits, Table 6.1 shows that Honesty and Conscientiousness are positively correlated ($r = 0.413$).

About the gains (variables 7, 8, and 9 of Table 6.1), it was not surprising to observe a negative correlation ($r = -0.912$) between the (virtual) proposer's gain and the average value of the offer accepted by the responder. The higher the value accepted by the responder the lower the gain made by the proposer. Offers in the ranges of values 1–3, 4–6, and 7–9 were termed *wretched*, *fair*, and *prodigal*, respectively.

Following a rational decision-maker it appears that it is always convenient to accept wretched offers rather than rejecting. This was confirmed by observing a negative correlation ($r = -0.560$) between the responder's gain and the average value of the offer accepted by the responder. The lower the value accepted by the responder the higher the gain made by the same responder. To explore this further, we considered the range of the offer as an independent variable and the acceptance rate as a dependent measure. A one-way repeated measures ANOVA was performed with $N = 28$ participants, with Bonferroni adjustment for multiple comparisons [41]. Indeed, the acceptance rate was significantly dependent on the offer range proposed by the virtual player, $F(1.60, 44.91) = 78.62$, $p < 0.001$ (after Huynh-Feldt correction for violation of sphericity [68], $\chi^2 = 9.82$, $p < 0.01$, $\varepsilon = 0.80$). All paired comparisons showed significant differences ($p < 0.05$) between acceptance rate for prodigal ($95.6 \pm 2.0\%$) compared to fair ($83.1 \pm 3.7\%$) and wretched ($31.6 \pm 5.8\%$) offers.

However, an interesting 'irrational' result was revealed by a high and positive correlation ($r = 0.810$) between the gains made by the responder and by the proposer. This indicates a strong tendency towards willingness to share expressed by the responders. Hence, we investigated further this aspect and studied whether differences in brain activity could be observed between participants expressing more or less fairness in their strategy.

6.6.3.2 Event-Related Potentials

The brain activity associated to the response made following the fairness of the offer was studied by means of the grand averages from central electrode positions (Fig. 6.3). The limited number of *prodigal* offers that were rejected did not allow us to include grand averaged ERPs in this set of results. During the trials characterized by the acceptance of wretched offers (Fig. 6.3, left panel) we noticed larger positive

Table 6.1 This table shows Pearson's correlation coefficients between personality traits and responder' gains and responder's average value of the accepted offer

	Personality						Responder		
Personality	1	2	3	4	5	6	7	8	9
1. **H**onesty									
2. **E**motionality	−0.158								
3. e**X**traversion	0.187	−0.256							
4. **A**greeableness	0.369	−0.226	0.098						
5. **C**onscientiousness	0.413*	−0.296	0.287	0.136					
6. **O**penness	0.143	−0.364	−0.022	−0.027	−0.330				
Responder									
7. Participant's gain	0.426*	−0.277	0.233	0.329	**0.463***	0.264			
8. Opponent's gain	0.277	−0.203	0.096	0.243	0.337	**0.424***	**0.810****		
9. Avg. accepted offer	−0.198*	0.109	−0.054	−0.174	−0.223	**−0.457***	−0.560**	**−0.912****	

Underlined coefficients fall within 95 % confidence interval after bootstrapping. Boldface and underlined coefficients fall within 99 % confidence interval after bootstrapping (*) significance $p < 0.05$; (**) significance $p < 0.01$

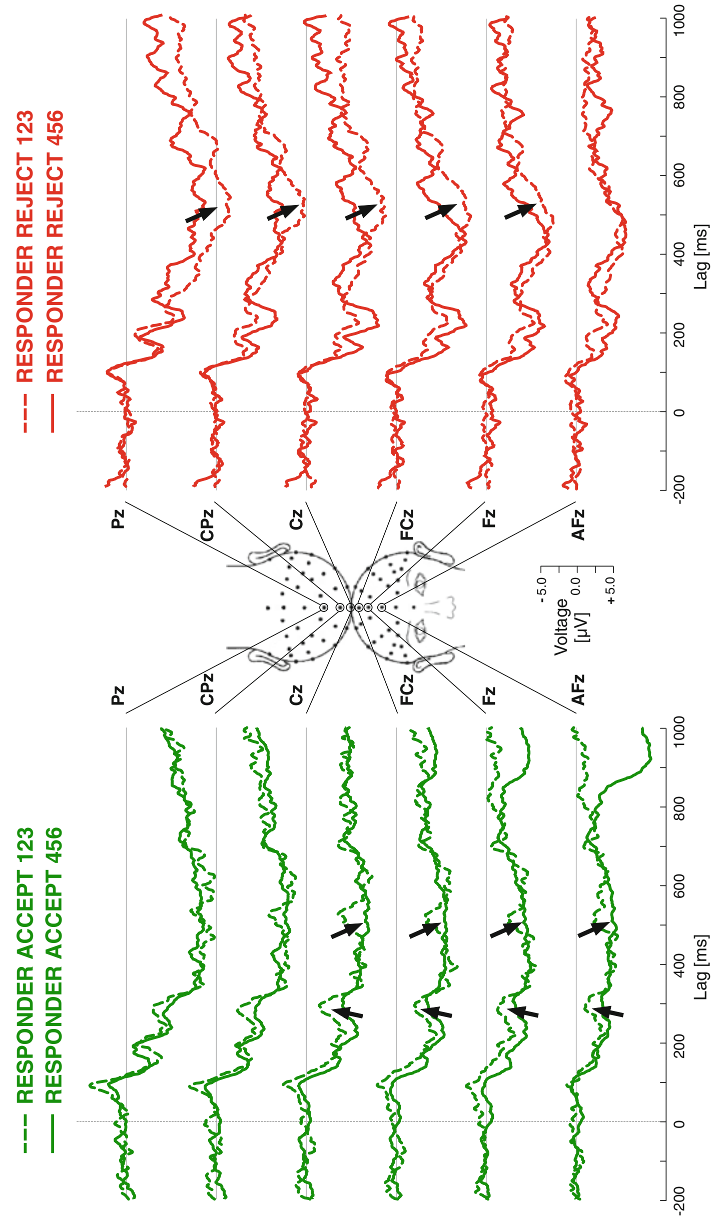

Fig. 6.3 Event related potentials during the Ultimatum Game. Grand-average ERPs at electrode sites AFz, Fz, FCz, Cz, CPz and Pz following the acceptance (*green lines*) or rejection (*red lines*) of an offer. *Dashed lines* refer to the decision following wretched offers (123) and *solid lines* following fair offers (456). The *arrow* at latency near 300 ms refers to the Feedback-Related Negativity ('FRN') and the *arrow* at latency near 550 ms to the late positive component ('LPP')

deflections at the central sites at latencies corresponding to FRN. It is interesting that acceptance of fair offers (Fig. 6.3, left panel solid line) and rejection of wretched offers (Fig. 6.3, right panel dashed line) were characterized by larger late positive component (LPP).

As mentioned above (Sect. 6.6.3.1, Table 6.1) the personality trait "Conscientiousness" was strongly associated with the participant's gain. We selected two subgroups following their conscientiousness score (10–minimum; 50–maximum) to the HEXACO questionnaire: highest rated participants (sample size $N = 6$) with a score in the range 39–48 and lowest rate participants ($N = 6$) with a score in the range 16–29. Figure 6.4 shows that for the FRN component the largest differences between the two groups were observed after rejecting the offer. Notice that here the responses to all kinds of offers (wretched, fair and prodigal) were pooled together. Lowest rated conscientiousness participants were characterized by larger negative deflections for the FRN, in particular in the fronto-central sites (FCz to AFz). In both cases, either after acceptance or rejection of the offer, the LPP component was larger for the highest rated participants. Interestingly, the difference in LPP tended to be located more posteriorly after response acceptance (Fig. 6.4, left panel) and more frontally after response rejection (Fig. 6.4, right panel).

6.7 STUDY 2: Investment Game

The Gneezy Potters' Game is a gambling task developed in order to test whether gambles could be influenced by the incidence of the outcomes' presentation [53]. Two distinct theories, namely the "Myopic Loss Aversion" (*MLA* [8]) and the "Subjective Expected Utility" (*SEU* [107]) have been called to explain this specific decision making process. The MLA theory relies on the fact that the individuals have the tendency to be more sensitive to losses than to gains (called *Loss Aversion* [70]) and on the methods used by the individuals when they take financial decisions (called *Mental Accounting* [115]). According to MLA, individuals would tend to evaluate each gamble in combination, and hence, bet higher stakes when the incidence of the outcomes is low. Conversely, according to SEU, individuals would tend to evaluate each gamble separately, and consequently, outcomes' incidence would not influence the amount of stakes.

Gneezy and Potters' set an experiment where, in the first part, the feedback information was given immediately after each trial (named *High frequency feedback*), and, in the second part, feedback was presented after a block of several (three) trials (named *Low frequency feedback*). Throughout the first part of the experiment, a fixed endowment was given to the subjects at the beginning of each trial, while bets within the second part were constituted of previous earnings at the time of the first part. The probability to win the lottery was set to 1/3, while the probability to loose the investment was 2/3. During the game, participants had the opportunity to adjust the sum of money they were willing to bet at each trial within the high frequency condition, whereas choices were unchangeable during the whole block in the low

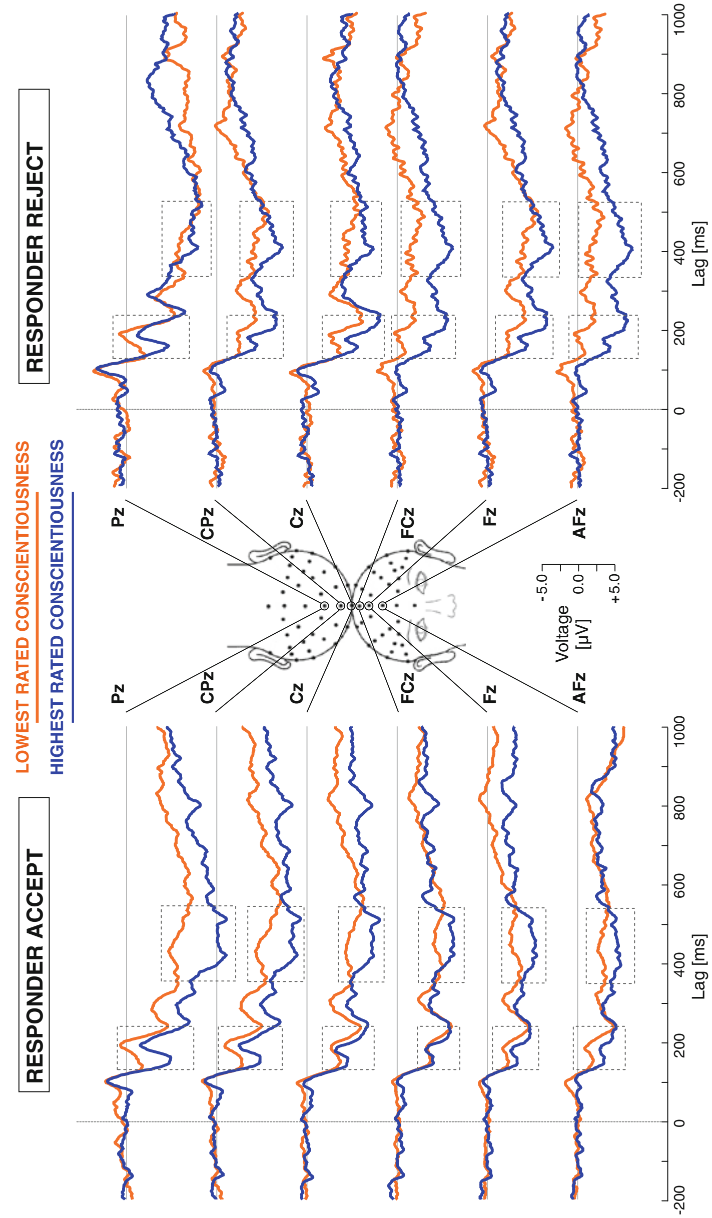

Fig. 6.4 Event Related Potentials during the Ultimatum Game. Grand-average ERPs at electrode sites AFz, Fz, FCz, Cz, CPz and Pz following the acceptance (*left panel*) or rejection (*right panel*) of any kind of offer (wretched, fair and prodigal pooled together). Participants are subdivided in two groups on the basis of their HEXACO score on conscientiousness (lowest rated—*orange* and *solid line*; highest rated—*blue* and *solid line*) The *dotted boxes* emphasize the waves close to the main negative component ('FRN') and to the late positive component ('LPP')

frequency condition. The original results indicated that gambles were influenced by the incidence of the outcomes' presentations [53]; in particular, subjects' bets were significantly larger in the trials belonging to the low frequency feedback condition, thus supporting the MLA theory.

6.7.1 Participants Task 2

Eighty-eight participants ($N = 88$ young adult subjects of either sex age range 18–30) were included in this study, as part of the sample of the participants enrolled in the research project supported the Swiss National Science Foundation grant CR13I1-138032. The sample included ADHD patients ($N_{ADHD} = 38$) and control subjects ($N_{CTRL} = 50$) (Table 6.2). All had normal or corrected-to-normal vision, none reported a history of sustained head injury. They were informed about the Investment Game at the beginning of the study and provided written consent for their participation in line with the Declaration of Helsinki [128]. The participants were comfortably seated in a sound- and light-attenuated room, watched a computer-controlled monitor at a distance of 60 cm, and were instructed to maintain their gaze on the center of the monitor throughout the experiment.

The pool of ADHD patients ($M = 22 \pm 0.48$ years old) was recruited after an initial screening appointment to ensure that patients were fulfilling the fourth edition's text revision of the Diagnostic and Statistical Manual of Mental Disorders fourth edition (DSM-IV-TR) for inattentive, hyperactive/impulsive or mixed subtypes [5]. We excluded ADHD patients with neuropsychiatric disorders such as mood disorder, bipolar disorder, psychosis, autism or Asperger's syndrome, antecedent of Tourette's syndrome, presence of motor tics, suicidal behavior, chronic medical conditions, and drug or alcohol abuse. The pool of control participants ($M = 22\pm = 0.42$ years old) was recruited through the student database of the University of Lausanne (Switzerland). Student from Economics and Psychology faculties did not took part in the experiment. One subject was excluded from the study, due to psychiatric history.

Two weeks before the appointment, all subjects were requested to answer the following online questionnaires: the HEXACO Personality Inventory [76], the Current

Table 6.2 Demographic characteristics of ADHD (left side) and control (right side) participants

	ADHD	Control
Total participants recruited	38	50
Gender (M/F)	31/7	33/16
Mean age (Y. old ± SEM)	22 (±0.48)	22 (±0.42)
Handedness preference (L/R/both)	5/32/1	2/47/0
Exclusions	0	1
Total included	38	49

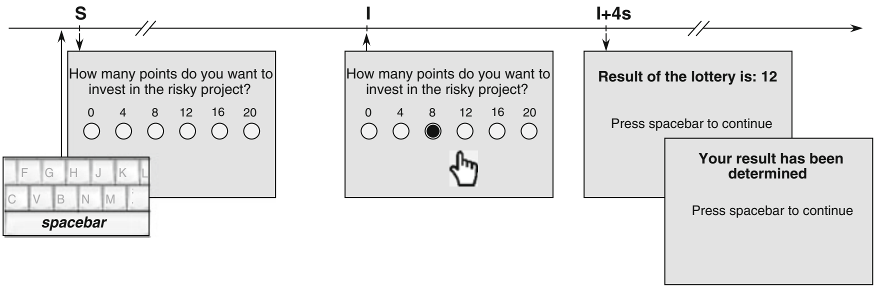

Fig. 6.5 Experimental protocol of the Investment Game. Participants started the task by pressing the spacebar (S) and then were asked to invest a certain amount of points in a risky project. The decision making process was not limited in time. Once the investment option selected (I), participants could modify their choice during 4 s before having the outcome (I + 4s)

Behavior Scale (*CBS*), developed to examine executive function deficits in adults with ADHD [12], the Conners Adult ADHD Rating Scales (*CAARS-S SV*) [30], and the adult ADHD Self-Report Scale (*ASRS*) symptom checklist [71]. On the experimental day the participants were welcomed and requested to complete a handedness inventory [91] and underwent a short structured diagnostic interview for psychiatric disorders known as Mini-International Neuropsychiatric Interview (*M.I.N.I*) [113].

6.7.2 Behavioral Task 2

The purpose of this study is to investigate risk-taking in the context of the occurrence's frequency of the feedback information in an Investment Game that is a modified version of the Gneezy Potters' task [53]. Subjects were endowed with 20 points at the beginning of each trial and were asked to choose the amount of points (out of the possible choices 0, 4, 8, 12, 16, 20 points) to invest in a risky project. The probability to win 3 times the amount invested was 1/3, whereas the probability to loose the entire investment was 2/3. The whole session was composed of 10 games × 4 blocks × 4 trials, overall 160 trials. Outcomes were presented immediately after half of the trials (condition "high frequency feedback", *HFFB*), while the other half were presented at the end of each block (condition "low frequency feedback", *LFFB*). Conditions were alternated at each block. The procedure of the Investment Game is summarized in the Fig. 6.5.

Each trial started with the pressure of the spacebar of the computer keyboard leading to the forthwith appearance of the investment option screen (event S). The participants selected an amount to be invested, in accordance to their desire without any time limit, by pressing a mouse key (event I). After the decision was made, an additional interval of 4000 ms was provided to the participant to modify the initial choice. Immediately thereafter the result screen appeared, revealing the end of the trial. The investment options were characterized by six circles of 1.4 cm diameter, with a total length of 11.6 cm. They were aligned next to each other and did not exceed 5° from the left or right of the monitor's center. Numerical labels were set at 1.8 cm above each option center.

The EEG was recorded throughout the duration of the Investment Game task. Markers corresponding to the events were inserted in the data files for off-line analysis. Data were segmented using time window from 500 ms prior to marker to 1500 ms post-marker presentation.

The participants belonging to each group and sample were determined according to their reaction time. For instance, trials characterized by an interval larger than 4 seconds to select the amount to be invested were discarded and the individuals whose behavior included a majority of such trials were left for other analyses. In addition, after rejecting segments with major artifacts, participants with less than 50 % of valid data segments were excluded from the ERPs analysis.

6.7.3 Results Task 2

6.7.3.1 Risk Taking

The count of times a participant selected a low investment risk (i.e., 0, 4, or 8 points), termed LIR, and the count of times a participant selected a high investment risk (i.e., 12, 16, or 20 points), termed HIR, were used to compute an investment risk index $IRi = \frac{HIR-LIR}{HIR+LIR}$. Thus, the value of IRi is centralized within the range $[-1 - +1]$; an index closer to -1 characterizes a participant with risk averse strategy, an index closer to $+1$ characterizes a risk seeking participant, and an index near zero being associated with a risk neutral attitude. Each individual was defined on a scatter plot with IRi calculated for (*HFFB*) trials on the abscissa and IRi for (*LFFB*) trials on the ordinate (Fig. 6.6). The distribution of IRi was rather flat for the pool of control participants with negative values of kurtosis (-0.81 and -0.95 for HFFB and LFFB conditions, respectively; Fig. 6.6a). On the opposite, the pool of ADHD patients showed a tendency to higher degree of peakedness with positive values of kurtosis (0.23 and 0.09 for HFFB and LFFB conditions, respectively; Fig. 6.6b). We can interpret this result as a clear tendency of ADHD patients to seek an investment strategy with neutral risk, neither too low neither too high.

In the same figure it is possible to evaluate the tendency of the participants to keep the same strategy with and without the feedback. A striking result allows to differentiate the control group and the pool of ADHD patients. If a participant keeps the same strategy, then the corresponding dot in the scatterplot would be lying along the diagonal line with unity slope. In the control group we observed 6/49 (12 %) participants who expressed a modified strategy assessed by a change in the IRi of more than 2 times the standard error of the mean (SEM) (Fig. 6.6a). Conversely, in the ADHD group we observed more than the double of participants (11/38, 29 %) characterized by a change in the IRi of more than 2 SEM between HFFB and LFFB conditions (Fig. 6.6b).

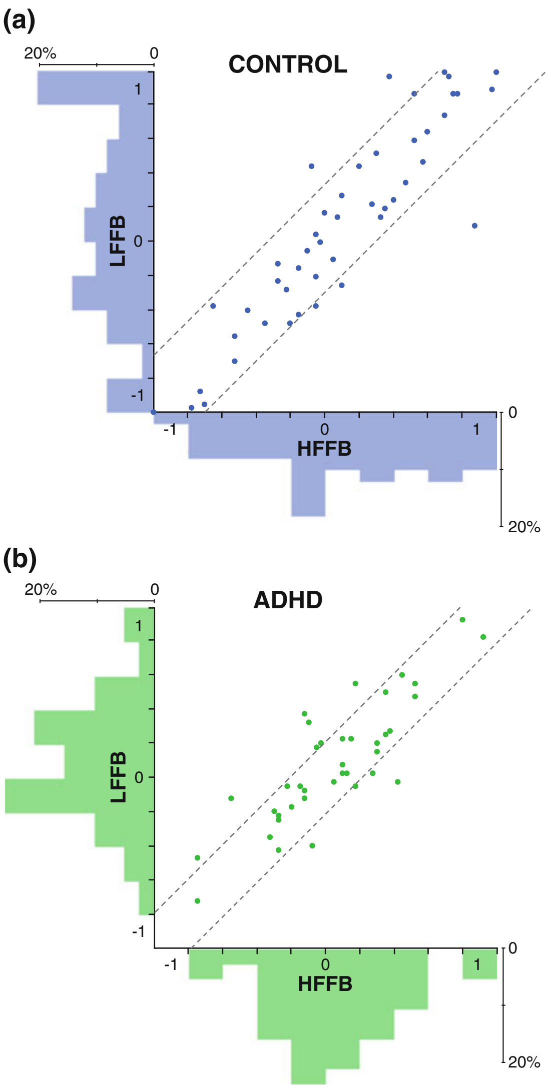

Fig. 6.6 Scatter plot of the investment risk index IRi during 'high frequency feedback' (HFFB) and 'low frequency feedback' (LFFB) conditions for control (panel **a**) and ADHD (panel **b**) participants. Each dot represents the data from one participant. *Dashed lines* represent the 95 % confidence interval. Histograms represents the marginal relative distributions of risk index IRi for each condition and group of participants

Linear regressions of the scatter plots in Fig. 6.6 allow to further assess the risky behaviors of the two groups of individuals in the high and low feedback conditions. With no change in strategy between the two conditions the slope of the regression would be equal to 1, thus indicating that participants did not take more risk in a condition rather than in the other. A regression line with a slope greater than 1 would mean that the participants of a group would consistently tend to take more risk in the LFFB condition compared to the HFFB trials. On the opposite, a slope less than 1 would characterize a group whose individuals would take more risk in

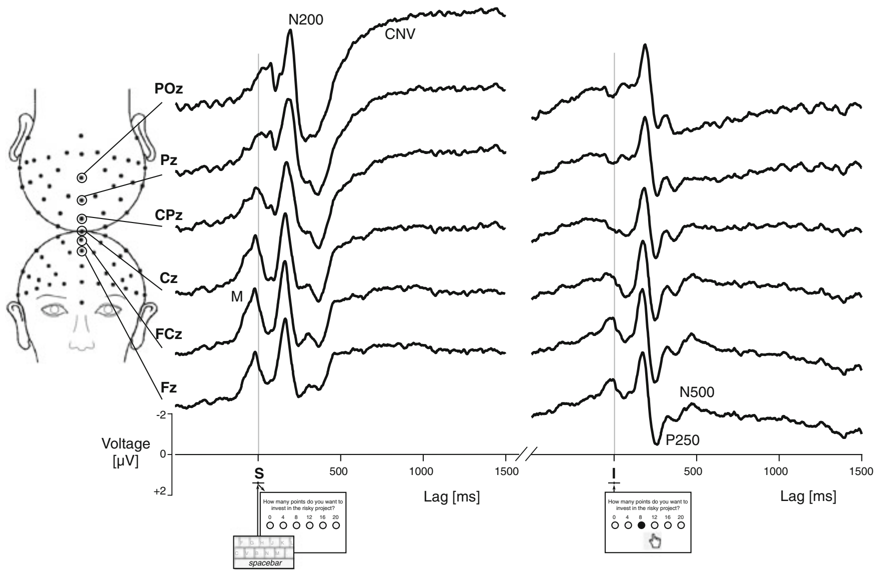

Fig. 6.7 Event related potentials during the Investment Game. Grand average at Fz, FCz, Cz, CPz, Pz and POz sites for all participants and all conditions pooled together. *Left side*: ERPs triggered by event S corresponding to the self-paced start of trial. *Right side*: ERPs triggered by event I corresponding to the choice of the investment amount

the HFFB condition. The regression equations for the two groups of participants were $y = -0.005 + 1.039x$ and $y = 0.045 + 0.813x$ for controls and ADHD patients, respectively (with x standing for IRi_{HFFB} and y for IRi_{LFFB}). We tested the difference between the two slopes after bootstrapping 1000 times with the null hypothesis that the slopes were the same. The difference was significant ($t_{(1998)} = 2.2156$, $p < 0.05$), thus suggesting that ADHD tended to show higher risk taking attitude during the HFFB trials.

6.7.3.2 Evoked Potentials

The brain activity associated to the risk taking behavior during the Investment Game is illustrated by the grand averages of the event related potentials from central electrode positions (Fig. 6.7). The trigger events were the self-paced start of trial (event S), when the participant pressed the spacebar, and the investment selection (event I, Fig. 6.5).

Self-paced Trial Onset

The decision to start a trial is clearly associated to a negative wave (here labeled "M") in the fronto-central sites beginning to appear 150–200 ms before pressing the spacebar (Fig. 6.7, left side). The trial onset S triggered also a negative deflection N200 spreading from frontal to occipital sites. Then, a mental activity related to the build-up of risk taking decision making appeared with main parieto-central distribution and expressed by a large positive deflection (P300) immediately followed by the contingent negative variation.

In order to assess the time course of the feedback frequency effect we calculated at first for each participant the ERPs for HFFB and LFFB trials separately. Hence, we calculated the feedback-related differential activities (in microvolts) for controls (subset of $n = 9$ participants, Fig. 6.8a blue lines) and ADHD participants (subset of $n = 14$ participants, Fig. 6.8a red lines) (see Sect. 6.7.2 for details on included participants) computed by subtracting the ERP associated with HFFB from the ERP associated with LFFB.

Differences between controls and ADHD participants were detected in time and space by computing the absolute value of the difference between the feedback-related differential brain waves for controls and ADHD participants. In Fig. 6.8b, these absolute differences are plotted for three intervals corresponding to the most significant differences (i.e., intervals characterized by the largest separations between the red and blue shaded areas). The first event occurred near 350 ms before the trigger onset. The absolute differential value was small and no specific distribution along the midline was observed. On the opposite, at lags near 1190 and 1450 ms after the trigger onset we observed a difference between the groups located mainly in the frontal areas. These latencies correspond to the contingent negative variation (CNV). For the ADHD patients the red curves were overlapping the zero line at CNV lag (after 1000 ms), thus indicating no feedback-related difference (Fig. 6.8b). For the controls, the feedback-related differential activities (blue lines) were significantly ($p < 0.05$) above the zero line, thus indicating that CNV for low frequency feedback was characterized by greater amplitude than CNV for high frequency feedback, at most at the level of the frontal sites.

Investment Choice

The investment choice (I) triggered a positive deflection near 250 ms (Fig. 6.7, right side), termed P250, that was larger in the frontal sites and propagated to the posterior regions. In the same way we have previously analyzed the activity after the self-paced trial onset, we assessed here the time course of the feedback frequency effect for HFFB and LFFB trials separately for each participant and calculated the grand averages of the differences for a subset of participants ($sample\,size\; N = 12$ and $N = 15$ for controls and ADHD, respectively, see Sect. 6.7.2 for details on included participants). Figure 6.9a shows feedback-related differential activities (in microvolts) for controls (blue lines) and ADHD participants (red lines) computed by subtracting the ERP associated with “high frequency feedback” (HFFB) from the ERP associated with “low frequency feedback” (LFFB). Time intervals of the most significant differences (i.e., intervals characterized by the largest separations between the red and blue shaded areas) were detected near 240 ms before the invest-

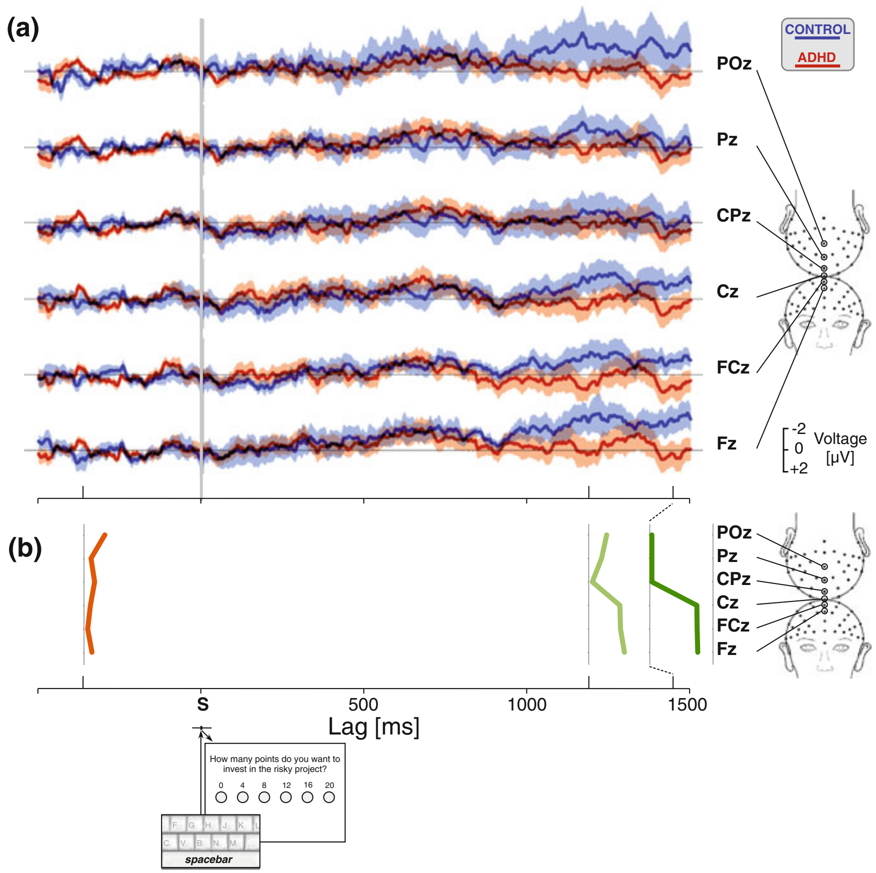

Fig. 6.8 Investment Game: brain activity triggered by self-paced trial onset (event S, Fig. 6.5). **a** Feedback-related differential activities showing the effects of feedback frequency for controls (*blue lines*) and ADHD participants (*red lines*). These feedback-related differential activities were computed by subtracting the ERP associated with 'high frequency feedback' (HFFB) from the ERP associated with 'low frequency feedback' (LFFB). The confidence interval (mean curve ±SEM) of the difference between the two conditions is shown for each differential activity by the *shaded areas*. **b** The absolute value of the difference between the feedback-related differential curves for controls and ADHD participants is presented as colour curves for electrodes Fz, FCz, Cz, CPz, Pz and POz at three time intervals, represented by the ticks along the time axis (Lag)

ment choice and 20 and 520 ms after the trigger (Fig. 6.9b). It is interesting to notice that the location of the differences between the two groups of participants tended to be located at the frontal sites for the first two intervals and at the parieto-central sites for the interval near 520 ms after the investment choice.

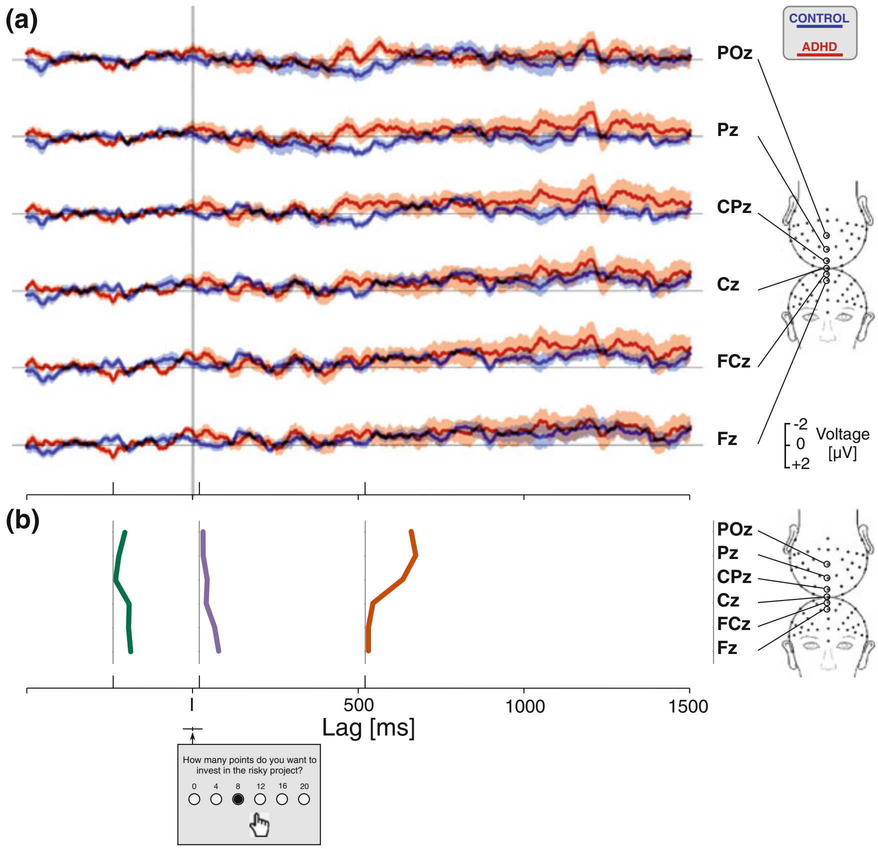

Fig. 6.9 Investment Game: brain activity triggered by the investment choice (event I, Fig. 6.5). **a** Feedback-related differential activities showing the effects of feedback frequency for controls (*blue lines*) and ADHD participants (*red lines*). These feedback-related differential activities were computed by subtracting the ERP associated with 'high frequency feedback' (HFFB) from the ERP associated with 'low frequency feedback' (LFFB). The confidence interval (mean curve ±SEM) of the difference between the two conditions is shown for each differential activity by the *shaded areas*. **b** The absolute value of the difference between the feedback-related differential curves for controls and ADHD participants is presented as colour curves for electrodes Fz, FCz, Cz, CPz, Pz and POz at three time intervals, represented by the ticks along the time axis (Lag)

Latencies and Personality

We analyzed the distributions of the scores for the the dimensions and sub-dimensions of the personality traits determined by the HEXACO-Personality Inventory. In the results presented in this chapter, we subdivided the groups of participants according to lower (below 31) and higher (above 31) score to Conscientiousness and Agreeableness dimensions and to lower (below 10) and higher (above 10) score to Sincerity, a sub-dimension of Honesty-Humility dimension. In order to determine whether brain activity during the Investment Game was associated with the selected personality traits determined by the HEXACO-Personality Inventory, we focused our analysis on the latencies of the peaks of two important ERP components observed during this task, to wit, N200 after the self-paced trial onset (Table 6.3) and P250 after the investment choice (Table 6.4).

We observed that in the ADHD group the frequency of feedback information affected overall the N200 peak latency across all sites (180 and 172 ms for HFFB and LFFB trials, respectively; the difference is significant $p < 0.05$), without any specific association with a personality trait considered here. It is interesting that during the HFFB condition the control participants with a high Conscientiousness score were characterized by a significantly shorter latency (approximately 30 ms, $p < 0.05$) of the N200 peak (Table 6.3). According to the Sincerity trait we observed at parietal sites that control participants with low scores were characterized by shorter N200 latencies (approximately 16 ms longer, $p < 0.05$), irrespective of the feedback frequency. On the opposite, for ADHD participants, only during HFFB and only at fronto-central sites, N200 peaked earlier for participants with higher scores. We did not observe any relevant change of N200 peak latency with respect to Agreeableness.

The analysis of P250, occurring after the investment choice (Table 6.4), for the ADHD group showed that the latency of the peak occurred 7 ms on average earlier in the LFFB than in the HFFB (248 ms versus 255 ms, $p < 0.05$). This difference was measured by pooling together all recording sites. Moreover, this analysis revealed some interesting effect of the ADHD participants personality traits. In the ADHD group the individuals exhibiting higher scores in Agreeableness showed a shorter P250 latency along all midline recording sites (approximately 18 ms faster, $p < 0.01$) in the low frequency feedback condition (Table 6.4). During high frequency feedback, the difference in latencies for the ADHD participants was limited to posterior sites POz and Pz. On the opposite, high scored Conscientiousness ADHD participants tended to show a shorter P250 latency only at fronto-central sites (approximately 9 ms faster, $p < 0.05$), irrespective of the feedback frequency. No effect of Sincerity was observed in the ADHD group.

In the control group, the latency of P250 was about the same (251 ms, on average) during both LFFB and HFFB conditions. Hence, it was very interesting to observe a major effect of the personality traits. High scored Conscientiousness control participants showed a P250 latency shorter by 22 ms ($p < 0.01$) compared to low scored Conscientiousness, irrespective of the feedback frequency. The effect of Agreeableness on controls was even larger, P250 latency was 25 ms shorter ($p < 0.01$) in low versus high scored Agreeableness participants, evenly distributed along the midline recording sites. The effect of Sincerity was similar to Agreeableness with P250 latency shorter in low scored participants, by 14 and 9 ms during low and high frequency feedback, respectively.

Table 6.3 Latencies (in ms) of the N200 peak at POz, Pz, CPz, Cz, FCz and Fz sites, after the self-paced start of the trial (S), following the HEXACO score on Conscientiousness, Agreeableness and Sincerity personality traits

	High frequency feedback				Low frequency feedback			
	Control		*ADHD*		Control		*ADHD*	
Personality trait score	Low	High	Low	High	Low	High	Low	High
Conscientiousness	$N =$ 8	23	19	7	8	23	19	7
POz	209	184	*187*	*187*	202	196	*187*	*184*
Pz	212	180	*187*	*187*	202	174	*177*	*170*
CPz	206	164	*177*	*177*	180	170	*164*	*164*
Cz	189	157	*177*	*167*	177	167	*170*	*167*
FCz	189	157	*170*	*170*	177	167	*167*	*167*
Fz	184	160	*170*	*167*	177	170	*160*	*167*
Agreeableness	$N =$ 15	16	16	12	15	16	16	12
POz	184	192	*199*	*187*	187	202	*199*	*189*
Pz	177	177	*199*	*187*	184	192	*184*	*167*
CPz	160	177	*180*	*177*	177	177	*167*	*167*
Cz	160	160	*167*	*170*	170	170	*164*	*164*
FCz	160	160	*164*	*170*	167	164	*164*	*164*
Fz	160	167	*170*	*170*	170	167	*167*	*170*
Sincerity	$N =$ 15	18	14	15	15	18	14	15
POz	187	196	*192*	*196*	184	199	*192*	*187*
Pz	180	202	*192*	*192*	180	199	*196*	*174*
CPz	167	164	*187*	*160*	184	170	*170*	*167*
Cz	164	160	*177*	*160*	170	170	*167*	*167*
FCz	164	164	*174*	*157*	170	167	*167*	*167*
Fz	167	167	*170*	*160*	174	167	*167*	*167*

Low and High scores were depending on the selected trait (see text). The sample size for each group is indicated by *N*

Table 6.4 Latencies (in ms) of the P250 peak at POz, Pz, CPz, Cz, FCz and Fz sites, after the Investment choice (I), following the HEXACO score on Conscientiousness, Agreeableness and Sincerity personality traits

	High frequency feedback				Low frequency feedback			
	Control		*ADHD*		Control		*ADHD*	
Personality trait score:	Low	High	Low	High	Low	High	Low	High
Conscientiousness	$N =$ 8	23	19	7	8	23	19	7
POz	273	251	*258*	*258*	277	248	*250*	*273*
Pz	271	248	*261*	*258*	277	251	*251*	*253*
CPz	268	241	*258*	*245*	264	241	*243*	*243*
Cz	261	238	*255*	*245*	264	245	*246*	*231*
FCz	261	238	*251*	*245*	261	241	*243*	*231*
Fz	261	245	*255*	*255*	258	245	*246*	*231*
Agreeableness	$N =$ 15	16	16	12	15	16	16	12
POz	245	268	*268*	*255*	245	273	*280*	*248*
Pz	241	268	*268*	*251*	241	277	*268*	*248*
CPz	241	264	*258*	*241*	245	264	*245*	*248*
Cz	238	261	*260*	*238*	245	268	*245*	*241*
FCz	238	261	*258*	*241*	241	271	*241*	*238*
Fz	238	264	*264*	*245*	245	268	*245*	*238*
Sincerity	$N =$ 15	18	14	15	15	18	14	15
POz	255	271	*261*	*258*	245	258	*273*	*264*
Pz	255	268	*261*	*261*	245	261	*258*	*251*
CPz	248	264	*255*	*258*	245	251	*248*	*248*
Cz	245	258	*248*	*258*	241	248	*241*	*245*
FCz	248	264	*245*	*255*	241	248	*241*	*241*
Fz	251	264	*251*	*261*	241	245	*251*	*245*

Low and High scores were depending on the selected trait (see text). The sample size for each group is indicated by N

6.8 Discussion

Study 1

In Study 1 we demonstrated the association of fairness and personality traits with specific components of the ERPs in the UG task. The behavioral results showed that Conscientiousness was the personality trait most related to the responder's gain (Table 6.1). Moreover, responders were more likely to accept an unfair offer when they were conscientious. The electrophysiological results showed larger FRN and smaller LPP components when the responders rejected fair versus wretched offers. In the accepting condition the LPP (especially in the posterior electrodes) showed different trends for participants characterized by lower versus higher score of Conscientiousness. This difference was bigger when the responders rejected the offer.

Behavioral results were in line with recent UG studies where both fairness [64, 119, 131] and emotional statement [21] strongly affected the acceptance rate of UG responders. In our previous study we found that offers made by proposers in the UG tended to fair split rather than unequal amount, with positive emotions predicting higher acceptance rate, and negative emotions higher amount of money offered [46]. Responders were more likely to accept an unfair offer when they were introverted, conscientious, and honest.

Integrity of the ventromedial prefrontal area was reported to be associated with the perception of fairness in the UG [111]. Patients with damages of this area were much more likely to reject unfair offers if the proposer could have made fair offers. Unfair offers in the UG evoked more negative emotional ratings and elicited larger FRN than fair offers [64].

The expectation of the value received by a responder plays an important role in the activity of frontal areas, as revealed by smaller amplitudes of FRN components when an outcome was better than expected and larger FRN amplitude when the outcome was worse than expected [66]. The increase of high feedback outcome volatility was associated with FRN [13], thus supporting the hypothesis that the FRN complex might be associated with the presence of contrasting cognitive responses and emotional motivations following changes in the outcome rule [15, 69, 134].

The FRN was suggested to reflect the impact of the midbrain dopaminergic signals on the ACC [65, 86]. The phasic decrease in dopamine input, elicited by negative prediction errors, would give rise to an increased ACC activity, associated with larger FRN amplitude. On the opposite, the phasic increase in dopamine signals, elicited by positive prediction errors, would decrease ACC activity, thus showing a smaller FRN amplitude. The relation of dopamine to personality traits [39] and the positive reward signal generated by the dopaminergic system contrasting the unfairness of the offers in the UG [21] support the hypothesis that dopamine plays a key role in modulating the decision making circuit.

Study 2

In the original version of the Gneezy Potters' task [53] the participants had to choose in advance the amount to invest for a set of three consecutive trials in the low frequency feedback condition only. In the Investment Game used in our study, the participants were given at each trial the possibility to select the amount to gamble regardless of the condition. In the original study, the frequency of feedback presentation had an impact on the amount invested, that is, the participants gambled larger amounts when the outcomes were presented less frequently, compared to blocks when the outcomes were shown at the end of each trial, in accordance with the Myopic Loss Aversion (*MLA*) [8]. In the present study, the behavioral results show that control participants exhibited a broad range of strategies, from poor to high risk taking, but their strategy tended to be unaffected by the feedback frequency of the outcome. These results suggest that control participants were more likely to evaluate each trial separately in agreement with the Subjective Utility Theory (SEU) [107]. Therefore, the results of the original task have not been replicated in the present study. However, the modification of the experimental manipulations may explain the difference between the original and the current studies; the discount of an endowment at the beginning of each trial in both conditions is likely to have left unaffected the participants' risk perception in our Investment Game.

Individuals suffering from ADHD generally exhibit hyperactivity, inattention and impulsivity since their childhood and are associated with cognitive impairments in inhibitory control and executive function, problems in social interaction, increased risk of depression and substance abuse. Medications used to treat ADHD suggest that a deficit in dopamine and norepinephrine regulation may constitute the primary neurochemical basis leading to ADHD symptoms, with anomalous interaction of the dopaminergic and serotoninergic neuronal systems [89, 112]. Despite significantly differing from controls in group comparisons, ADHD individuals also show considerable inter- and intra-individual variability [102]. The majority of the participants belonging to the ADHD group were characterized by a risk index close to zero inour Investment Game, thus suggesting a behavior generally oriented towards risk neutral attitude. The ADHD participants showed a tendency to take more risk during the high frequency feedback condition, somehow the opposite strategy observed during the original Gneezy Potters' task [53]. The attentional deficits combined to impulsivity in ADHD participant are factors likely to limit inferences in the low frequency feedback condition (*LFFB*). This may have encouraged them to express a greater risk-taking behavior in the condition where the feedback was immediately displayed, thus allowing them to adjust their investment in order to maximize their earnings.

N200 is a negative component that has been observed to peak between 180 and 325 ms after stimulus onset [93] in several tasks, such as Oddball, Stroop, Go No-Go and Flanker tasks [49]. Specific subcomponents of N200 have been associated with changes in the frequency of stimulus presentation and to the difference of target and non target items [49, 51]. In our Investment Game task N200 was triggered by the self-paced start of trial (event S). At the end of the game, the participants reported to decide the sum to invest just before clicking on the spacebar that starts the actual trial. Hence, the presentation of the amount to gamble (one among six possibilities) appears as a target amount surrounded by flankers, a condition well known to evoke N200. The latency of this component was generally shorter for ADHD participants during LFFB, compared to HFFB and to controls. It is interesting to notice that shorter N200 latencies were also observed in the control group but only for high Conscientiousness participants (in both frequency feedback conditions, although the effect was stronger in HFFB than LFFB). In the control group and during LFFB condition, we observed larger amplitudes for the contingent negative variations mainly at the level of the frontal sites.

The time when the participants selected the amount they wanted to gamble in the risky project (event I, the investment choice) triggered mainly a positive component P250 followed by a negative wave N500 in the ERPs. The P250 could be interpreted in terms of a P300-like, with an apparent maximum over frontal and fronto-central areas associated with the evaluation of the decision which has been taken.

The P300 component in decision making tasks is a positive deflection peaking near 300 ms after the trigger onset in relation with the response of the outcome after taking a decision [85, 100]. This wave is likely to be generated by the cognitive processing following the feeling of "dissonance", i.e. the possibility of being wrong after taking a decision [17]. It is interesting the fact that up to P250 the differences between ADHD and controls in feedback-related differential waves were located at fronto-central sites. In Study 2, larger differences in feedback-related differentials between the groups appeared at parieto-occipital sites for the N500. This ERP component was larger over the frontal areas but feedback-related effects were more relevant along the posterior sites of the midline. N500 is associated with the outcome evaluation in decision making under risk [99, 133] and the fact that differences appeared between the two groups for this wave support the hypothesis that ADHD participants processed the outcome of a risky investment following circuits and dynamics that are different from controls.

Personality

It is known that risky decision making is associated with personality traits [125, 126] and that dopamine and serotonin are essential modulators of the expression of personality traits and decision making brain circuits [23, 39]. In the present chapter we analyzed all main personality traits determined by the HEXACO dimensions [1, 2, 76, 126] for the Ultimatum Game. For the Investment Game we limited our analysis to personality traits identified on the basis of a non unimodal distribution among the control and ADHD participants, to wit, Conscientiousness, Agreeableness and Sincerity. For each personality trait we subdivided the participants to Study 2 in two subgroups, those with lower and those with higher score. Hence, the discussion is limited here to these three personality traits.

Conscientiousness has been defined by four facets, organization, diligence, perfectionism and prudence [76]. A structural MRI study found that Conscientiousness was associated with greater volume of the middle frontal gyrus in lateral prefrontal cortex, a region involved in planning and in voluntary control of behavior [40] and may reflect the function of the dorsal premotor cortex in executive function [75]. Conscientiousness was positively associated with the responder's gain in the Ultimatum Game. After rejecting the offer the participants with the lowest score of Conscientiousness were characterized by larger negative deflections for the FRN, in particular in the fronto-central sites. This result appears in agreement with the hypothesis that the FRN complex might be associated with the presence of contrasting cognitive responses and emotional motivations following changes in the outcome rule [15, 69, 134]. In the UG, after either acceptance or rejection of the offer, the participants with the highest score of Conscientiousness exhibited larger LPP component, ut the difference in LPP tended to be located more posteriorly after response acceptance. This late positive potential is an ERP component reflecting facilitated attention to emotional stimuli. In adults, the LPP is reduced following use of cognitive emotion regulation strategies such as reappraisal [37]. After presenting pleasant pictures fMRI studies [79] revealed that the LPP amplitude was correlated with the activation of the medial prefrontal cortex, amygdala, and precuneus (Fig. 6.1), whereas for unpleasant pictures the LPP amplitude was correlated with the activation of the ventrolateral prefrontal cortex, insula, and posterior cingulate cortex (Fig. 6.1).

Control participants with a high score of Conscientiousness were characterized by shorter N200 latency in our Investment Game. The lateral prefrontal cortex is likely to be associated with behavioral inhibition, which can suggest that individuals with a high score are likely to inhibit response to flankers faster than low score individuals. The effect of Conscientiousness on the latency of P250 was visible mainly in the control group and, to a lesser extent, only at fronto-central sites for the ADHD participants. The amplitude of P250 is likely to be larger over frontal and fronto-central areas associated with the evaluation of the decision which has been taken. P250 peaked earlier for individuals with higher score than in the low score subgroup. A possible interpretation is that individuals with high levels of Conscientiousness reach the evaluation of their decision prior to the least conscientious subjects. In control groups this processing appears to involve also posterior regions that are likely to be less activated in the ADHD.

Agreeableness has been defined by four facets, forgiveness, gentleness, flexibility and patience [76] and its social and emotional aspect can reflect the fact that individuals react to their own choice. Agreeableness has been linked to interpersonal conflict [57] and to susceptibility to framing [124]. The volume of brain regions involved in social interaction, including superior temporal sulcus, posterior cingulate cortex, and fusiform gyrus were associated with Agreeableness [40]. In a fMRI study Agreeableness predicted the activity in the left dorsolateral prefrontal cortex associated with emotion regulation [60]. In our Investment Game, P250 peaked earlier for controls with lower score of Agreeableness, but with ADHD participants P250 peaked earlier in higher ranked individuals. These results lead us to suggest that the difference between the subgroups is that *controls and ADHD individuals use different circuits to implement emotion regulation and evaluate interpersonal conflicts in a different way*.

Sincerity is one of the Honesty-Humility's facet within the HEXACO and has been associated to ethical and to the health and safety domains [126]. In control participants performing our Investment Game, N200 peaked earlier for individuals with lower scores of Sincerity only at the parietal sites. In the Investment Game the amount to gamble appears as a target amount surrounded by flankers. In ADHD participants, N200 tended to peak earlier for individuals with higher scores of Sincerity only at the fronto-central sites and only during high frequency feedback. This latter finding, along the same line of interpretation of N200 mentioned above, suggests that in these ADHD participants, the activity of the lateral prefrontal cortex was likely to inhibit the responses to flankers. The data regarding P250 show that the effect of Sincerity was similar to Agreeableness with P250 peaking earlier in low scored participants. Sincerity is related to the ethical risk taking and the interpretation could be that less sincere individuals reach the evaluation of their decision prior to the most sincere. Hence, the P300-like wave could represent a good marker sensitive to the ethical aspect of gambling.

6.9 General Conclusions

The aim of the present chapter was to highlight how the determinants of personality, assessed by the HEXACO (see Sect. 6.2) personality inventory, interacted with decision making, especially, with regard to fairness and risk taking. In this respect, we conducted 2 separate studies in which EEG signals were recorded while participants were performing either an Ultimatum Game or an Investment Game. In the Ultimatum Game, event-related potentials (ERPs) analysis revealed a greater feedback-related negativity (FRN) amplitude after the rejection of the offer among responders with lower score of Conscientiousness, whereas highly conscientious responders showed a larger late positive component (LPP) regardless their decision to reject or accept the offer. Conscientiousness, Agreeableness and Sincerity were associated with risky decision making. Indeed, latencies of the negative wave occurring at around 200 ms (N200) and of the positive deflection peaking at around 250 ms (P250) components dependent on how individuals process responses to a selected gamble and evaluate the outcome in the Investment task, in association with specific personality subgroups to which they belonged. In particular, N200 peaked earlier in individuals with high levels of conscientiousness, controls with low score of sincerity and highly sincere patients with attention deficit/hyperactive disorder (ADHD). Furthermore, P250 peaked earlier in highly conscientious individuals, controls with low levels of agreeableness and ADHD patients with high levels of agreeableness, and likewise for sincerity. These results clearly show that imperfect decision making and risk taking are affected by personality traits and can not be accounted by models based on rational computations.

Acknowledgments The Authors acknowledge the support of the Swiss National Science Foundation grant CR13I1-138032. The authors thank Maria Duarte for her participation to collect the data of Study 2.

References

1. Ashton, M.C., Lee, K.: Empirical, theoretical, and practical advantages of the hexaco model of personality structure. Personal. Soc. Psychol. Rev. **11**(2), 150–166 (2007)
2. Ashton, M.C., Lee, K.: The HEXACO-60: a short measure of the major dimensions of personality. J. Personal. Assess. **91**(4), 340–345 (2009)

3. Ashton, M.C., Lee, K., Perugini, M., Szarota, P., De Vries, R.E., Di Blas, L., Boies, K., De Raad, B.: A six-factor structure of personality-descriptive adjectives: solutions from psycholexical studies in seven languages. J. Personal. Soc. Psychol. **86**(2), 356–366 (2004)
4. Ashton, M.C., Lee, K., Pozzebon, J.A., Visser, B.A., Worth, N.C.: Status-driven risk taking and the major dimensions of personality. J. Res. Personal. **44**(6), 734–737 (2010)
5. American Psychiatric Association: Diagnostic and Statistical Manual of Mental Disorders: DSM-IV-TR. American Psychiatric Association, Washington (2000)
6. Bach, D.R., Dolan, R.J.: Knowing how much you don't know: a neural organization of uncertainty estimates. Nat. Rev. Neurosci. **13**(8), 572–586 (2012)
7. Barkley, R.A.: Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. Psychol. Bull. **121**(1), 65–94 (1997)
8. Benartzi, S., Thaler, R.H.: Myopic loss aversion and the equity premium puzzle. Q. J. Econ. **110**(1), 73–92 (1995)
9. Bernoulli, D.: Exposition of a new theory on the measurement of risk. Econometrica **22**(1), 23–36 (1954)
10. Biederman, J., Monuteaux, M.C., Doyle, A.E., Seidman, L.J., Wilens, T.E., Ferrero, F., Morgan, C.L., Faraone, S.V.: Impact of executive function deficits and attention-deficit/hyperactivity disorder (ADHD) on academic outcomes in children. J. Consult. Clin. Psychol. **72**(5), 757–766 (2004)
11. Biederman, J., Petty, C.R., Fried, R., Doyle, A.E., Spencer, T., Seidman, L.J., Gross, L., Poetzl, K., Faraone, S.V.: Stability of executive function deficits into young adult years: a prospective longitudinal follow-up study of grown up males with ADHD. Acta Psychiat. Scand. **116**(2), 129–136 (2007)
12. Biederman, J., Petty, C.R., Fried, R., Fontanella, J., Doyle, A.E., Seidman, L.J., Faraone, S.V.: Can self-reported behavioral scales assess executive function deficits? a controlled study of adults with ADHD. J. Nerv. Ment. Dis. **195**(3), 240–246 (2007)
13. Bland, A.R., Schaefer, A.: Electrophysiological correlates of decision making under varying levels of uncertainty. Brain Res. **12**(1417), 55–66 (2011)
14. Boksem, M.A., De Cremer, D.: Fairness concerns predict medial frontal negativity amplitude in ultimatum bargaining. Soc. Neurosci. **5**(1), 118–125 (2010)
15. Botvinick, M.M., Cohen, J.D., Carter, C.S.: Conflict monitoring and anterior cingulate cortex: an update. Trends Cogn. Sci. **111**, 395–429 (2004)
16. Brand, M., Kalbe, E., Labudda, K., Fujiwara, E., Kessler, J., Markowitsch, H.J.: Decision-making impairments in patients with pathological gambling. Psychiatry Res. **133**(1), 91–99 (2005)
17. Brehm, J.W.: Postdecision changes in the desirability of alternatives. J. Abnorm. Soc. Psychol. **52**(3), 384–389 (1956)
18. Burke, S.M., van de Giessen, E., de Win, M., Schilt, T., van Herk, M., van den Brink, W., Booij, J.: Serotonin and dopamine transporters in relation to neuropsychological functioning, personality traits and mood in young adult healthy subjects. Psychol. Med. **41**(2), 419–429 (2011)
19. Bush, G., Whalen, P.J., Rosen, B.R., Jenike, M.A., McInerney, S.C., Rauch, S.L.: The counting stroop: an interference task specialized for functional neuroimaging-validation study with functional MRI. Hum. Brain Mapp. **6**(4), 270–282 (1998)
20. Camerer, C., Thaler, R.H.: Anomalies: ultimatums, dictators and manners. J. Econ. Perspect. **9**(2), 209–219 (1995)
21. Campanhã, C., Minati, L., Fregni, F., Boggio, P.S.: Responding to unfair offers made by a friend: neuroelectrical activity changes in the anterior medial prefrontal cortex. J. Neurosci. **31**(43), 15569–15574 (2011)
22. Carter, C.S., Braver, T.S., Barch, D.M., Botvinick, M.M., Noll, D., Cohen, J.D.: Anterior cingulate cortex, error detection, and the online monitoring of performance. Science **280**(5364), 747–749 (1998)
23. Carver, C.S., Miller, C.J.: Relations of serotonin function to personality: current views and a key methodological issue. Psychiatry Res. **144**(1), 1–15 (2006)

24. Cattell, R.B., Eber, H.: Sixteen Personality Factor Questionnaire (16PF). Institute for Personality and Ability Testing, Champaign (1972)
25. Choi, J.S., Shin, Y.C., Jung, W.H., Jang, J.H., Kang, D.H., Choi, C.H., Choi, S.W., Lee, J.Y., Hwang, J.Y., Kwon, J.S.: Altered brain activity during reward anticipation in pathological gambling and obsessive-compulsive disorder. PloS One **7**(9), e45,938 (2012)
26. Civai, C., Corradi-Dell'Acqua, C., Gamer, M., Rumiati, R.I.: Are irrational reactions to unfairness truly emotionally-driven? dissociated behavioural and emotional responses in the ultimatum game task. Cognition **114**(1), 89–95 (2010)
27. Clark, L., Bechara, A., Damasio, H., Aitken, M., Sahakian, B., Robbins, T.: Differential effects of insular and ventromedial prefrontal cortex lesions on risky decision-making. Brain **131**(5), 1311–1322 (2008)
28. Clark, L., Manes, F.: Social and emotional decision-making following frontal lobe injury. Neurocase **10**(5), 398–403 (2004)
29. Cohen, M.X., Elger, C.E., Ranganath, C.: Reward expectation modulates feedback-related negativity and EEG spectra. Neuroimage **35**(2), 968–978 (2007)
30. Conners, C.K., Erhardt, D., Epstein, J.N., Parker, J.D.A., Sitarenios, G., Sparrow, E.: Self-ratings of ADHD symptoms in adults I: factor structure and normative data. J. Atten. Disord. **3**(3), 141–151 (1999)
31. Costa Jr, P.T., McCrae, R.R.: Four ways five factors are basic. Personal. Individ. Differ. **13**(6), 653–665 (1992)
32. Crichton, A.: An Inquiry into the Nature and Origin of Mental Derangement: Comprehending a Concise System of the Physiology and Pathology of the Human Mind, and a History of the Passions and Effects. AMS Press, New York (1976)
33. Crino, P., Morrison, J., Hof, P.: Monoaminergic innervation of cingulate cortex. In: Vogt, B.A., Gabriel, M. (eds.) Neurobiology of Cingulate Cortex and Limbic Thalamus: A Comprehensive Handbook, pp. 285–310. Birkhauser, Boston (1993)
34. Cui, Jf: Chen, Yh, Wang, Y., Shum, D.H., Chan, R.C.: Neural correlates of uncertain decision making: ERP evidence from the Iowa gambling task. Front. Hum. Neurosci. **7**, 776 (2013)
35. Currá, A., Modugno, N., Inghilleri, M., Manfredi, M., Hallett, M., Berardelli, A.: Transcranial magnetic stimulation techniques in clinical investigation. Neurology **59**(12), 1851–1859 (2002)
36. Damasio, A.R.: The somatic marker hypothesis and the possible functions of the prefrontal cortex. Philos. Trans. R. Soc. Lond. B. Biol. Sci. **351**(1346), 1413–1420 (1996)
37. Dennis, T.A., Hajcak, G.: The late positive potential: a neurophysiological marker for emotion regulation in children. J. Child Psychol. Psychiatry **50**(11), 1373–1383 (2009)
38. Devinsky, O., Morrell, M., Vogt, B.: Contributions of anterior cingulate cortex to behaviour. Brain **118**, 279–306 (1995)
39. DeYoung, C.G.: The neuromodulator of exploration: a unifying theory of the role of dopamine in personality. Front. Hum. Neurosci. **7**, 1–26 (2013)
40. DeYoung, C.G., Hirsh, J.B., Shane, M.S., Papademetris, X., Rajeevan, N., Gray, J.R.: Testing predictions from personality neuroscience. Brain structure and the big five. Psychol. Sci. **21**(6), 820–828 (2010)
41. Dunn, O.J.: Multiple comparisons among means. J. Am. Stat. Assoc. **56**, 52–64 (1961)
42. Ernst, M., Bolla, K., Mouratidis, M., Contoreggi, C., Matochik, J.A., Kurian, V., Cadet, J.L., Kimes, A.S., London, E.D.: Decision-making in a risk-taking task: a PET study. Neuropsychopharmacology **26**(5), 682–691 (2002)
43. Eysenck, H.J.: Dimensions of Personality. Transaction Publishers, New York (1947)
44. Eysenck, H.J.: The Structure of Human Personality (Psychology Revivals). Routledge, New York (2013)
45. Eysenck, H.J., Eysenck, S.B.G.: Manual for the Eysenck Personality Questionnaire: (EPQ-R Adult). Educational Industrial Testing Service, San Diego (1994)
46. Fiori, M., Lintas, A., Mesrobian, S., Villa, A.E.: Effect of emotion and personality on deviation from purely rational decision-making. In: Guy, T.V., Kárný, M., Wolpert, D.H. (eds.) Decision Making and Imperfection, Studies in Computational Intelligence, vol. 474, chap. 5, pp. 129–161. Springer, Berlin (2013)

47. Fitzgerald, P.B., Fountain, S., Daskalakis, Z.J.: A comprehensive review of the effects of rTMS on motor cortical excitability and inhibition. Clin. Neurophysiol. **117**(12), 2584–2596 (2006)
48. Flory, K., Molina, B.S., Pelham Jr, W.E., Gnagy, E., Smith, B.: Childhood ADHD predicts risky sexual behavior in young adulthood. J. Clin. Child Adolesc. Psychol. **35**(4), 571–577 (2006)
49. Folstein, J.R., Van Petten, C.: Influence of cognitive control and mismatch on the N2 component of the ERP: a review. Psychophysiology **45**(1), 152–170 (2008)
50. Gaertig, C., Moser, A., Alguacil, S., Ruz, M.: Social information and economic decision-making in the ultimatum game. Front. Neurosci. **6**, 103–103 (2012)
51. Garrido, M.I., Kilner, J.M., Stephan, K.E., Friston, K.J.: The mismatch negativity: a review of underlying mechanisms. Clin. Neurophysiol. **120**(3), 453–463 (2009)
52. Gehring, W.J., Willoughby, A.R.: The medial frontal cortex and the rapid processing of monetary gains and losses. Science **295**(5563), 2279–2282 (2002)
53. Gneezy, U., Potters, J.: An experiment on risk taking and evaluation periods. Q. J. Econ. **112**(2), 631–645 (1997)
54. Gneezy, U., Rustichini, A.: Pay enough or don't pay at all. Q. J. Econ. **115**(3), 791–810 (2000)
55. Goldberg, L.R.: An alternative description of personality: the big-five factor structure. J. Personal. Soc. Psychol. **59**(6), 1216–1229 (1990)
56. Gowin, J.L., Stewart, J.L., May, A.C., Ball, T.M., Wittmann, M., Tapert, S.F., Paulus, M.P.: Altered cingulate and insular cortex activation during risk-taking in methamphetamine dependence: losses lose impact. Addiction **109**(2), 237–247 (2014)
57. Graziano, W.G., Jensen-Campbell, L.A., Hair, E.C.: Perceiving interpersonal conflict and reacting to it: the case for agreeableness. J. Personal. Soc. Psychol. **70**(4), 820–835 (1996)
58. Güth, W.: The generosity game and calibration of inequity aversion. J. Socio-Econ. **39**, 155–157 (2010)
59. Güth, W., Schmittberger, R., Schwarze, B.: An experimental analysis of ultimatum bargaining. J. Econ. Behav. Organ. **3**(4), 367–388 (1982)
60. Haas, B.W., Omura, K., Constable, R.T., Canli, T.: Is automatic emotion regulation associated with agreeableness? a perspective using a social neuroscience approach. Psychol. Sci. **18**(2), 130–132 (2007)
61. Hajcak, G., Moser, J.S., Holroyd, C.B., Simons, R.F.: The feedback-related negativity reflects the binary evaluation of good versus bad outcomes. Biol. Psychol. **71**(2), 148–154 (2006)
62. Hanoch, Y., Johnson, J.G., Wilke, A.: Domain specificity in experimental measures and participant recruitment an application to risk-taking behavior. Psychol. Sci. **17**(4), 300–304 (2006)
63. Hervey, A.S., Epstein, J.N., Curry, J.F.: Neuropsychology of adults with attention-deficit/hyperactivity disorder: a meta-analytic review. Neuropsychology **18**(3), 485–503 (2004)
64. Hewig, J., Kretschmer, N., Trippe, R.H., Hecht, H., Coles, M.G., Holroyd, C.B., Miltner, W.H.: Why humans deviate from rational choice. Psychophysiology **48**(4), 507–514 (2011)
65. Holroyd, C.B., Coles, M.G.: The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. Psychol. Rev. **109**(4), 679–709 (2002)
66. Holroyd, C.B., Larsen, J.T., Cohen, J.D.: Context dependence of the event-related brain potential associated with reward and punishment. Psychophysiology **41**(2), 245–253 (2004)
67. Hsu, M., Bhatt, M., Adolphs, R., Tranel, D., Camerer, C.F.: Neural systems responding to degrees of uncertainty in human decision-making. Science **310**(5754), 1680–1683 (2005)
68. Huynh, H., Feldt, L.S.: Performance of traditional f tests in repeated measures designs under covariance heterogeneity. Commun. Stat. Theory Methods **9**, 61–74 (1980)
69. Jia, S., Li, H., Luo, Y., Chen, A., Wang, B., Zhou, X.: Detecting perceptual conflict by the feedback-related negativity in brain potentials. Neuroreport **18**(13), 1385–1388 (2007)
70. Kahneman, D., Tversky, A.: Prospect theory: an analysis of decision under risk. Econometrica **47**(2), 263–291 (1979)

71. Kessler, R.C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E., Howes, M.J., Jin, R., Secnik, K., Spencer, T., Ustun, T.B., Walters, E.E.: The world health organization adult ADHD self-report scale (ASRS): a short screening scale for use in the general population. Psychol. Med. **35**(2), 245–256 (2005)
72. Knoch, D., Gianotti, L.R., Pascual-Leone, A., Treyer, V., Regard, M., Hohmann, M., Brugger, P.: Disruption of right prefrontal cortex by low-frequency repetitive transcranial magnetic stimulation induces risk-taking behavior. J. Neurosci. **26**(24), 6469–6472 (2006)
73. Knutson, B., Wimmer, G.E., Kuhnen, C.M., Winkielman, P.: Nucleus accumbens activation mediates the influence of reward cues on financial risk taking. NeuroReport **19**(5), 509–513 (2008)
74. Kuhnen, C.M., Knutson, B.: The neural basis of financial risk taking. Neuron **47**, 763–770 (2005)
75. Kunisato, Y., Okamoto, Y., Okada, G., Aoyama, S., Nishiyama, Y., Onoda, K., Yamawaki, S.: Personality traits and the amplitude of spontaneous low-frequency oscillations during resting state. Neurosci. Lett. **492**(2), 109–113 (2011)
76. Lee, K., Ashton, M.C.: Psychometric properties of the HEXACO personality inventory. Multivar. Behav. Res. **39**(2), 329–358 (2004)
77. Lejuez, C., Read, J.P., Kahler, C.W., Richards, J.B., Ramsey, S.E., Stuart, G.L., Strong, D.R., Brown, R.A.: Evaluation of a behavioral measure of risk taking: the balloon analogue risk task (BART). J. Exp. Psychol.: Appl. **8**(2), 75–84 (2002)
78. Leland, D.S., Paulus, M.P.: Increased risk-taking decision-making but not altered response to punishment in stimulant-using young adults. Drug Alcohol Depend. **78**(1), 83–90 (2005)
79. Liu, Y., Huang, H., McGinnis-Deweese, M., Keil, A., Ding, M.: Neural substrate of the late positive potential in emotional processing. J. Neurosci. **32**(42), 14563–14572 (2012)
80. Luck, S.J.: An Introduction to Event-Related Potentials and Their Neural Origins. Massachusetts Institute of Technology, Cambridge (2005)
81. Manes, F., Sahakian, B., Clark, L., Rogers, R., Antoun, N., Aitken, M., Robbins, T.: Decision-making processes following damage to the prefrontal cortex. Brain **125**(3), 624–639 (2002)
82. Mäntylä, T., Still, J., Gullberg, S., Del Missier, F.: Decision making in adults with ADHD. J. Atten. Disord. **16**(2), 164–173 (2012)
83. Nelissen, R.M.A., Leliveld, M.C., van Dijk, E., Zeelenberg, M.: Fear and guilt in proposers: using emotions to explain offers in ultimatum bargaining. Eur. J. Soc. Psychol. **41**, 78–85 (2011)
84. Newcorn, J.H., Halperin, J.M., Jensen, P.S., Abikoff, H.B., Arnold, L.E., Cantwell, D.P., Conners, C.K., Elliott, G.R., Epstein, J.N., Greenhill, L.L., et al.: Symptom profiles in children with ADHD: effects of comorbidity and gender. J. Am. Acad. Child Adolesc. Psychiatry **40**(2), 137–146 (2001)
85. Nieuwenhuis, S., Aston-Jones, G., Cohen, J.D.: Decision making, the P3, and the locus coeruleus-norepinephrine system. Psychol. Bull. **131**(4), 510–532 (2005)
86. Nieuwenhuis, S., Holroyd, C.B., Mol, N., Coles, M.G.: Reinforcement-related brain potentials from medial frontal cortex: origins and functional significance. Neurosci. Biobehav. Rev. **28**(4), 441–448 (2004)
87. Nigg, J.T., Casey, B.J.: An integrative theory of attention-deficit/hyperactivity disorder based on the cognitive and affective neurosciences. Dev. Psychopathol. **17**(3), 785–806 (2005)
88. Novakova, J., Flegr, J.: How much is our fairness worth? the effect of raising stakes on offers by proposers and minimum acceptable offers in dictator and ultimatum games. PLoS One **8**(4), e60,966 (2013)
89. Oades, R.D.: Dopamine-serotonin interactions in attention-deficit hyperactivity disorder (ADHD). Prog. Brain Res. **172**, 543–565 (2008)
90. Ogawa, S., Lee, T.M., Kay, A.R., Tank, D.W.: Brain magnetic resonance imaging with contrast dependent on blood oxygenation. Proc. Natl. Acad. Sci. U.S.A. **87**(24), 9868–9872 (1990)
91. Oldfield, R.C.: The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia **9**(1), 97–113 (1971)

92. Oosterlaan, J., Sergeant, J.A.: Response inhibition and response re-engagement in attention-deficit/hyperactivity disorder, disruptive, anxious and normal children. Behav. Brain Res. **94**(1), 33–43 (1998)
93. Patel, S.H., Azzam, P.N.: Characterization of N200 and P300: selected studies of the event-related potential. Int. J. Med. Sci. **2**(4), 147–154 (2005)
94. Paulus, M.P., Rogalsky, C., Simmons, S., Feinstein, J.S., Stein, M.B.: Increase activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism. NeuroImage **19**(4), 1439–1448 (2003)
95. Pennington, B.F., Ozonoff, S.: Executive functions and developmental psychopathology. J. Child Psychol. Psychiatry **37**(1), 51–87 (1996)
96. Picton, T.W., Bentin, S., Berg, P., Donchin, E., Hillyard, S.A., Johnson, R., Miller, G.A., Ritter, W., Ruchkin, D.S., Rugg, M.D., Taylor, M.J.: Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. Psychophysiology **37**(2), 127–152 (2000)
97. Platt, M.L., Huettel, S.A.: Risky business: the neuroeconomics of decision making under uncertainty. Nat. Neurosci. **11**(4), 398–403 (2008)
98. Plöchl, M., Ossandón, J.P., König, P.: Combining EEG and eye tracking: identification, characterization, and correction of eye movement artifacts in electroencephalographic data. Front. Hum. Neurosci. **6**, 278–301 (2012)
99. Polezzi, D., Sartori, G., Rumiati, R., Vidotto, G., Daum, I.: Brain correlates of risky decision-making. Neuroimage **49**(2), 1886–1894 (2010)
100. Polich, J.: Updating P300: an integrative theory of P3a and P3b. Clin. Neurophysiol. **118**(10), 2128–2148 (2007)
101. Polson, M.J., Barker, A.T., Freeston, I.L.: Stimulation of nerve trunks with time-varying magnetic fields. Med. Biol. Eng. Comput. **20**(2), 243–244 (1982)
102. Purper-Ouakil, D., Ramoz, N., Lepagnol-Bestel, A.M., Gorwood, P., Simonneau, M.: Neurobiology of attention deficit/hyperactivity disorder. Pediatr. Res. **69**(5 Pt 2), 69R–76R (2011)
103. Qu, C., Wang, Y., Huang, Y.: Social exclusion modulates fairness consideration in the ultimatum game: an ERP study. Front. Hum. Neurosci. **7**, 505 (2013)
104. Sallet, J., Camille, N., Procyk, E.: Modulation of feedback-related negativity during trial-and-error exploration and encoding of behavioral shifts. Front. Hum. Neurosci. **7**(14), 209 (2013)
105. Martín San, R.: Event-related potential studies of outcome processing and feedback-guided learning. Front. Hum. Neurosci. **6**(304), 65–70 (2012)
106. Sanfey, A.G., Rilling, J.K., Aronson, J.A., Nystrom, L.E., Cohen, J.D.: The neural basis of economic decision-making in the ultimatum game. Science **300**(5626), 1755–1758 (2003)
107. Savage, L.J.: The Foundations of Statistics. Courier Dover, New York (1972)
108. Schoemaker, K., Bunte, T., Wiebe, S.A., Espy, K.A., Deković, M., Matthys, W.: Executive function deficits in preschool children with ADHD and DBD. J. Child Psychol. Psychiatry **53**(2), 111–119 (2012)
109. Schupp, H., Cuthbert, B., Bradley, M., Hillman, C., Hamm, A., Lang, P.: Brain processes in emotional perception: motivated attention. Cogn. Emot. **18**(5), 593–611 (2004)
110. Schwarz, N.: Emotion, congnition, and decision making. Cogn. Emot. **14**(4), 433–440 (2000)
111. Shamay-Tsoory, S.G., Suleiman, R., Aharon-Peretz, J., Gohary, R., Hirschberger, G.: Sensitivity to fairness and intentions of others in the ultimatum game in patients with ventromedial prefontal lesions. J. Int. Neuropsychol. Soc. **18**(6), 952–961 (2012)
112. Sharma, A., Couture, J.: A review of the pathophysiology, etiology, and treatment of attention-deficit hyperactivity disorder (ADHD). Ann. Pharmacother. **48**(2), 209–225 (2014)
113. Sheehan, D.V., Lecrubier, Y., Sheehan, K.H., Amorim, P., Janavs, J., Weiller, E., Hergueta, T., Baker, R., Dunbar, G.C.: The mini-international neuropsychiatric interview (M.I.N.I.): the development and validation of a structured diagnostic psychiatric interview for DSM-IV and ICD-10. J. Clin. Psychiatry **59**(Suppl 20), 22–33 (1998)
114. Spencer, T.J., Biederman, J., Mick, E.: Attention-deficit/hyperactivity disorder: diagnosis, lifespan, comorbidities, and neurobiology. J. Pediatr. Psychol. **32**(6), 631–642 (2007)

115. Thaler, R.H.: Mental accounting matters. J. Behav. Decis. Mak. **12**(3), 183–206 (1999)
116. Thompson, A.L., Molina, B.S., Pelham, W., Gnagy, E.M.: Risky driving in adolescents and young adults with childhood ADHD. J. Pediatr. Psychol. **32**(7), 745–759 (2007)
117. Tversky, A., Kahneman, D.: Prospect theory: cumulative representation of uncertainty. J. Risk Certain. **4**(5), 297–324 (1992)
118. van Hoesen, G., Morecraft, R., Vogt, B.: Connections of the monkey cingulate cortex. In: Neurobiology of Cingulate Cortex and Limbic Thalamus: A Comprehensive Handbook. Birkhauser, Boston (1993)
119. Van der Veen, F., Sahibdin, P.: Dissociation between medial frontal negativity and cardiac responses in the ultimatum game: effects of offer size and fairness. Cogn. Affect. Behav. Neurosci. **11**, 516–525 (2011)
120. von Neumann, J., Morgenstern, O.: Theory of Games and Economic Behavior. Princeton University Press, Princeton (1944)
121. Villa, A.E.P., Missonnier, P., Lintas, A.: Neuroheuristics of decision making: from neuronal activity to EEG. In: Guy, T.V., Kárný, M., Wolpert, D.H. (eds.) Decision Making with Imperfect Decision Makers, Intelligent Systems Reference Library, pp. 159–194. Springer, Berlin (2012)
122. Weafer, J., Milich, R., Fillmore, M.T.: Behavioral components of impulsivity predict alcohol consumption in adults with ADHD and healthy controls. Drug Alcohol Depend. **113**(2), 139–146 (2011)
123. Weber, E.U., Blais, A.R., Betz, N.E.: A domain-specific risk-attitude scale: measuring risk perceptions and risk behaviors. J. Behav. Decis. Mak. **15**(4), 263–290 (2002)
124. Weber, E.U., Johnson, E.J.: Mindful judgment and decision making. Annu. Rev. Psychol. **60**, 53–85 (2009)
125. Weller, J.A., Thulin, E.W.: Do honest people take fewer risks? personality correlates of risk-taking to achieve gains and avoid losses in HEXACO space. Personal. Individ. Differ. **53**(7), 923–926 (2012)
126. Weller, J.A., Tikir, A.: Predicting domain-specific risk taking with the HEXACO personality structure. J. Behav. Decis. Mak. **24**(2), 180–201 (2011)
127. Willcutt, E.G., Doyle, A.E., Nigg, J.T., Faraone, S.V., Pennington, B.F.: Validity of the executive function theory of attention-deficit/hyperactivity disorder: a meta-analytic review. Biol. Psychiatry **57**(11), 1336–1346 (2005)
128. World Medical Association: World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. JAMA 284(23), 3043–3045 (2000)
129. Wu, Y., Hu, J., van Dijk, E., Leliveld, M.C., Zhou, X.: Brain activity in fairness consideration during asset distribution: does the initial ownership play a role? PLoS One **7**(6), e0039,627 (2012)
130. Wu, Y., Zhou, X.: The P300 and reward valence, magnitude, and expectancy in outcome evaluation. Brain Res. **1286**, 114–122 (2009)
131. Wu, Y., Zhou, Y., van Dijk, E., Leliveld, M.C., Zhou, X.: Social comparison affects brain responses to fairness in asset division: an ERP study with the ultimatum game. Front. Hum. Neurosci. **5**, 131 (2011)
132. Xue, G., Lu, Z., Levin, I.P., Bechara, A.: The impact of prior risk experiences on subsequent risky decision-making: the role of the insula. Neuroimage **50**(2), 709–716 (2010)
133. Yang, J., Li, H., Zhang, Y., Qiu, J., Zhang, Q.: The neural basis of risky decision-making in a blackjack task. NeuroReport **18**(14), 1507–1510 (2007)
134. Yang, J., Zhang, Q.: Electrophysiological correlates of decision-making in high-risk versus low-risk conditions of a gambling game. Psychophysiology **48**(10), 1456–1461 (2011)