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Does working memory training affect decision making ? : a neuroeconomic study

SARAH MESROBIAN K.

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DOES WORKING MEMORY TRAINING AFFECT DECISION MAKING ? A NEUROECONOMIC STUDY

Thèse de doctorat en Neurosciences

présentée à la

Faculté de Biologie et de Médecine
de l'Université de Lausanne

par

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Abstract

We all make decisions of varying levels of importance every day. Because making a decision implies that there are alternative choices to be considered, almost all decision involves some conflicts or dissatisfaction. Traditional economic models esteem that a person must weight the positive and negative outcomes of each option, and based on all these inferences, determines which option is the best for that particular situation. However, individuals rather act as *irrational* agents and tend to deviate from these rational choices. They somewhat evaluate the outcomes' subjective value, namely, when they face a risky choice leading to losses, people are inclined to have some preference for risk over certainty, while when facing a risky choice leading to gains, people often avoid to take risks and choose the most certain option. Yet, it is assumed that decision making is balanced between deliberative and emotional components. Distinct neural regions underpin these factors: the deliberative pathway that corresponds to executive functions, implies the activation of the prefrontal cortex, while the emotional pathway tends to activate the limbic system. These circuits appear to be altered in individuals with ADHD, and result, amongst others, in impaired decision making capacities. Their impulsive and inattentive behaviors are likely to be the cause of their irrational attitude towards risk taking. Still, a possible solution is to administrate these individuals a drug treatment, with the knowledge that it might have several side effects. However, an alternative treatment that relies on cognitive rehabilitation might be appropriate.

This project was therefore aimed at investigate whether an intensive working memory training could have a spillover effect on decision making in adults with ADHD and in age-matched healthy controls. We designed a decision making task where the participants had to select an amount to gamble with the chance of 1/3 to win four times the chosen amount, while in the other cases they could loose their investment. Their performances were recorded using electroencephalography prior and after a one-month Dual N-Back training and the possible near and far transfer effects were investigated.

Overall, we found that the performance during the gambling task was modulated by personality factors and by the importance of the symptoms at the pretest session. At posttest, we found that all individuals demonstrated an improvement on the Dual N-Back and on similar untrained dimensions. In addition, we discovered that not only the adults with ADHD showed a stable decrease of the symptomatology, as evaluated by the CAARS inventory, but this reduction was also detected in the control samples. In addition, Event-Related Potential (ERP) data are in favor of an change within prefrontal and parietal cortices.

These results suggest that cognitive remediation can be effective in adults with ADHD, and in healthy controls. An important complement of this work would be the examination of the data in regard to the attentional networks, which could empower the fact that complex programs covering the remediation of several executive functions' dimensions is not required, a unique working memory training can be sufficient.

Résumé

Nous prenons tous chaque jour des décisions ayant des niveaux d'importance variables. Toutes les décisions ont une composante conflictuelle et d'insatisfaction, car prendre une décision implique qu'il y ait des choix alternatifs à considérer. Les modèles économiques traditionnels estiment qu'une personne doit peser les conséquences positives et négatives de chaque option et en se basant sur ces inférences, détermine quelle option est la meilleure dans une situation particulière. Cependant, les individus peuvent dévier de ces choix rationnels. Ils évaluent plutôt les valeur subjective des résultats, c'est-à-dire que lorsqu'ils sont face à un choix risqué pouvant les mener à des pertes, les gens ont tendance à avoir des préférences pour le risque à la place de la certitude, tandis que lorsqu'ils sont face à un choix risqué pouvant les conduire à un gain, ils évitent de prendre des risques et choisissent l'option la plus sûre. De nos jours, il est considéré que la prise de décision est balancée entre des composantes délibératives et émotionnelles. Ces facteurs sont sous-tendus par des régions neurales distinctes: le chemin délibératif, correspondant aux fonctions exécutives, implique l'activation du cortex préfrontal, tandis que le chemin émotionnel active le système limbique. Ces circuits semblent être dysfonctionnels chez les individus ayant un TDAH, et résulte, entre autres, en des capacités de prise de décision altérées. Leurs comportements impulsifs et inattentifs sont probablement la cause de ces attitudes irrationnelles face au risque. Cependant, une solution possible est de leur administrer un traitement médicamenteux, en prenant en compte les potentiels effets secondaires. Un traitement alternatif se reposant sur une réhabilitation cognitive pourrait être appropriée.

Le but de ce projet est donc de déterminer si un entrainement intensif de la mémoire de travail peut avoir un effet sur la prise de décision chez des adultes ayant un TDAH et chez des contrôles sains du même âge. Nous avons conçu une tâche de prise de décision dans laquelle les participants devaient sélectionner un montant à jouer en ayant une chance sur trois de gagner quatre fois le montant choisi, alors que dans l'autre cas, ils pouvaient perdre leur investissement. Leurs performances ont été enregistrées en utilisant l'électroencéphalographie avant et après un entrainement d'un mois au Dual N-Back, et nous avons étudié les possibles effets de transfert.

Dans l'ensemble, nous avons trouvé au pré-test que les performances au cours du jeu d'argent étaient modulées par les facteurs de personnalité, et par le degré des symptômes. Au post-test, nous avons non seulement trouvé que les adultes ayant un TDAH montraient une diminutions stable des symptômes, qui étaient évalués par le questionnaire du CAARS, mais que cette réduction était également perçue dans l'échantillon des contrôles. Les rsultats expérimentaux mesurés à l'aide de l'éléctroencéphalographie suggèrent un changement dans les cortex préfrontaux et pariétaux.

Ces résultats suggèrent que la remédiation cognitive est efficace chez les adultes ayant un TDAH, mais produit aussi un effet chez les contrôles sains. Un complément important de ce travail pourrait examiner les données sur l'attention, qui pourraient renforcer l'ide qu'il n'est pas nécessaire d'utiliser des programmes complexes englobant la remédiation de plusieurs dimensions des fonctions exécutives, un simple entraiment de la mémoire de travail devrait suffire.

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Acronyms

TotG Total Gains. 37, 44, 49

ADHD Attention Deficit Hyperactive Disorder. 15, 16, 18–28, 39–42, 44, 47, 49–64, 175

ANT Attentional Network Test. 30, 33, 63

ASRS Adult ADHD Self-Report Scale. 27, 28, 41, 44, 47, 57

BART Balloon Analogue Risk Taking Task. 12, 25, 49, 58

CAARS-S:SV Conners Adult ADHD Rating Scales. 28, 44, 49–51, 60, 62

CBS Current Behavior Scale. 28

CGT Cambridge Gambling Task. 12

CNV Contingent Negative Variation. 8, 21, 23, 39, 52, 53, 62

dlPFC Dorsolateral Prefrontal Cortex. 13, 14, 19, 22, 23, 25

EEG Electroencephalography. 5, 6, 29–31, 34, 37, 61

EHI Edinburg Handedness Inventory. 29, 31

ERP Event-Related Potential. 6, 7, 21, 23, 24, 37, 39, 40, 52, 53, 55, 61

fMRI functional Magnetic Resonance Imaging. 4, 5

FRN Feedback Related Negativity. 8, 9, 39

GDT Game of Dice Task. 12, 49

HF high frequency feedback. 32, 37, 38, 51, 53, 54, 64

ICA Independent Component Analysis. 37

IGT Iowa Gambling Task. 11, 12, 24, 25, 49

LC–NE Locus Coeruleus Norepinephrine System. 9

LF low frequency feedback. 32, 37, 38, 44, 51, 53, 54, 64

LPP Late Positive Potential. 8, 21, 39

MINI Mini-International Neuropsychiatric Interview. 29, 31, 194

MLA Myopic Loss Aversion. 51

MMN Mismatch Negativity. 7, 21

MPH Methylphenidate. 20, 21, 24, 41, 42, 44, 47

NHRG NeuroHeuristic Research Group. ii

OFC Orbitofrontal Cortex. 13–15, 19

PET Positron Emission Tomography. 4, 25

PGT Probabilistic Gambling Task. 29, 31, 32, 37, 40, 44, 49–53, 58, 60, 61, 64

RI Global Risk Index. 37, 49

SEU Subjective Utility Theory. 51

TMS Transcranial Magnetic Stimulation. 5

vmPFC Ventromedial Prefrontal Cortex. 11, 14, 25

WM Working Memory. 22, 55, 56, 58, 59, 63

WMT Working Memory Training. 28, 41, 44, 55, 56, 58, 59, 63

1 Introduction

Human behavior is determined by the interaction of several internal and external bodily factors. The why and how of the behavior can therefore be complex. The animals have only involuntary reflexes subject to the laws of nature, but man can execute behavior on a voluntary basis. Decision making is a talent being tested everyday, that each individual faces consciously or unconsciously. But what is decision making? It can be defined as the process of making choices among possible alternatives, with varying levels of risk. Several areas have started to study this phenomenon, including economics, psychology and neurosciences and gave rise to the new research field called neuroeconomics.

1.1 Psychological concepts

In the early 20th century, when psychology has tried to establish itself as an independent discipline, Behaviorism was a school of thought that was influenced by Darwin. It was solely based on the observation of the behavior and on the conditions in which it takes place. The unobservable processes happened in a "black box" and did not constitute an object of research. During the 30s and 40s, the rational approach came back in a more modern form. The observation of laboratory rats allowed to demonstrate that there was not only learned responses, but also new answers. It was therefore necessary to understand how an organism perceives its environment.

Classical and operant conditioning

Classical conditioning is a form of learning that combines several types of stimuli, to induce a reflex response which is not naturally induced. This concept was experimented by Pavlov, by teaching his dog to associate the sound of a bell, the neutral stimulus, with food, the unconditional stimulus, resulting the salivation, the unconditional reaction. By presenting regularly some food while the bell was ringing, the dog learned to associate the bell sound to the fact that he would be fed, thus evoking the salivation. The neutral stimuli became a conditioned stimulus, and the unconditioned reaction became a conditional response. Once an organism has learned to associate a conditioned stimulus to an unconditioned stimulus, it can also respond to similar type of stimuli (Pavlov and Anrep, 2003; Watson and Rayner, 1920).

Skinner later introduced the term of operant conditioning. The main idea is that all behaviors are determined by their consequences, that can either be positive, like a reward, or negative, such as a penalty. Behavioral responses are thought to precede environmental events that produce the future behavior. Reinforcements can either be positive (the presentation of the stimulus increases the probability to have a behavior) or negative (the elimination of the stimulus increases the probability to have a behavior) (Skinner, 1938).

Behavioral activation and inhibition systems

Gray proposed a biopsychological theory of personality in 1970 based on extensive animal research. Gray's theory was based on the existence of three independent but interacting systems that underlie behaviors: the activation and inhibition behavioral systems (*BAS* and *BIS* respectively), and the fight-flight-freezing system (*FFFS*). The BAS system is activated by signals of reward or withdrawal of a punishment, and is thought to be responsible for approach behaviors. The BIS system is responsible for the interruption of a ordinary behavior, and is activated when there are some conflicting goals, which causes an anxious response. The FFFS is activated by potential punishment signals and is responsible for the leakage behavior. Generally, the BAS would be associated with positive affect, BIS to anxiety states, and FFFS with negative emotions (Corr, 2002, 2004; Gray, 1970; Gray and McNaughton, 2003).

Executive functions

There is no consensus on the executive functions' definition, but their common feature defines a list of skills allowing individuals to adapt their behavior to their environment. All of them are related to a hierarchical system handling and executing high-level cognitive processes, localized within the frontal lobes. According to Luria, there are four phases: an initial data analysis, the development of a program to arrange and organize the various steps necessary for the realization of the task, the execution of the program and finally the comparison of the result with the initial data (Luria, 1966). The model of Stuss (1992) covers specific functions such as anticipation, selection of goals, the formulation of plans, evaluation and control of behavior, attentional functions such as selectivity and persistence. This illustrates the role management and regulation of behavior. The Shallice's supervisor attentional model distinguishes three different levels of action's control, there are two automatic levels and one supervisory attentional system located in the prefrontal lobes. The first level is used for controlling the action through automated schematics units. The second level, "contention scheduling" is the conflict manager: it is automatically activated when two schemes that do not require attentional resources are activated at the same time. Finally, the supervisory attentional system intervenes when the other two levels are exceeded, in a new situation which can not be resolved by automatisms (Shallice, 1982). Baddeley's model of working memory is composed of three slave systems and a coordination system. The first three components are the phonological loop, head of verbal information, the visuospatial sketchpad, responsible for visual information and episodic buffer, responsible for retrieving information allowing the consolidation to long term memory. These three systems operate in a loop within working memory, in order to supply informations to the Central Executive. The Central Executive is the central component that coordinates the slave systems and keeps the information available. It is the equivalent of the supervisory attentional system of Norman Shallice's model (Baddeley, 1992, 2000). Together, these models have listed the abilities allowing the brain to adapt to non-routine situations, namely, planning, attention, anticipation, working memory, inhibition, and mental flexibility, skills that appear to be fundamental components involved in decision making processes (Del Missier et al., 2012).

Emotions

> *"Everyone knows what an emotion is, until asked to give a definition. Then, it seems, no one knows"* (Fehr and Russell, 1984).

One proposition of definition has been advanced by Scherer (2005):

> *Emotion is defined as an episode of interrelated, synchronized changes in the states of all or most of the five organismic subsystems in response to the evaluation of an external or internal stimulus event as relevant to major concerns of the organism. The components of an emotion episode are the respective states of the five subsystems and the process consists of the coordinated changes over time.*

Historically, many theories have been advanced trying to understand the manner by which emotions were processed. William James is an American philosopher and psychologist, who is considered as the father of experimental psychology. His theory postulates that the emotions are triggered by the perception of bodily changes using a specific peripheral pattern of activation. The process would be as follows: first, the individual perceives the event, then all the body modifications arise, and only after these changes the emotion is identified. The revolution of his theory is that the bodily changes are necessary and precede emotions (James, 1884).

This theory was criticized by Walter Cannon, an American physiologist, founder of the concept of homeostasis, by saying that if the emotions were generated by the perception of bodily changes, then they should be totally dependent on the integrity of the sensory cortex. Following experiments on animals, he discovered that emotional behavior was not impaired when the viscera were disconnected from the brain, and thus argued that the source of the emotion should be in the central nervous system, rather than in the viscera (Cannon, 1931).

In 1937, the anatomist James Papez proposed one of the most influential theories on the cerebral substrate of emotions. He suggested that a brain circuit was involved in emotional processing. This circuit was revolutionary and would connect the hypothalamus to the medial cortex. The main idea was that when an emotional stimulus arise, it is sent to a very important first relay, the thalamus. Then, there are two possible pathways, the normal route through the sensory cortex and then the expressway, which is directly linked to the hypothalamus, giving rise to an emotional response (Papez, 1937).

Finally, the somatic markers hypothesis postulated by Damasio is certainly the one that has the most inspired researchers. Everything started with the story of Phineas Gage, the most famous case studied in neuropsychology. He worked as a foreman for a railway construction company during the mid-19th century. One day, an explosion was triggered due to mishandling of dynamite, and projected an iron bar which pierced his skull, causing a lesion to the prefrontal cortex. He did not die after the accident, and was treated for several months. Although there was no sign of neurological impairment, his relatives noticed a drastic change in his behavior. He was moody, sometimes coarse, unstable and capricious. His social status changed, resulting in a chaotic professional career. He died 13 years later, after a series of severe seizures. The history of this clinical case has triggered the beginning of the somatic marker hypothesis (Damasio, 2010). The somatic marker hypothesis postulates that the prefrontal cortex is responsible for the creation of neurobiological markers. These markers are the result of an association between life events and emotional states and feelings, stored in memory in order to be consciously or unconsciously reactivated when required, for instance when an individual has to make a decision. The use of somatic markers allows individuals to automatically reject certain negative values and to give priority to other positive values, by reducing the number of alternatives for the decision. Structures such as the amygdala and the ventromedial prefrontal cortex appear to be fundamental components of somatic markers model. Damasio's assumption was therefore that inappropriate behaviors came from an inability to recall somatic states previously associated with similar social situations (Bechara and Damasio, 2005; Damasio, 1996). This theory was powered by the observation of clinical cases having the same lesions than Phineas Gage, localized within the ventral and medial parts of the prefrontal cortex. Surprisingly, the intellectual capacities of such patients were not affected, but their ability to make rational decisions regarding social or personal aspects were totally disrupted, usually leading them to financial bankrupt and social isolation.

1.1.1 Experimental methods

Functional magnetic resonance imaging

The functional Magnetic Resonance Imaging (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. 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 generates an image and the changes in their distribution as a function of an external event generate 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 (Belliveau et al., 1991; Ogawa et al., 1990).

Positron Emission Tomography

Brain activity can also be measured with thePositron Emission Tomography (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) (Basdevant and Rich, 2005), 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 radiolabeling 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 (Nutt, 2002; Pichler et al., 2008).

Transcranial magnetic stimulation

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 (Currá et al., 2002). The principle of this technique is to use electromagnetic induction to induce weak electric currents in the brain using a rapidly changing magnetic field (Polson et al., 1982). 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, paired pulses or repetitive pulses at specific frequencies may provoke very different effects when applied to the same cortical area (Fitzgerald et al., 2006).

Despite the remarkable advances brought by the advent of imaging techniques related to nuclear medicine, Electroencephalography (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.

1.2 Event-Related Potentials

The brain is the site of a spontaneous electrical activity generated by nerve cells, giving rise to fluctuations in electrical potential that can be recorded on the scalp as a difference between a reference electrode and a measuring electrode. The recorded signals are characterized by waves, which are the result of the summation of postsynaptic action potentials synchronized from a large number of neurons. An electrode does not measures the activity of neurons located directly below it, it rather represents the sum of all neural activations within the head, as demonstrated by the paper of Cobb and Sears (1960), which reports one of the most impressive demonstration of volume conduction phenomenon. Four patients with hemispherectomy were studied. Their hemicranial cavities were half-filled with air and their heads were positioned so that either air on cerebrospinal fluid was under the target electrode. The potentials over air were higher than over cerebrospinal fluid, demonstrating that superimposition of signals are produced everywhere in the brain (Fabiani et al., 2000; Luck, 2005).

It is possible to extract so-called Event-Related Potential (ERP) from EEG signals. They represent the changes in electrical potential produced by the nervous system in response to sensory and motor stimuli, but also to internal cognitive time-locked events. Compared to EEG signal, ERPs have a low intensity and are superimposed on the spontaneous EEG activity, which is much larger in amplitude. Therefore, to extract the event-related responses, it is necessary to use an averaging technique, in order to increase the signal to noise ratio, thus removing the background noise to keep the stimulation specificities. Traditionally, a distinction has been made between exogenous and endogenous components. Exogenous components are always obtained with an external sensory or motor stimulation, they vary depending on the physical characteristics of a stimulus and tend to be observed early after stimulus onset. Endogenous components tend to be observed later following an internal stimulation, and vary depending on different aspects of cognitive processing. ERPs are usually called after their polarity and peaking latency, for instance P300 or P3 means that the wave is positive, and is peaking around 300 milliseconds (Fabiani et al., 2000; Ibanez et al., 2012b; Luck, 2005). An illustration of the major ERP component is provided in Figure 1.

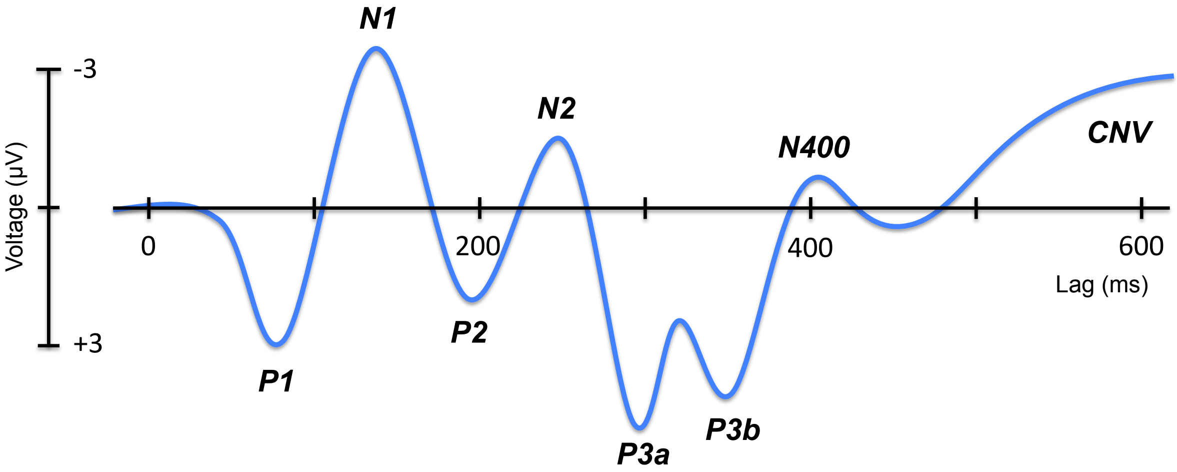

Figure 1: Representation of the main Event-Related Potentials with lag.

1.2.1 Main Event-Related Potentials components

P1, N1 and P2

P1 is a positive component typically onsets at around 60–90 ms following the stimulus presentation in the lateral occipital cortex. It has generally been reported to reflect exogenous sensory responses elicited by visual stimulation, however, P1 can be responsive to internal factors such as attention (Koivisto and Revonsuo, 2010; Luck and Ford, 1998; Luck, 2005). N1 usually peaks between 100–200 ms post-onset on posterior sites. Two subcomponent have been identified, the first one is thought to be generated by the occipital cortex in response to discrimination process, while the second one is rather sensitive to spatial attention when arising from the parietal cortex (Koivisto and Revonsuo, 2010; Luck and Ford, 1998; Luck, 2005). The N1 wave is followed by P2, a positive component peaking at around 200 ms following the stimulus presentation. Within the anterior sites, P2 has been linked to selective attention and to stimulus frequency (Ibanez et al., 2012b; Luck, 2005).

N2

N2 is a negative wave usually peaking in between 180–320 ms that has been divided into 3 main subcomponents. The first subcomponent has been labeled N2a or Mismatch Negativity (MMN), because of its sensitivity to novelty or mismatch in the auditory modality, with higher amplitudes following unfrequent stimulation. The "classical" N2, sometimes called N2b, has a more anterior distribution. It has consistently been reported to be associated to cognitive control processes, and is thought to be an index of response conflict, because of its sensitivity to stimulus' probability. N2b is larger in response to nontarget compared to target, even if it is elicited by both types of stimuli in visual and auditory modalities. The last subcomponent, the N2c, has a more posterior distribution for the visual modality, and a more frontocentral distribution for the auditory stimuli. This component has been linked to attentional processes, because it requires a conscious attention. It is generally larger for target stimuli compared to nontargets, and its latency varies with reaction time (Donkers and van Boxtel, 2004; Folstein and Van Petten, 2008; Ibanez et al., 2012b; Luck, 2005; Patel and Azzam, 2005).

P3

P3 is a positive ongoing ERP, peaking at around 250–600 ms post-stimulus presentation and can be divided into two subcomponents: the P3a and the P3b. P3a is thought to reflect attentional load, because its amplitude can be modulated by the amount of attentional resources engaged in the task performance and processing of novel stimuli. It is generally larger on frontal sites and appear to peak between 250–280 ms and its amplitude has been reported to be enhanced in response to novel stimuli, but habituates rapidly when the stimuli are repeated. P3b, or classical P3 component has been associated to active attention and working memory processes, because of its responsiveness to stimulus probability, with enhanced amplitude following rare stimuli, and to workload capacity. P3b is maximal on posterior sites and tends to peak approximately 100 ms after P3a (Ibanez et al., 2012b; Luck, 2005; Mennes et al., 2008; Nieuwenhuis et al., 2005a; Patel and Azzam, 2005; Polich, 2007; Pontifex et al., 2009; Squires et al., 1975).

N400

The N400 is a positive ERP wave typically evoked near 400 ms post stimulus. It has been widely linked to language processing in both visual and auditory modalities, with greater amplitudes for semantic violation over left temporal lobe. It is also possible to elicit a N400 following meaningful stimuli containing non-verbal informations. Syntactic violations however, are more likely to evoke a P600 potential, having the same sensitivity as the N400 (Fabiani et al., 2000; Kutas and Federmeier, 2011; Luck, 2005).

Late Positive Potential and Contingent Negative Variation

The Late Positive Potential (LPP) is a component arising approximately from 300 to 400 ms following onset. It has been detected in various experimental designs in association with the processing of affective content. The amplitude of the LPP has been reported to be larger for positive and negative stimuli compared to neutral, and has been linked to structures associated with visual and emotional processing (Dennis and Hajcak, 2009; Schupp et al., 2004; Singhal et al., 2012; Weinberg and Hajcak, 2010). The Contingent Negative Variation (CNV) is a slow negative wave occurring in between two stimuli, a first warning stimulus and a second imperative stimulus, appearing after about 30 trials. It has been linked to the motor preparation to the upcoming target, and is generally larger on central and frontal areas (Fabiani et al., 2000; Luck, 2005; Tecce, 1972).

1.2.2 Event-Related Potentials in decision making

The processes of decision making have been shelled in terms of milliseconds, thereby providing important and complementary information to the data provided by brain imaging. Many studies have focused on the mechanisms underlying outcome evaluation and reward processing and several components have been identified. The most important one are the Feedback Related Negativity (FRN), and the P3 (San Martín, 2012).

The FRN is a negative component peaking at around 250 ms following the presentation of the outcome and is generated by the anterior cingulate cortex (Miltner et al., 1997; Nieuwenhuis et al., 2005b). Several studies reported an effect of valence, with an enhanced amplitude evoked by negative feedback, in comparison to positive outcomes in paradigms involving monetary and non monetary rewards (Cui et al., 2013; Luque et al., 2012; Polezzi et al., 2010; Sato et al., 2005; Wu and Zhou, 2009; Yeung and Sanfey, 2004; Yu and Zhou, 2009; Yu et al., 2011). Contradictory results were found in regard to outcome magnitude. Some researches have failed to detect an effect, (Cui et al., 2013; Polezzi et al., 2010; Sato et al., 2005; Yeung and Sanfey, 2004), another study perceived an more negative wave for larger outcomes (Yu and Zhou, 2009), and another one reported the opposite pattern (Wu and Zhou, 2009). Moreover, not only the violation of the expected reward magnitude has been found to provoke a greater FRN when the outcomes were not expected, compared with expected rewards (Wu and Zhou, 2009), but also reward probability (Yu et al., 2011). These difference could have been caused by the method employed to measure the wave (San Martín, 2012; Wu and Zhou, 2009). Together these findings are aligned with the reinforcement learning theory, a learning technique borrowed to machine learning discipline, explaining how individuals learn while interacting with their environment. The foundations of this technique are based on actions: by using the trial and error method, individuals are able to optimize their behavior and choices (Sutton, 1988; Sutton and Barto, 1998). According to this theory, FRN would be a reflection of the prediction error, indicating the response of the anterior cingulate cortex (Cohen and Ranganath, 2007; Sallet et al., 2013). Learning would be encoded by the phasic activity of dopamine neurons via the basal ganglia and frontal cortex. These neurons are believed to signal to the individual the magnitude of the error between its estimate of current and future value (prediction error) (Glimcher, 2011), and the anterior cingulate cortex would be a kind of filter used to select the response in accordance with the signal sent by dopamine neurons, and in some way learns how to have a better efficiency. Yet, available data indicate that the anterior cingulate cortex is modulated by impact of dopamine, therefore modifying the amplitude of the FRN, a phasic decrease of dopamine is associated with an enhancement of FRN, while a phasic increase is associated with a FRN reduction (San Martín, 2012).

In the decision making area, P3 has been considered to be generated by the temporal parietal junction following the examination of patients with lesions of this region showing great reduction of the P3 (Nieuwenhuis et al., 2005a; Robertson et al., 1988; Verleger et al., 1994). Unlike the FRN, the P3 seems to be responsive to the magnitude of the outcome. This assumption has been demonstrated several times as illustrated in many research papers. Overall, the results of these studies indicate that the P3 becomes gradually wider as the outcome magnitude increases (Bellebaum et al., 2010; Cui et al., 2013; Goyer et al., 2008; Gu et al., 2011; Polezzi et al., 2010; Sato et al., 2005; Wu and Zhou, 2009). The responsiveness of the P3 to the outcome valence did not obtain an unanimous support. Although some reports associate a valence effect to the P3, (Bellebaum et al., 2010; Cui et al., 2013; Li et al., 2010a; Polezzi et al., 2010; Sallet et al., 2013), others could not perceive any effect (Sato et al., 2005; Yeung and Sanfey, 2004). Nieuwenhuis et al. (2005a) speculated that the P3 was modulated by the activity of the Locus Coeruleus Norepinephrine System (LC–NE). The main source of norepinephrine is the locus coeruleus within the neocortex, and it innervates the prefrontal and parietal cortex (Morrison and Foote, 1986). Physiological recordings have delivered data highlighting two types of activity of these neurons, a phasic activity and a tonic activity (Aston-Jones and Cohen, 2005). The assumption linking the P3 to this system is supported by the fact that the phasic activity of norepinephrine neurons discharge at the same latencies as the P3. In addition, both the P3 and the LC–NE seem to respond to similar events, particularly to the valence of stimuli and probability of occurrence (Aston-Jones and Cohen, 2005; Nieuwenhuis et al., 2005a; San Martín, 2012). Thus the modulation of the P3 would be expressed be the LC–NE phasic activity involved in the outcome evaluation and decision making processes.

1.3 Decision neuroscience

The term of neuroeconomics appeared for the first time in a book written by Paul W. Glimcher in the early 2000s, titled *Decisions, Uncertainty, and the Brain: The Science of Neuroeconomics* (Glimcher, 2004). Today neuroeconomics shows a growing scientific interest, particularly since the psychologist Daniel Kahneman was awarded with the Nobel Prize in Economics in 2002.

Around the world, universities have developed multidisciplinary research laboratories and included this discipline in economics or in neuroscience programs. Neuroeconomics encompasses a broad variety of research areas, but is particularly interested in the study of decision making in contexts of risk.

1.3.1 Behavioral economics

Traditional economics models assume that risk taking is the result of individuals' ability to think as rational agents (Thaler, 2000). Work derived from behavioral economics are based on the principle that individuals have preferences on probabilities. When they are confronted with a choice, they calculate each option's (x) "Utility", measuring its welfare or degree of satisfaction, and its associated probability (p) in order to select the option that has the greatest yield, called "expected value" ($EV_{(x)}$), expressed by the following formula (1) (Von Neumann and Morgenstern, 1944):

$$EV_{(x)} = \sum p_{(x)} \times x \tag{1}$$

Four axioms were derived from this rational perspective: completeness (equation (2)), transitivity (equation (3)), independence (equation (4)), and continuity (equation (5)):

1. *Completeness* assumes that an individual can establish a preference between two lotteries.

$$\text{Either } A \geq B \text{ or } A \leq B \tag{2}$$

2. *Transitivity* assumes that preferences are transitive.

$$\text{If } A \geq B \text{ and } B \geq C, \text{ then } A \geq C \tag{3}$$

3. *Independence* assumes that two gambles mixed with a third one maintain the same preference order as when the two are presented independently of the third one.

$$\text{If } A > B, \text{ then for any number n } \in [0,1] \text{ and any lottery C, } nA+(1-n)C \geq B+(1-n)C \tag{4}$$

4. *Continuity* assumes that when there are three lotteries and if the individual prefers A to B and B to C, then there should be a possible combination of A and C in which the individual is then indifferent between this mix and the lottery B.

$$\text{If } A > B, \text{ then for some number n } \in [0,1]; nA + (1-n)B \geq B \tag{5}$$

However, a choice is not solely based on reward or on probabilities, it is also a reflection of the attitude of the individual towards risk. Under conditions of uncertainty, people rather tend to avoid risky choices in favor of safer options, phenomenon called “risk aversion”, which decreases according to the increase in wealth (Bernoulli, 1954). This fundamental concept of risk aversion was illustrated by the famous St Petersburg paradox, which has given evidence that making a choice over another is more likely to be linked to its consequences rather than to its underlying probabilities. This paradox is illustrated by a heads or tails game. Originally, the start amount is fixed at 2 *ducats* and the coin is tossed. If head appears, the player wins 2 ducats and the game is stopped. Otherwise, the coin is relaunched, as long as the coin lands on tails. Mathematically, the problem is exposed as follows (equation (6)):

$$EV(X) = (0.5 * 2) + (0.25 * 4) + (0.125 * 8) + etc. \tag{6}$$

Although this model provides a simple and rational framework, it is not representative of decisions made in the real world. In fact, a growing literature has shown that, in many situations and under some conditions, the human violates the rationality and risk preferences assumptions (Allais, 1953; Camerer and Fehr, 2006; Tversky and Kahneman, 1981). When facing a risky choice leading to losses, people rather adopt a “risk seeking” behavior, while when facing a risky choice leading to gains, people rather adopt a “risk averse” behavior, meaning that individuals’ chances of success are rather evaluated by the outcomes’ subjective values in terms of gains or losses over certainty (Kahneman and Tversky, 1979, 1984).

1.3.2 Neuropsychology

The IIowa Gambling Task (IGT) was developed to understand the mechanisms linking emotional deficits to decision making in real life context exhibited by patients with prefrontal lesions. In this task, participants are asked to maximize their gains by selecting a card among four decks. Each deck is associated with various levels of rewards and and penalties. Over the game, participants should learn that some decks, the “good decks”, provide smaller gains and lower penalties, leading to a final gain, while others, the “bad decks”, are characterized by larger gains, but even higher penalties, resulting in a final loss. The main results of those experiments showed that individuals having ventromedial prefrontal lobe lesions systematically choose the disadvantageous decks favoring immediate reward options, but finalizing in a loss of total earnings in long term. Those results indicate that these patients are insensitive to future consequences (Bechara et al., 1994). Another candidate brain region seems to be part of the network. Using the same task, patients with amygdala lesion demonstrated similar impairments by persistently selecting the most unfavorable options. In addition, the lack of anticipatory physiological responses, allowed the group of Damasio to demonstrate that amygdala is a key structure involved in the activation of somatic markers. (Bechara et al., 1999; Damasio, 2010). Nevertheless, both areas seem to have distinct function: the amygdala is involved in the recognition and evaluation of the emotional valence of sensory stimuli, thus its injury prevents the individual to assign affective states to stimuli (Zald, 2003), while the Ventromedial Prefrontal Cortex (vmPFC) is more related to the information’s integration of the somatic state. A recent meta-analysis reviewed the findings linking the IGT with regard to executive functions. The results indicated that the performance in the gambling task seem to be dissociated from impulsivity set shifting, working memory and intelligence (Toplak et al., 2010). It is important to notice that this task was originally aimed at assessing "myopia for the future" in patients showing similar lesions than Phineas Gage, thus it may not be the best task to evaluate a link between cognitive abilities and decision making.

A recent study designed to investigate how individual differences might influence decision making competence found that the capacity to have consistent judgements towards risky events was linked to higher shifting capacities, while the ability to apply decision rules was associated with higher capacities to inhibit interfering or irrelevant information. (Del Missier et al., 2010). In a latter study, the same group argued that various executive components were indeed associated to some aspects of decision making, but decision making competence might also depend on other cognitive and non-cognitive abilities (Del Missier et al., 2012). In line with these results, more recent theories have proposed a new approach that involves a dual model of decision making reflecting a dissociation between so called "hot components", from the "cold components". The hot system corresponds to a more automatic emotional processing, while the cold system reflects more deliberative decisions, and involves executive functions (Figner et al., 2009; Metcalfe and Mischel, 1999; Krain et al., 2006; Phelps et al., 2014).

The IGT became a reference tool assessing decision making in populations with mental disorders such as schizophrenia, attention deficit hyperactive disorder, addiction to substances, pathological gambling, mood or anxiety disorders, personality disorders, etc (Li et al., 2010b). Since then, several other paradigms have been developed, such as the Cambridge Gambling Task (CGT), (Rogers et al., 1999), the Game of Dice Task (GDT) (Brand et al., 2005), and the Balloon Analogue Risk Taking Task (Lejuez et al., 2002). The CGT measures risk taking in a gambling situation. Participants have to guess where is located a yellow token hidden behind a row of 10 boxes divided into an unbalanced number of red and blue boxes, that change at each trial. In the gambling stages, participants have the possibility to select an amount of points to bet on the gamble, reflecting their judgement confidence in the gamble. If they find the right color, the amount is added to their saving, but if they choose the wrong color, the amount is subtracted. The aim of the game is to accumulate as many points as possible. The GDT was designed to assess the influence of executive functions on decision making in a gambling situation. In this game, participants are asked to increase their capital by throwing a die. At each trial, participants have to bet on the number that will occur in the next throw. They have the possibility to select from one to four numbers prior to the throw, however, wins and losses are adjusted to the outcome probability of the combination selected, meaning that selecting one die results in larger wins, but also higher levels of risk taking than the other combinations. If the selected number coincides with the outcome, the participant earns some money, whereas if the trial is unsuccessful, he will loose some money. The Balloon Analogue Risk Taking Task (BART) is a measure of risk taking behavior. In this task, participant are asked to win money by pumping up a virtual balloon. Each pump results in an inflation of the balloon size, and of total earned money, but also increases the risk of explosion. If the ballon explodes, the participant looses all saved money, but he has the possibility to cash-out before its explosion.

Another task was developed to evaluate the modulators of the so-called "myopic loss aversion" phenomenon. This concept is a combination of loss aversion, where individuals tend to weigh losses more heavily than gains, and mental accounting, which refers to people's ability to classify and evaluate economic outcomes (Gneezy and Potters, 1997). In this game, participants had to select an amount of points to gamble in a risky lottery, where they had a probability of 1/3 to win two and a half times the amount bet, and a probability of 2/3 to loose the amount bet. They were informed about the objective probabilities of winning and losing. In a first sequence, participants were endowed with a certain amount of points at the beginning of each trial, but did not have the possibility to bet the money accumulated. In a second sequence of the game, participants were not longer endowed with points but had to bet with the money accumulated during the first sequence. In both sequences, the feedback frequency of the outcome was manipulated. In the high frequency treatment, the outcomes were delivered immediately following each gamble, whereas in the low frequency treatment, the outcomes were presented following a block of three trials. In the high frequency of feedback condition, participants could bet at each trial, while they had to choose only one bet per block in the low feedback condition, meaning that the bet was similar for the three trials.

1.3.3 Neural correlates

The growing number of imaging studies indicate that some brain activity changes are affecting the quality of decision making. Advances in imaging technologies allowed scholars to open the "black box" and to provide some insights about the organization of decision making.

Different aspects of risk

Uncertainty is a term that can have different meanings depending on the area of expertise of the person. What is called risk for an economist can therefore mean uncertainty for a psychologist. A proper use of uncertainty needs to be defined in order that everyone could understand which kind of risk is assessed in the document they read. Risk can been defined as a situation where individuals know the exact probabilities of outcome, while ambiguity refer to risk where individuals can not infer the outcomes' probabilities (Hsu et al., 2005; Mohr et al., 2010; Platt and Huettel, 2008). Nonetheless, it is important to stress that one should always beware when reading a paper to be sure that there is no confusion. Neural investigations has given evidence that these two forms of uncertainty were linked to different brain areas; ambiguity is associated with the activation of the Dorsolateral Prefrontal Cortex (dlPFC), the anterior cingulate cortex, and parts of the parietal cortex, while risk involves Orbitofrontal Cortex (OFC), parts of the rostral anterior cingulate, and parietal cortex (Krain et al., 2006). A recent meta-analysis investigated whereas the decision to take a risk, or its anticipation could be differentiated within the brain. From their analyses resulted that both decision and anticipation of risk activated bilateral insula, dorsomedial prefrontal cortex, and thalamus. However, the decision to take a risk activated right insula, dlPFC, parietal cortex, striatum, and occipital cortex, while anticipation was more likely to activate left insula, and left superior temporal gyrus. In addition, they addressed the same questions in regard to gains and losses, and found that in the presence of potential losses, left insula, left superior temporal gyrus and left precentral gyrus was activated, whereas possible gains were more likely to activate dorsomedial prefrontal cortex, dlPFC, right parietal cortex, thalamus and occipital cortex. A model of risk processing was then proposed: when the risky stimulus is perceived, it is evaluated through the interaction of emotional and cognitive processes, but modulated by distinct brain areas. The emotional component is processed by insula and thalamus, while the cognitive component is evaluated by dorsomedial prefrontal cortex. Following the anticipation processes, the decision would activate dlPFC and parietal cortices (Mohr et al., 2010).

Valuation

Some studies have provided evidence that there is a valuation system within the prefrontal cortex. In a simple task, when monkeys had to choose between different types of juices, the implication of the OFC in the valuation process was stressed. In fact, within this structure, there are distinct groups of neurons that encode the value of offered and chosen goods. This results support the conclusion that the OFC is part of a network that assigns the value of economic choices (Padoa-Schioppa and Assad, 2006, 2008; Padoa-Schioppa, 2009, 2013). Another study found that the activity of phasically active neurons in monkey striatum were correlated to action values, chosen value, and choice neurons. The action value responses occurred at the time of the monkey's choice, while chosen value responses was closer to the time of reward (Lau and Glimcher, 2008). Using the same kind of paradigm, McCoy and Platt (2005) showed that the neurons located in the posterior cingulate cortex were sensitive to risk, and to the subjective target utility. In addition, Kennerley et al. (2006) found that the anterior cingulate cortex was involved in the learning processes helping to guide the choices based on value actions.

In humans, the valuation role of the OFC has been replicated within studies (Hare et al., 2008; Plassmann et al., 2007; Stalnaker et al., 2015), but vmPFC appeared to be most frequently concerned by value-based decision making tasks (Wallis, 2012). One study has suggested that these two structures might have different attributions, choices could be guided through their association with anticipated emotions, involving the vmPFC, while emotions might signal a modification of the behavior following the choices, process handled by OFC (Levens et al., 2014). The amygdala appeared also to be involved in the valuations process in combination with OFC. Conditioning paradigms have allowed to emphasize their implication following the devaluation of the target stimulus. The activation of amygdala and OFC were decreased compared to stimuli that were not devaluated, leading to the conclusion that reward representation within the brain was encoded in these areas (Gottfried et al., 2003). One possible explanation differentiating both structures is that the value signals encoded by the OFC could be influenced by the amygdala (Jenison et al., 2011). This hypothesis was supported by a two-choice reward-guided task in monkeys. Amygdalectomy was found to reduce the number of value-encoding cells in OFC, but not entirely the encoding of reward value recorded before and after the reward delivery, thus suggesting that the amygdala have an influence on OFC (Rudebeck et al., 2013). Other structures might be part of the the system. In a delay discounting task, Kable and Glimcher (2007) found that ventral striatum, medial prefrontal cortex and posterior cingulate cortex correlated with the subjective value of the delayed reward. This activity was negatively associated with the degree of impulsivity of the subject, the more impulsive they scored, the lesser the activity within these region was pronounced. Striatum and anterior cingulate cortex activity have been linked to changes in risky choices in a gambling task. Participants' striatal activity was responsive to the value's magnitude independently from their utility, while anterior cingulate cortex contributed to risk coding. These results suggest that the brain encodes the choices' properties and combines neural signals to compute a choice (Christopoulos et al., 2009).

1.4 Attention deficit hyperactive disorder

Attention Deficit Hyperactive Disorder (ADHD) is a neurodevelopemental disorder usually diagnosed during childhood. The prevalence of ADHD can vary across studies, but it is generally assume that it affects more than 4% of the children, with a greater representation of boys (Brown et al., 2001; Faraone et al., 2003; Polanczyk et al., 2007; Willcutt, 2012). Individuals living with this condition manifest attentional impairments, such as daydreaming, distractibility, difficulties in concentrating and maintaining focused attention, high degree of impulsivity, as well as excessive level of activity and talking. Disturbance associated with ADHD during childhood may also include learning difficulties that can lead to academic failure and social issues, thus increasing the risk of substance abuse and low self-esteem (Biederman, 2005). In addition, it is not uncommon to observe a multiple range of associated disorders. Comorbidity rates may vary depending on the study, but the most commonly reported diseases represent both internal and external disorders, such as oppositional defiant disorder, and conduct disorder, mood and anxiety disorders, bipolar disorder, tic disorders including Tourette syndrome, obsessive-compulsive disorders, schizophrenia and other non-affective psychotic conditions, substance use disorders, and personality disorders (Gillberg et al., 2004).

1.4.1 Diagnostic

ADHD is a disorder that has aroused great interest for many years. Some illustrations from the 19th century already describe the major symptoms characterizing the current definition of ADHD, for instance, the story of "Fidgety Phil" in 1845, depicts a scene where a restless child drives the dinner particularly hectic (Hoffmann, 2006). What is now called ADHD has undergone many definitions over time. The most popular theories have named the disorder *minimal brain damage* (Pincus and Glaser, 1966; Lange et al., 2010), *minimal brain dysfunction* (Menkes et al., 1967; Wender, 1975), *hyperkinetic reaction of childhood* (Conners, 1970; American Psychiatric Association (APA), 1968), *attention deficit disorder with and without hyperactivity* (Barkley et al., 1992; American Psychiatric Association (APA), 1980), and *attention deficit hyperactive* *disorder* (Barkley, 1997; American Psychiatric Association (APA), 2000, 2013).

ADHD has long been regarded as a childhood disease, but in recent years, scientific proofs have demonstrated that the symptoms did not decrease during adolescence, on the contrary, it can persist into adulthood (Avisar and Shalev, 2011; Biederman et al., 2007a; Hervey et al., 2004). The frequency, severity of symptoms, and associated disorders can vary among individuals, leading to difficulties in the establishment of the diagnosis. There are no simple tests allowing practitioners to detect ADHD, however, several types of evaluation grids have currently been developed to confirm the presence of the disorder and to assess the severity of the symptoms. These methods take into account the evaluation by close relatives, by teachers and by self-assessment questionnaires. A medical examination is required, as well as a physical examination. In addition, it is preferable to specify the strength and weakness of the child's neuropsychological condition, by including batteries evaluating IQ, and cognitive functioning during the diagnostic interview.

The DSM-V classifies ADHD in the group of neurodevelopemental disorder and defines specific diagnostic criteria:

A. A persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development, as characterized by (1) and/or (2):

  1. Inattention: Six (or more) of the following symptoms have persisted for at least 6 months to a degree that is inconsistent with developmental level and that negatively impacts directly on social and academic/occupational activities:

     Note: The symptoms are not solely a manifestation of oppositional behavior, defiance, hostility, or failure to understand tasks or instructions. For older adolescents and adults (age 17 and older), at least five symptoms are required.

     a. Often fails to give close attention to details or makes careless mistakes in schoolwork, at work, or during other activities (e.g., overlooks or misses details, work is inaccurate).
     b. Often has difficulty sustaining attention in tasks or play activities (e.g., has difficulty remaining focused during lectures, conversations, or lengthy reading).
     c. Often does not seem to listen when spoken to directly (e.g., mind seems elsewhere, even in the absence of any obvious distraction).
     d. Often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace (e.g., starts tasks but quickly loses focus and is easily sidetracked).
     e. Often has difficulty organizing tasks and activities (e.g., difficulty managing sequential tasks; difficulty keeping materials and belongings in order; messy, disorganized work; has poor time management; fails to meet deadlines).
     f. Often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (e.g., schoolwork or homework; for older adolescents and adults, preparing reports, completing forms, reviewing lengthy papers).
     g. Often loses things necessary for tasks or activities (e.g., school materials, pencils, books, tools, wallets, keys, paperwork, eyeglasses, mobile telephones).
     h. Is often easily distracted by extraneous stimuli (for older adolescents and adults, may include unrelated thoughts).

        i. Is often forgetful in daily activities (e.g., doing chores, running errands; for older adolescents and adults, returning calls, paying bills, keeping appointments).

2. Hyperactivity and impuisivity: Six (or more) of the following symptoms have persisted for at least 6 months to a degree that is inconsistent with developmental level and that negatively impacts directly on social and academic/occupational activities:

   Note: The symptoms are not solely a manifestation of oppositional behavior, defiance, hostility, or a failure to understand tasks or instructions. For older adolescents and adults (age 17 and older), at least five symptoms are required.

   a. Often fidgets with or taps hands or feet or squirms in seat.
   b. Often leaves seat in situations when remaining seated is expected (e.g., leaves his or her place in the classroom, in the office or other workplace, or in other situations that require remaining in place).
   c. Often runs about or climbs in situations where it is inappropriate. (Note: In adolescents or adults, may be limited to feeling restless).
   d. Often unable to play or engage in leisure activities quietly.
   e. Is often ‘‘on the go,’’ acting as if ‘‘driven by a motor’’ (e.g., is unable to be or uncomfortable being still for extended time, as in restaurants, meetings; may be experienced by others as being restless or difficult to keep up with).
   f. Often talks excessively.
   g. Often blurts out an answer before a question has been completed (e.g., completes people’s sentences; cannot wait for turn in conversation).
   h. Often has difficulty waiting his or her turn (e.g., while waiting in line).
   i. Often interrupts or intrudes on others (e.g., butts into conversations, games, or activities; may start using other people’s things without asking or receiving permission; for adolescents and adults, may intrude into or take over what others are doing).

B. Several inattentive or hyperactive-impulsive symptoms were present prior to age 12 years.

C. Several inattentive or hyperactive-impulsive symptoms are present in two or more settings (e.g., at home, school, or work; with friends or relatives; in other activities).

D. There is clear evidence that the symptoms interfere with, or reduce the quality of, social, academic, or occupational functioning.

E. The symptoms do not occur exclusively during the course of schizophrenia or another psychotic disorder and are not better explained by another mental disorder (e.g., mood disorder, anxiety disorder, dissociative disorder, personality disorder, substance intoxication or withdrawal).

   Specify whether:

   Combined presentation: If both Criterion A1 (inattention) and Criterion A2 (hyperactivity-impulsivity) are met for the past 6 months.

   Predominantly inattentive presentation: If Criterion A1 (inattention) is met but Criterion A2 (hyperactivity-impulsivity) is not met for the past 6 months.

   Predominantly hyperactive/impulsive presentation: If Criterion A2 (hyperactivity- impulsivity) is met and Criterion A1 (inattention) is not met for the past 6 months.

   Specify if:

   in partial remission: When full criteria were previously met, fewer than the full criteria have been met for the past 6 months, and the symptoms still result in impairment in social, academic, or occupational functioning.

> Specify current severity:
>
> Few, if any, symptoms in excess of those required to make the diagnosis are present, and symptoms result in no more than minor impairments in social or occupational functioning.
>
> Moderate: Symptoms or functional impairment between ‘‘mild’’ and ‘‘severe’’ are present.
>
> Severe: Many symptoms in excess of those required to make the diagnosis, or several symptoms that are particularly severe, are present, or the symptoms result in marked impairment in social or occupational functioning.

1.4.2 Etiology

A better understanding of etiological factors involved in the disorder entails progress in the understanding of the risk factors. Different theories have been advanced, however, there is still no clear consensus. To date, the result of scientific work demonstrates that there are several possible etiologies, including genetic, neurobiological, and neuropsychological factors. To assess the underlying determinants of ADHD, a growing number of studies have been conducted.

Genetic factors

Data from family studies support the hypothesis that genetic factors are involved in causing ADHD, by showing that relatives had a much higher chance of developing the disorder than in the general population. A review evaluated that diagnostic criteria were met in 25% of first-degree relatives, against 5% in the control population (Biederman et al., 1990). A complementary study concluded that ADHD would be less frequently reported in more distant families (Faraone et al., 1994). Further, children adopted within healthy families, but having biological parent carrier of the disease exhibit more frequently the symptoms of ADHD compared to those adopted but having healthy biological parents (Sprich et al., 2000). Twin studies have also demonstrated its inheritance character, the mean heritability rate has been evaluated to be much more higher in comparison with other disorders (Larsson et al., 2004; Levy et al., 1997; Sherman et al., 1997). Moreover, monozygotic twins have a concordance rate of the disorder 2 to 3 times higher than dizygotic twins (Eaves et al., 1997). Together, these findings are consistent with the hypothesis that some genetic factors may underlie ADHD.

Neuropsychological factors

Research conducted on the neurobiological characteristics of ADHD includes the work assessing the impairments that people with ADHD have to live with. Through these investigations, some neuropsychological and neurobiological factors have been identified. Most consistent findings have shown a link between ADHD and executive functions. These studies agree on the fact that some aspects are deficient in the clinical populations, such as response inhibition, working memory, planning, and set shifting (Biederman et al., 2004; Nigg et al., 2002a; Pennington and Ozonoff, 1996; Quay, 1997; Willcutt et al., 2005).

A prominent theory attempt to explain the origin of ADHD's symptoms was foremost proposed by Quay (1988), and further reedited by Barkley (1997). They assumed that poor behavioral inhibition was the key of the disease. Barkley's unified model had identified the cause of the symptoms as being related to a disturbance of the neurocognitive circuit underpinning the executive functions. More particularly, ADHD is perceived as a developmental disorder affecting behavioral inhibition ability, rather than an attentional disorder as suggested by its name. Response inhibition would be the main cause of the symptoms, while attention problems are likely to be its consequences. For Barkley, behavioral inhibition is used to inhibit immediate responses, to terminate the ongoing responses and to limit interference. It is linked to 4 processes: working memory, allowing the maintenance of events in memory, and to act accordingly; emotional and motivational autoregulation, creating a response time to give the individuals the opportunity to withdraw from the event; internalization of language, which influences the behavior by encouraging questioning and internal reflection; and the reconstitution, providing the means to analyze and to synthesize the behavior.

More recently appeared a new theoretical current that shifted the focus from impaired inhibition to the conception of delay aversion. The model of Sonuga-Barke (2003) suggests that hyperactive behaviors are not the consequence of a behavioral inhibition default but rather an expression of an underlying motivational state, which leads them to seek to escape from delay, which is able to cause them hyperactivity, inattention, and impulsivity symptoms. According to this model, the proposition presented by Barkley did not totally encompass the motivational-related dysfunction. In particular, when faced with a choice between a small but immediate reward and a strong but more distant gratification in time, ADHD individuals will prefer immediacy. Cognitive disorders appear to be the consequences of a particular attitude, related to time sequence. The main idea is that ADHD individuals operate in order to escape the experience of delay by allocating their attention towards non-temporal environmental cues, otherwise creating themselves non-temporal stimulation. The model is divided into tho main pathways: the first pathway is likely to be associated with dysfunctions of the executive circuit, while the second one would be linked to the reward circuit signaling delay aversion. Evidence has been brought to confirm the complementary aspect of these two pathways, rather than perceiving them as being in competition: the first dysexecutive function pathway would be linked with the dlPFC, while the reward/motivational pathway would be associated with the OFC. Both pathways present functional abnormalities within these loops, resulting by the expression of different symptoms. Hyperactivity and inattention are more likely to be related to motivational and reward constructs, while impulsivity would be more representative of the inhibitory deficit (Sonuga-Barke, 2003, 2005).

Neurobiological factors

Several studies have focused on the role of dopamine in the expression of symptoms associated with ADHD. Dopamine is a neurotransmitter belonging to the class of catecholamines, mainly produced in the substantia nigra and ventral tegmental area, located in the midbrain. It plays a vital modulatory role in motor and cognitive functions, as well as in the reward circuit (Fallon and Moore, 1978; Schultz, 2007). Some evidences might suggest a connection between dopamine dysfunction and ADHD. For instance, stimulant-based treatment have been shown to improve cognitive skills by producing an increase of dopamine transporter (Coghill et al., 2014). Furthermore, depletion of the DAT gene in mice produced similar disturbances than individuals with ADHD (Gainetdinov and Caron, 2000). Finally, some studies have shown that dopamine receptor density was weaker than in healthy individuals. It has been suggested that the DAT-1 dopamine transporter and DRD4 receptor were implicated in this reduction, but this effect may be weak given the relatively low level of variance explained by these studies (Cortese, 2012; Sharma and Couture, 2014; Swanson et al., 2000).

1.4.3 Clinical treatment

There seems to be no treatment to cure ADHD. The objective of the care is to reduce the symptoms of ADHD in children and adults. Actual treatments are divided into 2 currents: drug treatments and non-pharmacological treatments, such as psychological assistance or cognitive remediation, and neurofeedback (Arns et al., 2009; Jensen et al., 1999; Sharma and Couture, 2014). Only methylphenidate psychostimulant medication and cognitive remediation will be introduced here.

Pharmacology

The most common treatment is Methylphenidate (MPH), a stimulant of the central nervous system acting by blocking the reuptake of dopamine. It was synthesize in 1944, and prescribed in 1954, but its intended audience was initially for patients with depression and narcolepsy, and since the end of the 50s has been indicated for patients with ADHD. From a pharmacological point of view, its action is close to cocaine, but it does not lead to dependance. The main difference between the two molecules is the mode of administration. Being orally ingested, MPH does not have the time to produce the reinforcing effects associated with rapid changes in serum concentrations and presumably fast dopamine increases, as obtained using intravenous injection or insufflation, while the therapeutic effects are associated with a slow increase of the serum concentration and presumably a gradual increase in dopamine levels. At therapeutic doses, MPH acts in order to increase the value of stimuli having difficulty to elicit dopamine responses, which could be amplified by being more salient and drive interest and attention (Casey and Durston, 2014; Kimko et al., 1999; Leonard et al., 2004; Patrick and Markowitz, 1997; Volkow and Swanson, 2003; Volkow et al., 2005). Different effects of this treatment have been reported in literature, for instance, it seems to have a positive impact on the symptoms severity. In addition, executive functions deficits, academic performance and emotional status have been shown to be significantly improved (Coghill et al., 2014; Hechtman et al., 2004; Kimko et al., 1999; Sunohara et al., 1999; Yildiz et al., 2011). A recent meta-analysis was interested in estimating the neurocognitive effects of MPH. The results emerging from this analysis show that during inhibition tasks, stimulants increased the activation of the frontal cortex/insula, and at a lower level, the putamen, thus enhancing the cognitive control region of the brain (Rubia et al., 2014). Another study indicated that psychostimulants improved the performance during attentional tasks by suppressing the default-mode activity in the anterior cingulate cortex and in the ventral posterior cingulate cortex. They concluded that this type of medication improves performance by normalizing the activity of the circuit (Peterson et al., 2009).

Evidence from ERP studies have also emphasized the effects of stimulant on various ERP components disturbances. For instance, Verbaten et al. (1994) reported that children with ADHD taking MPH had an improved N2 and P3 amplitude, but did not find any effect on N1 and P2 waves. Winsberg et al. (1997) reported an increased P3 amplitude in an auditory oddball task, but no effect on neither the MMN nor N2. These results can been explained by the fact that this medical treatment leads to an increase of alertness and accuracy. In an auditory and visual selective attention task, the frontal processing negativity and P3b amplitudes were greater in both modalities with children under medication. The authors concluded that MPH affects selective attentional processing, even if the performances were not improved. (Jonkman et al., 1997). The same group reported further an enhancement of P3 amplitude following task-relevant stimuli, but not the P3 novelty component (Jonkman et al., 2000), suggesting that MPH did not improve the capacity-allocation deficit of ADHD children. In a decision making task, feedback-related P2 and LPP components were found to be similar in MPH-treated children with ADHD and control children (Groen et al., 2013b). In addition, following a cure of 8 weeks with a washout period of 2 of MPH treatment, children with ADHD showed an increase of the CNV induced by a Attentional Network Test (Kratz et al., 2012). This enhancement was not found in those treated with atomoxetine, the alternative non-stimulant medication, suggesting that both treatments do not have the same impact on attentional networks, even if behavioral symptoms were improved in both conditions; MPH rather have an impact on dopaminergic neurons within the cortico-striato-thalamo-cortical circuit. Another study has highlighted a dose-dependent effect of MPH. While performing a continuous performance test, only the P3 latency became comparable to those of individuals controls after taking a low dose of the drug, while a high dose normalized both N2 and P3 latencies (Sunohara et al., 1999).

Cognitive remediation

ADHD is considered a chronic disorder, thus, the need to continue a treatment for a prolonged period can be costly and problematic. Particularly, it is important to notice that medical treatment using psychostimulant can raise some questions, including the use of psychotropic drugs for children, the risk of over-medicalization, or merely the fact that everyone does not respond in the same manner to this treatment; some people tolerate it quite well, while others manifest a long list of side effects that can lead to the decision to head towards another type of therapy, or simply to avoid to treat themselves (Halperin and Healey, 2011; Leonard et al., 2004; Patrick and Markowitz, 1997; Yildiz et al., 2011). When the drug option is not conceivable, it is possible to test another type of therapy, such as cognitive remediation.

Cognitive training programs have been developed relatively recently. The aim of these trainings is to provide a treatment with long lasting effects, on the contrary to medicated treatments.

They are essentially based on the improvement of attention and of working memory. Several programs have been used in the ADHD community, such as “Pay Attention!” (Kerns et al., 1999), the “Computerized Progressive Attentional Training” (Shalev et al., 2007), and the “Cogmed Working Memory Training Program” (Klingberg et al., 2002, 2005). These programs have been linked to improvement on several neurocognitive and academic skills, as well as a reduction of the symptoms. However, as they implement several type of tasks, it can be difficult to find out specifically which was the one responsible for these improvements.

The N-Back is a game which has been developed in the late 50s in order to study the age-related effects on short-term memory (Kirchner, 1958). It is now frequently used to assess Working Memory (WM) capacity in various populations (Carter et al., 2014; Harvey et al., 2005; Jaeggi et al., 2010; Tsuchida and Fellows, 2009; Valera et al., 2014). Programs using N-back or Dual N-Back tasks have shown that WM performances can be improved significantly. In addition to WM enhancements, some studies have shown that other untrained constructs might benefit from WM trainings with these tasks, such as temporary memory measures, fluid intelligence and to some aspects of executive functions (task switching, attention, cognitive control, reading comprehension), while other studies did not found any near or far transfer effect, neither on general fluid intelligence, nor on executive function skills (Chooi and Thompson, 2012; Dahlin et al., 2008; Jaeggi et al., 2008; Lilienthal et al., 2013; Morrison and Chein, 2011; Oelhafen et al., 2013; Owens et al., 2013; Redick et al., 2013; Salminen et al., 2012; Thompson et al., 2013). The difference perceived between studies might be due to several factors, including methodological issues within studies or the lack of consistency between studies, as well as motivation and expectancy of the participants (Morrison and Chein, 2011).

1.4.4 Neuroanatomic imaging data

Numerous studies have examined the neural characteristics of ADHD. Findings have identified cortical differences affecting some specific areas. Overall, volumetric analyses have reported a reduction of the total brain volume, and global reductions in gray matter volumes in children affected by ADHD. In addition, more specific areas of the brain appear to be smaller than those of healthy individuals. A decreased size of the regions within frontal lobe have been reported as well as differences in the symmetry of the prefrontal region, due to a significant decrease in right prefrontal area (dlPFC). In addition, reductions of globus pallidus, caudate nucleus, cerebellum, putamen, and parietal cortex have been consistently described (Aylward et al., 1996; Castellanos et al., 1996, 2002; Krain and Castellanos, 2006; Nakao et al., 2011). Shaw and colleagues showed that the development of cortical thickness and surface area, more specifically prefrontal cortex, was delayed in young ADHD subjects. These delays were mostly evident in regions controlling cognitive processes including motor skills and attention planning (Shaw et al., 2007, 2012).

Several studies have indicated that ADHD symptoms are still present in adulthood. Indeed, it has been reported that approximately 40% of individuals still meet the diagnostic criteria. Hyperactivity and impulsive symptoms seem to be reduced, leaving room to attention deficits

(Barkley et al., 2002; Biederman et al., 2000, 2007a, 2010; Shaw et al., 2013). In line with these behavioral reports, the cortical abnormalities appear also to be maintained into adulthood. The group of Makris found that ADHD adults presented a diminished volume of right dlPFC, anterior cingulate cortex, and inferior parietal lobule, regions linked to attention and executive functions (Makris et al., 2007). These results are in agreement with those reported by Shaw (Shaw et al., 2013). In this longitudinal study, the findings allowed further the authors to discuss an association between cortical thickness to the severity of symptoms in adults with ADHD.

1.4.5 Event-Related Potentials correlates

Owing to their high temporal resolution, ERPs have been used to study brain responses related to specific events. Research conducted in ADHD patients have allowed to bring some insights about brain waves' characteristics in regard to sensory and cognitive processing.

Attention

Attentional processes have been widely examined through ERP reports. The findings demonstrate that early preparatory processes might be impaired in ADHD patients, as shown by absence or decreased amplitude of the CNV wave reported by several studies (Banaschewski et al., 2003, 2008; Doehnert et al., 2010; Dumais-Huber and Rothenberger, 1992; Perchet et al., 2001). Moreover, IQ and executive functions capacities have been found to be associated with the amplitude of CNV, suggesting that the severity of executive impairments in ADHD are reflected by the differential activity of the CNV (Sartory et al., 2002).

Other works have demonstrated that various attentional stages of processing might differ in comparison from healthy controls. For instance, discrimination processes, as reflected by the N1 component, have been shown to be reduced or inexistent in children and adults with ADHD (Banaschewski et al., 2003; Barry et al., 2009; Bekker et al., 2005; Brown et al., 2005; Lawrence et al., 2005; Sable et al., 2013). Moreover, most studies have reported abnormal N2 and P3 amplitude while performing active attentional tasks in both children and adult community (Anjana et al., 2010; Doehnert et al., 2010; Lazzaro et al., 2001; MacLaren et al., 2007; Satterfield et al., 1994). Yet, the results are not unanimous, some studies failed to find such difference with normal controls, in both children and adult samples (Barry et al., 2009; Brown et al., 2005; Fisher et al., 2011; Karch et al., 2010; Lopez et al., 2006). In sum, these findings suggest that ADHD show attentional processes alterations, they tend to exhibit readiness deficits, as well as deviant resources allocation and processing of attentional stimuli.

Inhibition

Inhibitory control has also been widely considered in the ADHD community. Reduction of N2 and P3 responses have been consistently detected following stimuli requiring inhibition of the response (Fallgatter et al., 2005; Gow et al., 2012; Johnstone et al., 2010b; Liotti et al., 2005, 2010). A meta-analysis conducted in adults with ADHD pointed out consistent findings in regard with the P3 component. Most of the studies analyzed in this work were in accordance with the reduction of the amplitude during target detection, with only one exception found in Barry et al. (2009). It was further demonstrated that this decrease was associated with age and gender, the older the people are, the more negative is the effect size, and the higher percentage of males in the ADHD group is, the less negative is the effect size (Szuromi et al., 2011). The diminution of the P3 activity has been associated with a dysfunction of the LC-NE network, suggesting that the P3 activity may reflect a reduction of inhibitory control in ADHD (Fallgatter et al., 2005). Together, these ERP results adjust behavioral data supporting a deficit of behavioral inhibition in ADHD populations.

Overall, it appears that results are quite consistent between studies, with some exceptions. Several factors could have been affecting the results. Firstly, since the 90s, the definition of ADHD has been changed many times, thus, the difference found in comparison with older studies could have been due to the update of diagnostic criteria. Secondly, the differences between these studies may be related to the age, gender and comorbid factors within the groups of patients studied. In addition, the diversity of experimental paradigms may have also impacted the results. Finally, comparison between studies always implies methodological issues, for instance the number of subjects that have participated in the study, or even the method used to analyze the data. These factors have certainly influenced both latencies and amplitude of ERP components, which are quite sensitive to the environment and context.

1.4.6 Decision making and ADHD

Individuals with ADHD tend to be implicated in greater situation where they meet risk. Some studies have pointed out the over-representation of road accidents and violation of traffic rules (Barkley et al., 1996), or abuse of substances such as alcohol or drugs (Lee et al., 2011). Other researches have also examined risk in ADHD by showing that these *irrational* attitudes towards risk taking were not limited only to the field of safety and health, but also in the financial sector. For this purpose, several research studies have been conducted to highlight correlates of decision making in adults with ADHD.

Some studies reported that ADHD were characterized by more risky performance compared to normal controls, however, other reports did not found impaired performances. Specifically, in a double blind placebo experiment, using the IGT, Agay et al. (2010) did not detect any significant difference nor in the selection of bad decks neither in the total net score between all groups. In contrast, whilst playing to the Foregone Payoff Gambling Task, a modified version of the IGT where participants could see all hidden cards following the choice, they found that ADHD adults in both placebo and drug administration pools had chosen significantly more cards from the bad decks compared to the controls, suggesting that the additional information might have distracted ADHD individuals. They concluded that MPH administration on the gambling task did not affect performance. Much like Agay et al. (2010), another study did not find any behavioral difference between the ADHD group and the healthy controls (Ernst et al., 2003).

However, PET data highlighted the recruitment of other neural networks and reduced activation of the vmPFC, dlPFC and insular cortices. On the contrary to these data, other studies have pointed out a more risky behavior using the IGT. ADHD disclosed a lower total score compared with a control group (Malloy-Diniz et al., 2007). Additionally, Mäntylä et al. (2012) analyzed the behavioral performances in 4 different tasks, two subtests of the A-DMC battery, evaluating the ability to apply decision rules and participant's confidence judgement respectively, the IGT and the BART task, where individuals had to earn money by pumping up balloons as much as possible before it exploded. ADHD were not impaired in their confidence' judgment ability, but showed significant difference in the 3 other tasks. In the IGT, the total earned money was significantly lower than in the normal control group and they also took greater risks in the BART task, reflecting poor decision making capacities, which may have been mediated by executive functioning impairments. In line with these results, the Game of Dice Task has provide contradictory data. In particular, Matthies et al. (2012) found that individuals with ADHD were more likely to perform the task in a riskier fashion, as indicated by the number of disadvantageous alternative's selection, but Wilbertz et al. (2012) did not detect such behavior.

Several hypothesis have been postulated in order to explain the suboptimal decision making abilities characterizing individuals with ADHD (Sonuga-Barke and Fairchild, 2012). The first hypothesis stipulates that the medial prefrontal cortex–posterior cingulate cortex circuitry is involved in the abilities to have a self-referential thought, to have a sense of self, and to pursue specific goals. This circuitry has been shown to be less effective in ADHD, and might explain goal setting impairments, planing difficulties and intention deficits involved in the processes of valuation and intention to take risks. The second hypothesis explains difficulties that ADHD patients encounter towards uncertainty and delayed rewards. It includes the dlPFC, underpinning executive functioning deficits in ADHD. This hypothesis postulates that working memory deficits prevent from holding information in mind, resulting in poor economic decision making capacities. The last hypothesis involves dopaminergic dysregulation in ventral frontostriatal loops supporting outcome prediction and evaluation, and learning competences, that have been reported to be less efficient in ADHD individuals.

1.5 Aim of the project

ADHD is a neuropsychiatric disorder that evolves continuously between childhood and adulthood. Yet, each individual presents a specific profile, making the diagnosis difficult to establish. Most common negative symptoms being reported are attention deficit, which may be accompanied by disturbances of motor activity expressed through hyperkinesia in some individuals. Inattention problems are also frequent and can lead to many difficulties in daily life. An effective way to fight against these symptoms is to follow a treatment with methylphenidate, a psychostimulant acting on dopamine transporters. Its effect is fast, but requires several administrations per day depending on the intensity of the disorder. Moreover this treatment may not suit everyone, some people have severe side effects that can lead to discontinuation of treatment in favor of other methods that can be harmful, such as drugs or alcohol intake.

Other therapies have also proved their worth, such as cognitive remediation. These methods can reduce symptoms and improve some deficient aspects, such as improving executive functions capacities on more extended periods. In particular, cognitive trainings conducted with the Dual N-Back have shown significant symptoms reduction, as well as positive effects on working memory. The aim of the present study is therefore to examine the effects of an intensive working memory training conducted with the Dual N-back task in a population of young adults with ADHD and match-controls through various measures including electroencephalography. In the context of an original interdisciplinary collaboration, the results of this research will provide objective measures of the impact of working memory training on cognitive processes, but will not be limited to a theoretical contribution on economic decision making abilities, they will also provide new perspectives in the evaluation of interactions between the executive and decision making process in adults with ADHD.

This study could also show the benefits of cognitive training in healthy subjects, which would provide public health arguments against the current trends of self-administration of drugs and psychoactive substances to boost attention in high-pressure work environments. According to the research results, applications could be developed for target populations, such as cerebral cognitive deficits, addiction to electronic games, and pathological gamblers, using cognitive training on working memory, attentional control, impulsivity and decision making.

2 Methods and Materials

2.1 Participants

Two hundred and thirty-two subjects below the age of thirty were selected to participate in this study (see Table 1). Ninety-six clinically referred young adult ADHD patients were recruited either in the Psychiatric Department of the University Hospital of Lausanne or at a psychiatrist's practice in collaboration with the University Hospital, following an initial screening appointment, to ensure that they were fulfilling the criteria defined by the DSM-IV-TR for inattentive, hyperactive/impulsive or mixed subtypes (American Psychiatric Association (APA), 2000). Subjects with neuropsychiatric conditions such as acute mood/anxious disorder, bipolar disorder, psychosis, autism or Asperger's syndrome, antecedent of Tourette's syndrome, presence of motor tics, suicidal behavior, chronic medical conditions were excluded from this study. Any subjects taking other psychotropic agents such as anti-depressants, mood stabilizers, non-stimulant medications for ADHD, or dopamine receptor-blocking agents were also excluded from this study. Subjects taking psychostimulants at time of the study were required to stop medication 24 hours prior to testing (Cross-Villasana et al., 2015; Groom et al., 2008; Mazaheri et al., 2014).

The University of Lausanne or EPFL volunteer students were approached through the *ORSEE* database, based on their scores reported by a questionnaire evaluating ADHD symptoms. We created an index of Adult ADHD Self-Report Scale (ASRS) scores (ASRS, described below) based on the presence of symptoms assessed by 6 essential items. That is, the index was build only with the answers of those questions. Individuals that had a score below 10 points on this index constituted the low ASRS group, while those having a score above 22 points were placed in the high ASRS group (see Figure 2). Following a short explanation on the aims of our study, 93 individuals having strictly lower or greater predefined scores responding to our criteria were selected.

In order to form the second control group composed of apprentices, flyers were posted in professional schools to attract young volunteers' curiosity. The advantage of this group is that it allowed us to find young adults having a level of education comparable to the ADHD patients group, and who were naive to experimental manipulations, unlike the university campus students who have long been accustomed to this practice. All control participants were screened prior to the experimental session to ensure that they would not report any neuropsychiatric disorders or any other exclusion criteria. None of them were taking any psychoactive medications. One student was excluded from the study following the report of psychosis antecedent.

The study was carried out in accordance with the latest version of the Declaration of Helsinki (World Medical Association., 2000) and approved by the Ethics Committees of the Faculty of Business and Economics of the University of Lausanne, and by the Cantonal Ethics Committee of Canton Vaud on behalf of the Swiss Federal Authorities. All participants had normal or corrected-to-normal vision, none reported a history of sustained head injury.

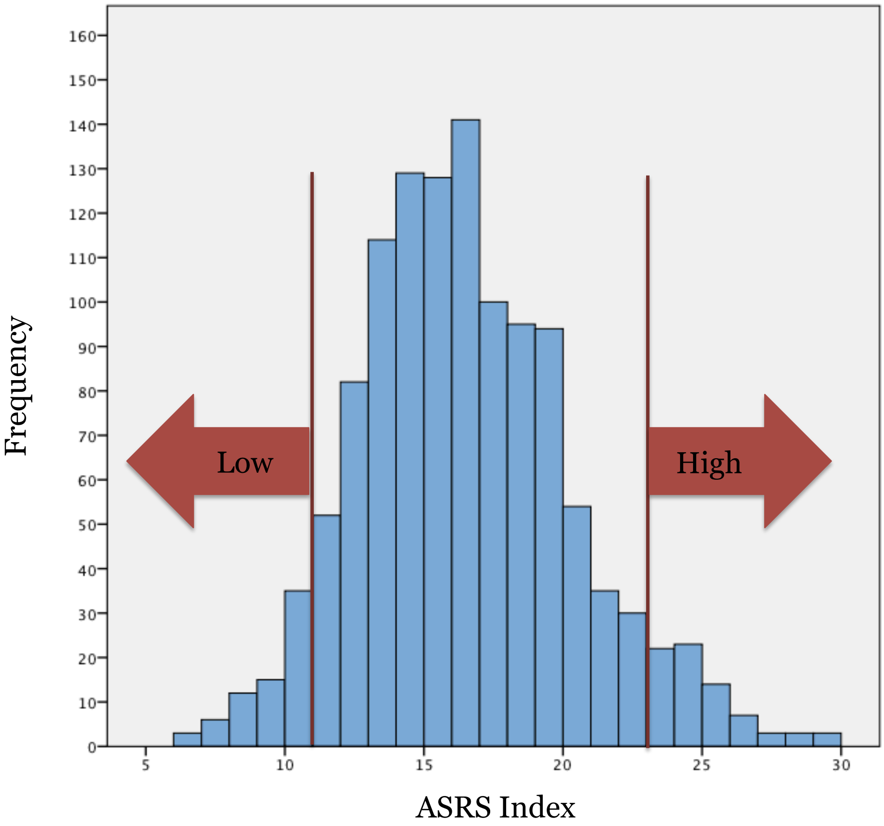

Figure 2: Distribution of the index of the ASRS' score in all individuals (N=1300) who responded online to the survey. UNIL/EPFL students with a score below 10 points constituted the low ASRS group, while those having a score higher than 22 were selected in the high ASRS group.

2.2 Procedure

To shorten the duration of the testing period in the laboratory, online questionnaires were sent to the subjects two weeks before the appointment. The questionnaires included the *HEXACO* personality inventory (Lee and Ashton, 2004), an instrument that assesses the six major dimensions of personality (Honesty-Humility, Emotionality, eXtraversion, Agreeableness, Conscientiousness and Openness to Experience); the Current Behavior Scale (CBS), (Biederman et al., 2007b) developed to examine executive function deficits in adults with ADHD; the Conners Adult ADHD Rating Scales Conners Adult ADHD Rating Scales (CAARS-S:SV), (Conners et al., 1999), and the ASRS Symptom Checklist (Kessler et al., 2005), both covering features of adults with ADHD. Participants' clinical assessment are summarized in the Table 2.

The whole protocol was divided into three parts: a pretesting session taking place in the experimental laboratory (Labex, HEC–UNIL), a 20-period of Working Memory Training (WMT) at home, and finally a posttest session back in the Labex. The whole procedure is summarized in the Figure 3.

Table 1: Demographic characteristics of all participants

		Training type	Total at pretest	Total at posttest	Gender[a] (M/F)	Age[a,b] (Y. old)	Laterality[a,c] (%Right)	Withdrawals
UNIL/EPFL	Low score	Baseline	25	22	10/12	21 20±0.4	83 90±7	3
		Adaptive	22	21	14/7	22 21±0.6	68 90±14	2
	High score	Baseline	23	21	12/9	22 21±0.8	83 90±9	2
		Adaptive	23	20	13/7	21 21±0.5	84 90±9	3
Prof.	School	Baseline	20	20	9/11	22 22±0.9	89 90±5	0
		Adaptive	23	21	11/10	22 22±0.4	80 90±9	2
ADHD	No MPH	Baseline	23	17	14/3	22 21±0.6	68 90±12	6
		Adaptive	23	17	11/6	22 19±0.8	62 90±14	6
	MPH	Baseline	26	21	10/11	22 21±0.6	82 95±8	5
		Adaptive	24	21	13/8	23 23±0.7	64 84±11	3

[a] Participants who completed the study; [b] Mean, median ±SEM; [c]Evaluated by the Edinburg Handedness Inventory

2.2.1 Experimental sessions in the Labex

On the first experimental day in the Labex, participants were welcomed and requested to complete the Edinburg Handedness Inventory (EHI), (Oldfield, 1971)), and underwent the Mini-International Neuropsychiatric Interview (MINI), (Sheehan et al., 1998)), a short structured diagnostic interview assessing psychiatric disorders, under the supervision of a trained clinical psychologist. Following a short explanation about the EEG technique, participants were prepared for the testing session. The sound and light attenuated testing room measured approximately 6 m^2 and was equipped with a 19" computer monitor, where they were comfortably seated at a distance of 65 cm. All participants started the protocol by playing to the Prob-

Table 2: Clinical assessment of participants having completed the study

		Training type	ASRS	CAARS A	CAARS B	CAARS C	CAARS D
UNIL/EPFL	Low score	Baseline	33 33±1.4	50 43±3	46 41±2.5	48 42±2.8	44 41±2.2
		Adaptive	35 35±0.9	48 46±2	47 44±2.7	48 43±2.7	45 42±1.4
	High score	Baseline	62 61±1.9	62 61±3	53 51±2.4	59 57±2.5	54 55±1.7
		Adaptive	60 61±1.7	67 68±3	57 58±3	65 65±3.2	57 54±2.1
Prof. School		Baseline	46 48±1.9	57 56±3	50 52±2	55 58±2.1	51 50±1.4
		Adaptive	45 47±1.9	49 51±2	45 41±2.1	47 45±1.8	45 45±1.8
ADHD	No MPH	Baseline	60 60±2.8	74 76±3	64 69±2.5	73 79±3.1	59 57±2.1
		Adaptive	48 55±2.3	69 74±3	60 59±2.7	65 65±4.3	56 57±2.2
	MPH	Baseline	62 68±2.3	78 80±2	65 69±4	76 80±2.3	66 68±2.5
		Adaptive	60 61±2.8	73 75±2	57 59±3.9	68 69±3	60 60±2.5

Mean, median ±*SEM* measures of ASRS and CAARS A–D indexes. CAARS A, DSM-IV Inattentive symptoms; CAARS B, DSM-IV Hyperactive/impulsive symptoms; CAARS C, DSM-IV ADHD symptoms total, CAARS D, ADHD index.

abilistic Gambling Task (PGT), a modified version of the Gneezy and Potters' task (Gneezy and Potters, 1997), which lasted around 25 minutes. Subsequently, subjects exercised the Dual N-Back task (Jaeggi et al., 2008) for 25-30 minutes, and finally, 25-minutes of Attentional Network Test (ANT), (Fan et al., 2002) concluded the EEG recording testing period. Following the removal of EEG's equipment, participants had the opportunity to take a short break to wash their hair. Before the end of the session, two complementary span tasks were administered: the WAIS-IV digit span task (Wechsler, 2008), and the Corsi Block-Tapping task (Kessels et al.,

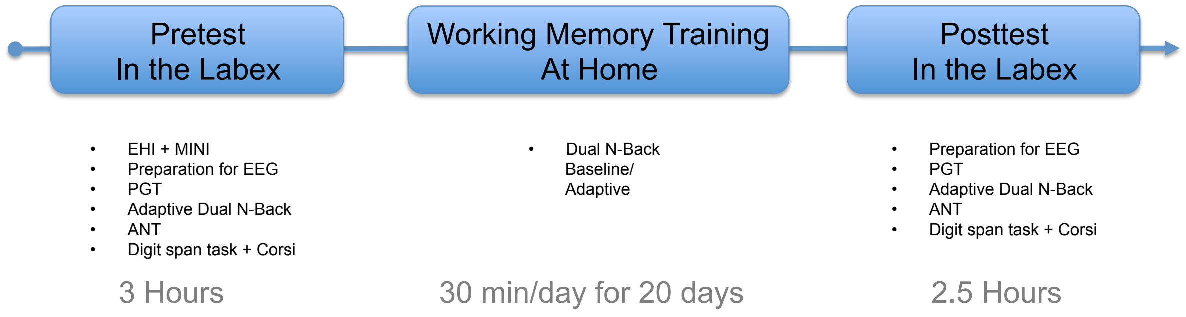

Figure 3: Experimental procedure of the whole study. In the first step, participants were invited in the experimental laboratory (Labex, HEC–UNIL) for a pretest session. The second step consisted in a 20-period of working memory training at home. The posttest session was the last step of the study.
EHI: Edinburg Handedness Inventory; MINI: Mini-International Neuropsychiatric Interview; PGT: Probabilistic Gambling Task; ANT: Attentional Network Test.

2000). The whole EEG registration had a total length of time of approximately 90 minutes, whereas the complete protocol duration was three hours.

The posttest session was held in the same manner as the pretest, except for the administration of EHI and MINI questionnaires. If necessary, an explanation of EEG was recalled before starting the preparation of the subject. The session was shortened by 30 minutes compared to the pretest.

2.2.2 Working memory training

Working memory training began the day after the pretest. Participants were asked to perform 20 trainings composed of 20 blocks during an entire month. They were told that they would have to practice the Dual N-Back task for about 30 minutes per day during the week and to rest for two-day in the weekend. Each experimental group was divided into two conditions, the first half made a progressive training (*adaptive training*), while the other half was blocked at the level 1 during the whole training phase (*baseline training*). Participants were monitored through a specific program, allowing us to verify whether if the trainings were done correctly. In case of problems, they were advised to retrieve the incomplete sessions during the weekends. Were excluded from the study those who did not completed successfully at least 18 complete sessions.

2.3 Tasks

2.3.1 Probabilistic Gambling Task

At the beginning of each trial, subjects were endowed with 20 points and were asked to gamble a certain amount of these points in the PGT among the following choices: 0, 4, 8. 12, 16, 20. The outcome of the gambling was either to win four times the chosen amount, with a probability $P_{win} = 1/3$, or to loose the entire amount with a probability $P_{loose} = 2/3$ with a

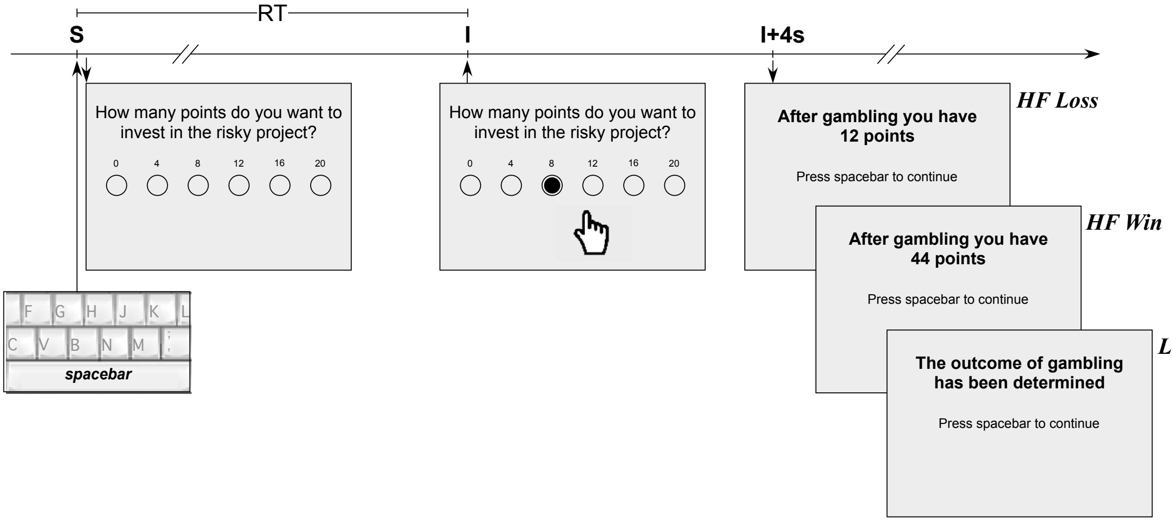

Figure 4: Experimental design of the Probabilistic Gambling Task. Each trial begins by pressing the spacebar (S), which is immediately followed by a message on the computer-controlled monitor with the request to choose a selected amount of points to gamble in a game. The reaction time (RT) is determined by selecting the amount to gamble (I). After an additional fixed interval of 4 seconds (I+4s) the participant was informed about the outcome of the gambling (*HF Loss* or *HF Win*) in the *HF* condition or simply informed about the determination of the gambling in the *LF* condition.

uniformly distributed probability. In the high frequency feedback (HF) condition, the participant was informed about the overall amount of points owned after gambling (e.g., if the participant selected 8 points, the outcome would be $12 = (20 - 8)$ in case of loss, or $44 = (20 - 8) + (8 \times 4)$ in case of win). In the low frequency feedback (LF) condition, the participant was just informed that the outcome of the gambling was determined. In both conditions, participants had the possibility to modify their initial choice during 4 seconds. The overall amount of points held by the participant was displayed every four trials. Each participant played the PGT in 10 alternated blocks of *HF* and *LF* 16 trials each, hence 80 trials for each condition. The procedure of the Investment Game is summarized in the Figure 4.

2.3.2 Dual N-Back Task

The Dual N-Back task was adapted in French from the task proposed by Jaeggi et al. (2008). The task consisted of 20 blocks of 20+N trials. Each trial was composed of an auditory and a visual stimuli presented simultaneously. Visuals stimuli were represented by 3.8 x 3.8 cm blue squares, taking place at one of 8 possible locations on the computer screen. Auditory stimuli were one of 8 letters (Q, D, H, G, K, M, R and Z) delivered by a female voice. Subjects were asked to detect and to press a key if any of the current stimuli corresponded to the ones presented in the previous trial. They had to press the “A” keyboard letter to report the correspondence with a visual target while the auditory target required the pressing of the “L” key (Figure 5). 6 targets had to be discovered within each modality at each block. The level of difficulty was adjusted in function of the performance (adaptive difficulty). If the response was correct, a

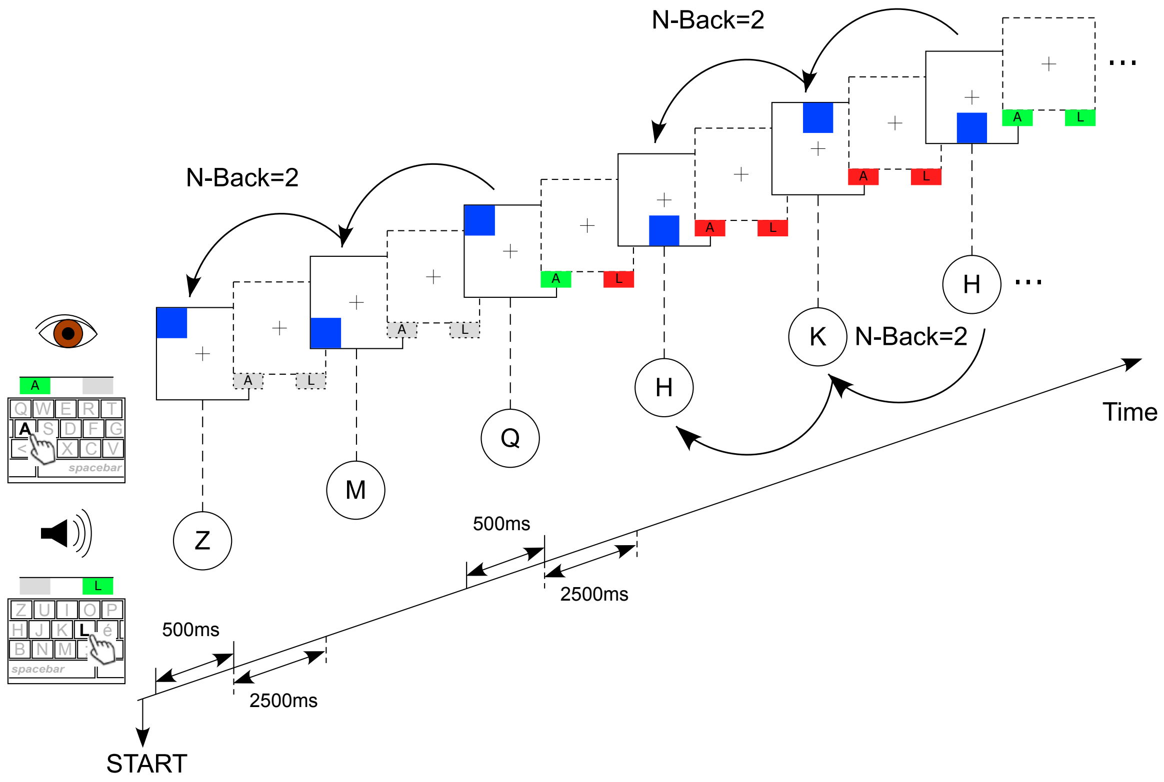

Figure 5: Experimental design of the Dual N-Back Task. Subjects were asked to press the "A" key and/or the "L" key to signal the presence of the identical visual and/or auditory stimuli as presented N-trials before. The figure illustrates a Dual 2-Back condition.

green warning light switched on, whereas a red light indicated a wrong response. In the case where participant made less than 3 mistakes in both modalities, the difficulty was increased by 1, while 5 errors in any modality resulted in a decrease of the level. In the other cases, the level remained unchanged. All subjects played the same version of the Dual N-Back in the laboratory. Each trial lasted 3000 ms. The visual stimulus was presented for 500 ms together with the auditory stimulus. Participants had to give an answer for 2500 ms before the next trial, otherwise accounted as no response.

2.3.3 Attentional Network Test

This task was originally reproduced from the original ANT designed by Fan et al. (2002). Subjects were requested to determine as quickly as possible the direction of a target located in the center of a line constituted of 5 items. Targets were arrows surrounded on both sides by 2 congruent (same direction), incongruent (opposite direction) or neutral (simple lines) flankers, presented above or under a fixation cross. A right click was needed if the target arrow was pointing on the right, while a left click was required in the other case. Prior to the occurrence of the stimuli appeared either a center cue (superimposed on the fixation cross), a double cue (disposed above and under the fixation cross), a spatial cue presented either above or under the fixation cross, in the same location as the imminent stimulus, or no cue at all (Figure 6).

The practice block was composed of a 24 trials, and subjects were informed on their reaction time and accuracy, while the experimental session gathered 3 block of 96 trials. The total length of a trial was 4000 ms and was divided into 5 events. First, the fixation cross appeared in the center of the screen for a variable duration (400–1600 ms); second, the cue emerged for 100 ms; then, the fixation cross remained alone for 400 ms; after that, the stimulus occurred until the participant's response, but did not exceed 1700 ms; finally, the fixation cross remained alone until the end of the trial. Targets, flankers and cues were pseudo-randomly assigned. The practice block lasted approximately 2 minutes whereas one experimental block required around 6 minutes.

2.4 EEG recordings

Electrophysiological signals were recorded using 64 scalp Ag/AgCl active electrodes (ActiveTwo MARK II Biosemi EEG System, BioSemi B.V., Amsterdam, The Netherlands), mounted on a headcap (extended international 10/20 layout (Klem et al., 1999), NeuroSpec Quick Cap, see Figure 7) and referenced to the linked earlobes.

Vertical and horizontal ocular movements were recorded using two pairs of bipolar electrodes placed beneath and above each eye next to the lateral canthi. The data acquisition (DC amplifiers and software by Biosemi, USA) was set with a sampling rate of 1024 Hz at 24 bits resolution and band-passed filtered with lower cutoff at 0.05 Hz and upper cut-off at 200 Hz. Electrode impedances were checked and kept always below 20 $k\Omega$ for all channels before starting the continuous recording of the EEG (Kappenman and Luck, 2010).

At the begin of the recording session, the EEG was recorded during two minutes while the participants kept the eyes closed, and during two minutes while they fixated a cross on the center of the computer screen. In order to reduce the saccadic eye movements all graphical messages were displayed in a screen area corresponding to a vertical angle of 3 degrees and an horizontal angle of 8 degrees, hence falling within the range of the normal human parafoveal region in reading (Rayner, 1998). Participants were asked to restrain their movements, especially concerning their eye motions during the whole performance.

2.5 Statistical analysis

Statistical analyses were performed with the R language and environment for statistical computing (R Core Team, 2013; Venables and Ripley, 2002), and with the SPSS package (IBM Corp. Released 2012. IBM SPSS Statistics for Macintosh, Version 21.0. Armonk, NY: IBM Corp., only for the first article). All statistical hypotheses were tested with a two-tailed level of significance of $2p = .05$, unless otherwise reported. Student's t-test was used to determine if unpaired or paired two-samples of data were significantly different from each other, reporting

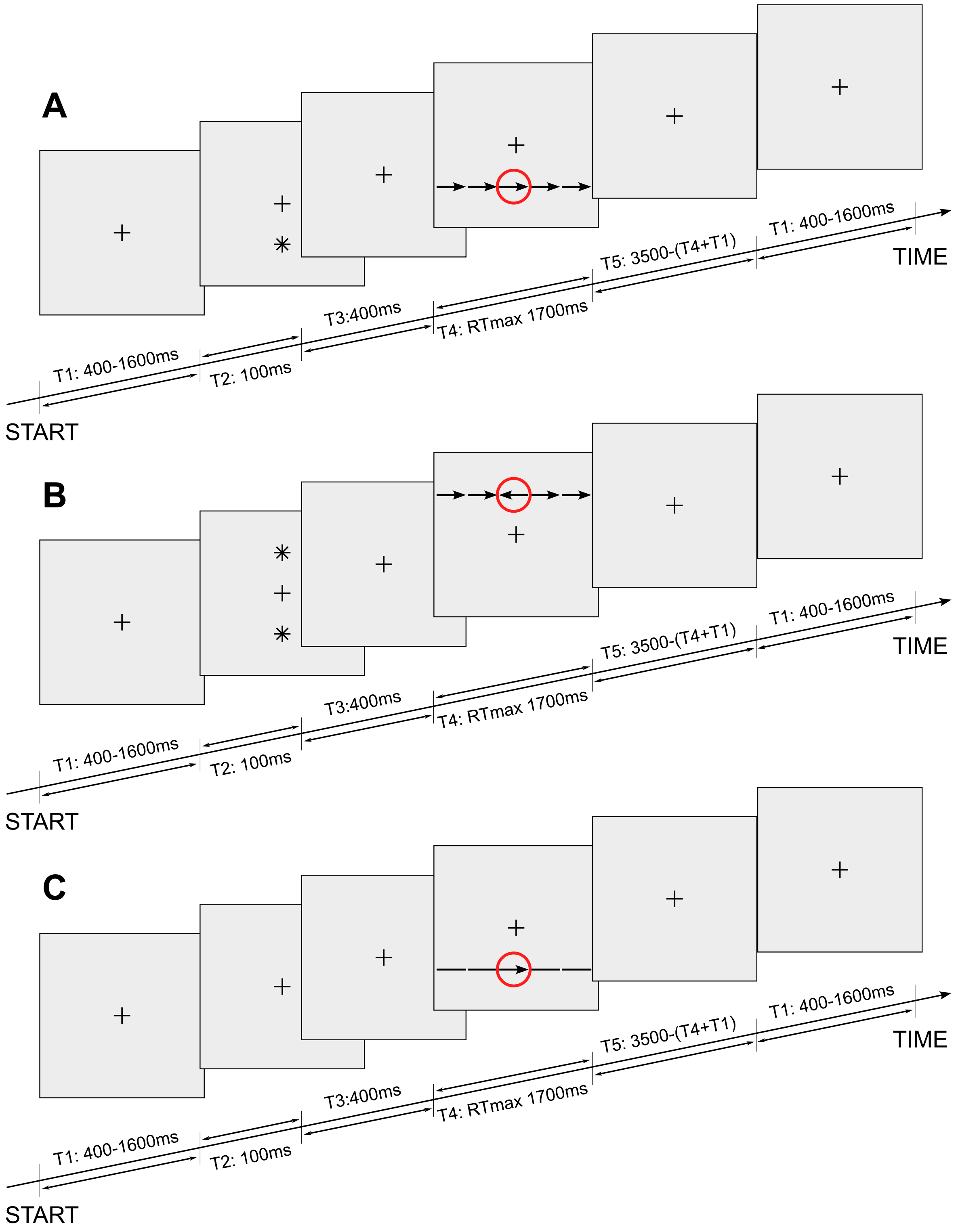

Figure 6: Experimental design of the Attentional Network Test. Participants were requested to indicate the direction of the target (circled in red) as fast as possible. **A**: This figure illustrates the presentation of a spatial cue delivered under the fixation's cross preceding the apparition of a congruent stimulus; **B**: Double cue condition preceding the apparition of an incongruent stimulus; **C**: No cue condition preceding a neutral stimulus.

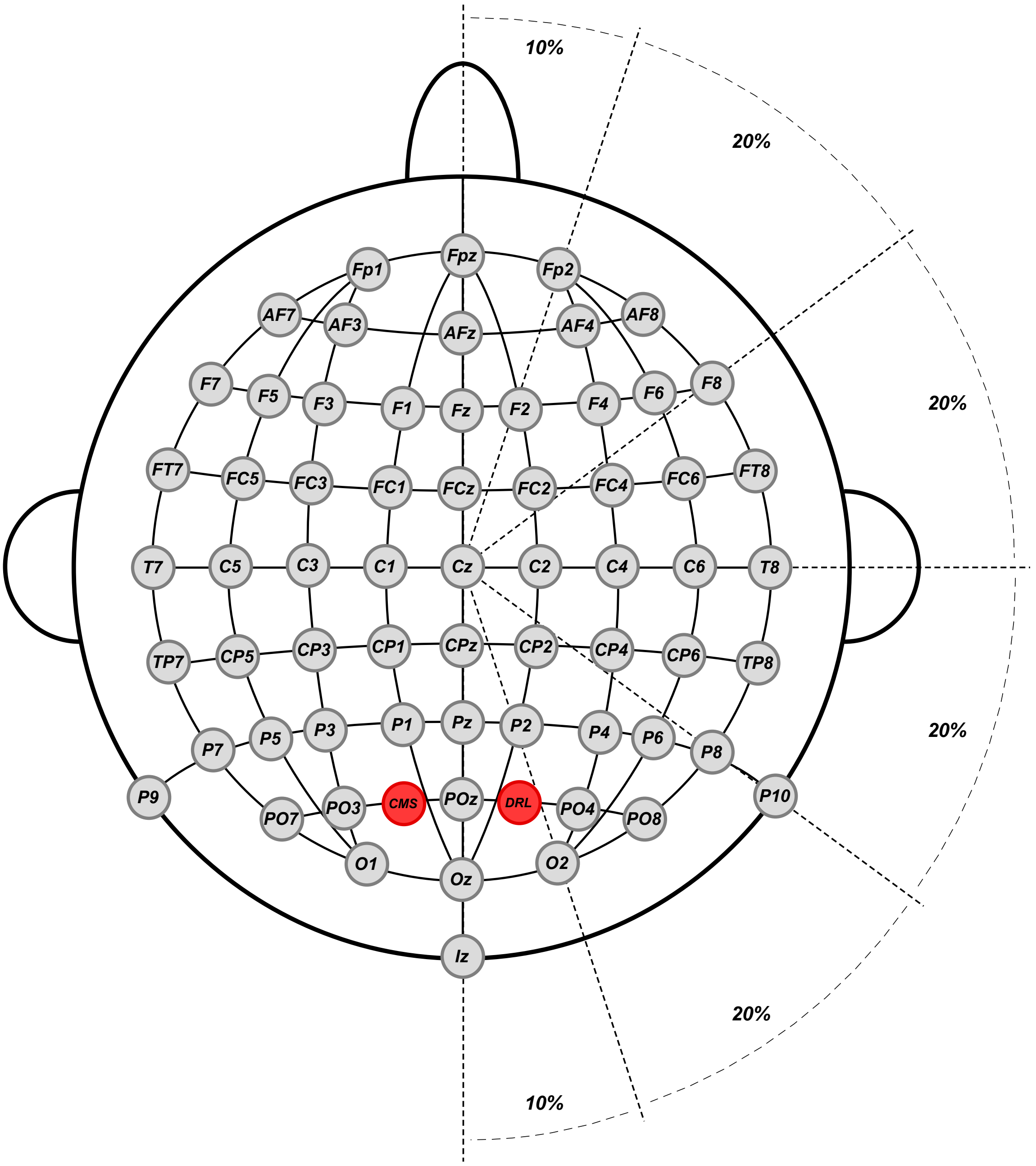

Figure 7: International 10–20 system for EEG with 64 + 2 channels. The system is based on the relationship between the location of an electrode and the underlying area of cerebral cortex. The 10–20 system refers to the actual distances between adjacent electrodes, measured between the nasion (bridge of the nose) and inion (occipital pretuberance) landmarks. Cz represents the top of the head. The other electrodes are either 10% or 20% of the total front-back or right-left distance of the skull. The additional CMS and DRL channels replace the ground electrodes. *CMS*, Common Mode Sense, active electrode; *DRL*, Driven Right Leg, passive electrode. Hemisphere location is defined by a specific letter and number on the top of each electrode. Fp, frontopolar; F, frontal; T, temporal; C, central; P, parietal; O, occipital, I, inion.

the values of the test statistic (t), two-tailed level of significance ($2p$) and Cohen's d effect size. For Chi-squared tests the effect size is reported by Cramer's V (Liebetrau, 1983). Nonparametric comparisons of sample distributions (Zeileis et al., 2008) were assessed by the Wilcoxon signed-rank test using the Z statistic for paired observations and by the Mann-Whitney U test for independent samples with effect size (r). In the second article and additional results, we used robust statistics throughout all the analyses (Boudt et al., 2012; Bodenhofer et al., 2013; Wang et al., 2014; Rousseeuw et al., 2015), including the robust mixed effects model (Koller, 2014) and otherwise stated the linear mixed-effects models for within-subject factorial analyses (Bates et al., 2014).

Behavioral analysis

The performance of the participants was assessed by the total gains earned after the end of playing the whole task (Total Gains ($TotG$)), during low frequency feedback trials ($TG(LF)$), during high frequency feedback trials ($TG(HF)$), and by three risk indexes. The relative number of trials a participant gambled 0, 4, or 8 points defined a low risk index LR. A high risk index HR was defined for gambling amounts of 12, 16, or 20 points. A Global Risk Index (RI) centralized within the range [-1, +1] was calculated as $RI = (HR - LR)/(HR + LR)$. Then, a RI towards -1 is characteristic of a risk-averse strategy, an index towards +1 for a risk-seeking participant, and $RI \approx 0$ being associated with a risk-neutral attitude. Each participant could be further characterized with the corresponding RIs calculated following the feedback frequency trials, i.e. $RI(LF)$ and $RI(HF)$. The behavior of the participants was also assessed by measuring the reaction times (RT) in ms. The trials with $RT < 250$ ms and $RT > 10$ seconds were discarded. Additional trials detected as outliers on the basis of a robust analysis (Breunig et al., 2000) were also discarded from further analyses.

ERP analysis

The brain signals were preprocessed and analyzed with BrainVision Analyzer 2.0.4 (Brain Products, Gilching, Germany) for the PGT. Visual inspection of the EEG was performed to remove immediately those trials containing high amplitude muscle activity related noise, large eye blinks and other easily identifiable artifacts. Saccade-related eye movements were corrected using Infomax Independent Component Analysis (ICA), (Luck, 2005). Markers were used off-line to segment the continuous EEG data into epochs triggered by pressing the spacebar (event S in Figure 4) and by clicking on the selected amount to gamble (event I). The epochs were further scanned and visually inspected to detect any contamination by residual minor artifacts. For the analysis of ERP the trials were cut into epochs lasting 1500 ms ranging from -500 to +1000 ms around the trigger events of interest (i.e., events S and I). ERP analyses were performed on the artifact-free trials, band-pass filtered between 0.1 and 30 Hz (-12dB/octave). Subsequently the trials were baseline corrected to the interval 500 ms prior to trigger onset and averaged for both conditions LF and HF.

Differential waveform analysis

For each participant we calculated separately the ERPs for HF and LF trials. The feedback related differential ERPs were obtained by subtracting the ERP recorded during LF from the ERP recorded during HF condition. In order to assess the group factor we compared the feedback related differential ERPs for controls and ADHD participants triggered by the trial start and by the gambling choice.

3 Summary of the results

3.1 Imperfect Decision Making and Risk Taking are affected by Personality

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In *Decision Making: Uncertainty, Imperfection, Deliberation and Scalability* (pp. 145-184). Springer International Publishing.

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) 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 vs. 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.

Contribution: Recruitment of participants and data acquisition for both studies. Data analysis, and writing for study 2.

3.2 Decision Making Processes in Young Adults Affected by Attention-Deficit/ Hyperactivity Disorder Revealed by Event-Related Potentials During a Gambling Task

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In preparation to be submitted to Biological psychiatry

Abstract: Attention-deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by deficits of executive functions with electrophysiological correlates during childhood and adolescence. Contradictory results exist whether altered event-related potentials (ERPs) in adults are associated with the tendency of ADHD patients towards risky behavior. Clinically diagnosed ADHD patients and healthy controls, aged less than 30 years, were screened with the Conners' Adult ADHD Rating Scales and assessed by the Mini-International Neuropsychiatric Interview, adult ADHD Self-Report Scale, and by the 60-item HEXACO Personality Inventory. All ADHD ($n = 18$) and controls ($n = 18$) performed a probability gambling task (PGT), adapted from the Gneezy-Potters' task, with two frequencies of the feedback information of the outcome. For each trial ERPs were triggered by the self-paced trial start and by the gamble selection. ADHD patients tended to express impulsivity associated with lower values of the agreeableness personality dimension. Both groups exhibited a broad range of individual strategies irrespective of the frequency of the outcome feedback. The latency of the first N2-P3a ERP component, associated with the attentional load, was shorter in the ADHD group. A larger N400-like component in the ADHD in the high feedback frequency condition suggested a larger affective stake confirmed by longer reaction times compared with low feedback frequency. ERP markers showed the build-up of a fronto-parietal activity associated with the emotional percept accompanying the motor response. Our results indicate that in young adult ADHD patients ERP analyses offer as a tool more sensitive than classical behavioral markers to assess the neural dynamics involved in decision making processes.

Contribution: Recruitment of participants, data acquisition and analysis, and writing the paper.

3.3 Additional results

This section summarizes the effects of the Working Memory Training that were not reported in the original papers. The analyses were performed using robust statistical packages from the "R" software.

3.3.1 Dual N-Back performance

At pretest, all individuals reached the level 2 whilst playing to the Dual N-Back task, independently of the training treatment (baseline and adaptive, $\chi^2(1) = 0.74$, $2p = .39$, $V = .06$). However, we found that there were differences between specific groups ($\chi^2(4) = 24.2$, $2p < .001$, $V = .17$), in particular, the group of students UNIL/EPFL with high ASRS score reached significantly higher levels than both ADHD groups, as indicated in the Figure 8. We did not find other group difference at pretest stage of the study with regard to this task.

Following the training, performance on the dual N-Back was enhanced in all groups, including individuals that were assigned with the baseline training ($\chi^2(1) = 104.2$, $2p < .001$, $V = .50$). Nonetheless, we found significant differences between the type of training ($\chi^2(1) = 89.1$, $2p < .001$, $V = .68$) and between the groups ($\chi^2(4) = 28.9$, $2p < .001$, $V = .19$), more specifically, patients with medication reached significantly lesser levels than the three students groups, whereas the non medicated group was only less efficient than the UNIL/EPFL high ASRS group (see figure 8). Interestingly, we did not find significant performance difference between the 2 UNIL/EPFL groups, neither between the two ADHD groups, nor between the 2 UNIL/EPFL and the students recruited in professional schools. The time at which the participants completed the trainings is illustrated in the figure 9.

3.3.2 Span task performance

We were also interested to investigate whether the WMT could have a spillover effect on similar working memory tasks. For this purpose, the WAIS-IV digit span task subtests (global score, *DS-TOT*; number correct forward, *DS-F*; number correct backward, *DS-B*; number in ascending order, *DS-A*), as well as the Corsi Block-Tapping task (correct forward only), evaluating the verbal and visuospatial constructs respectively were administered before the end of the session in the laboratory.

In line with the Dual N-Back data, the pretest span tasks' performance were not equivalent between the groups ($\chi^2_{DS-TOT}(4) = 30.2$, $2p < .001$, $V = .18$, and $\chi^2_{Corsi}(4) = 11.1$, $2p = .003$, $V = .11$). In particular, performance was markedly different between the patient groups and the three students groups (only a trend between UNIL/EPFL students and ADHD with MPH), the patients were characterized by lower scores in the DS-TOT dimension compared with the students, while no difference was found within all students groups and within both patient groups. In addition, a group effect was also found in the three subtests ($\chi^2_{DS-F}(4) = 12.13$, $2p = .02$, $V = .12$, $\chi^2_{DS-B}(4) = 28.13$, $2p < .001$, $V = .18$, $\chi^2_{DS-A}(4) = 22.48$, $2p < .001$, $V = .16$). In regard to the Corsi, the only dissimilarity was found between ADHD with medication and

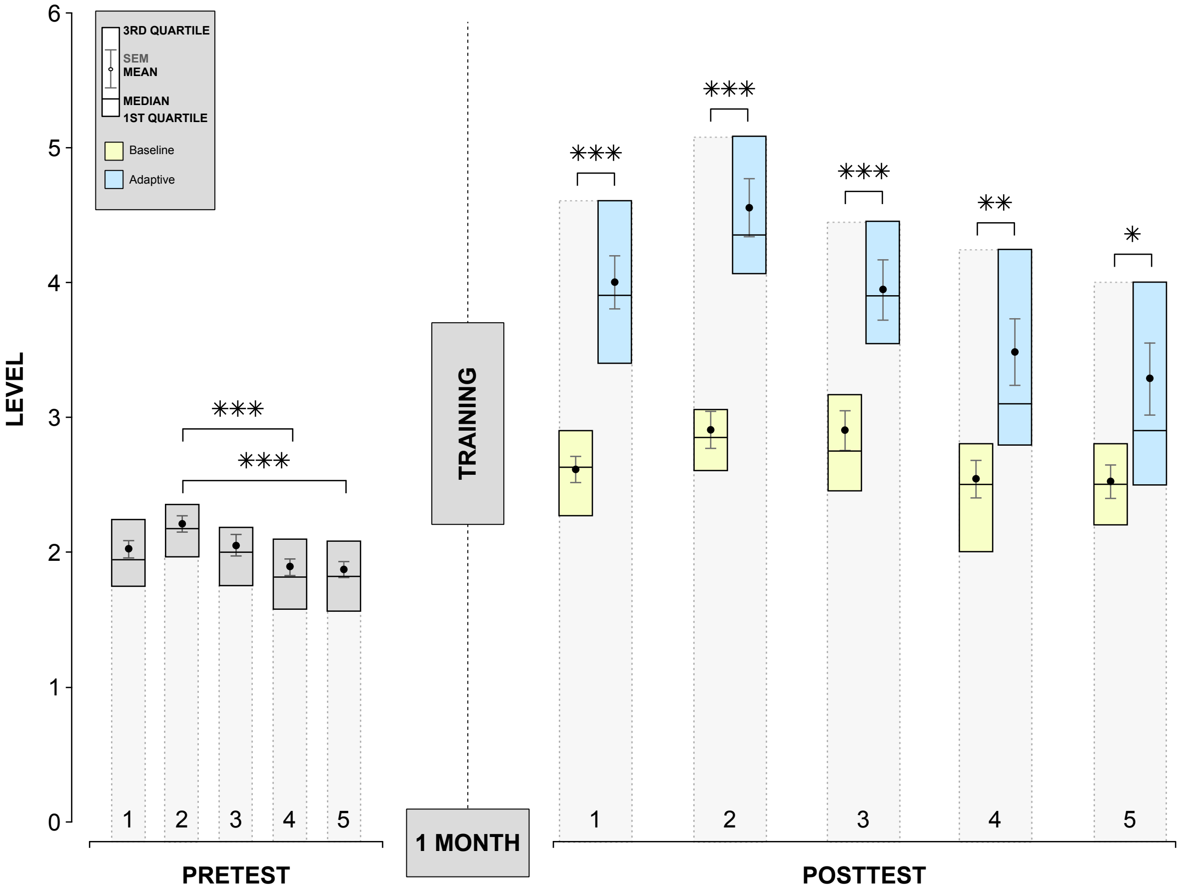

Figure 8: Dual N-Back performance at pretest (left side) and at posttest (right side) sessions in each group, calculated with the nonparametic Mann-Whitney U test with a two-tailed ($2p$) level of significance. 1, UNIL/EPFL student with low ASRS score; 2, UNIL/EPFL student with high ASRS score; 3 professional school students; 4, ADHD without MPH medication; 5, ADHD with MPH medication. ***$2p \leq .001$; **$2p \leq .01$; *$2p \leq .05$

the students from professional schools. Among these comparisons, results indicated that the patient group had lower scores in all tests compared with the students. No difference according to the training type was found within the groups for all tasks.

At the posttest session, all individuals increased their memory span in each task (see table 3, $\chi^2_{DS-TOT}(1) = 60.3$, $2p < .001$, $V = .37$, and $\chi^2_{Corsi}(1) = 9.3$, $2p = .002$, $V = .15$). Furthermore, we found a main effect of the group for the digit span task DS-TOT ($\chi^2_{DS-TOT}(4) = 13.2$, $2p = .01$, $V = .13$). This effect was mainly driven by the fact that all students from professional schools performed much better than the patients groups with MPH medication. We did not find any other difference between the groups. In addition, DS-B subtest was also marked by a group effect ($\chi^2(4) = 18.73$, $2p < .001$, $V = .16$), whereas this effect was close to significance in the DS-A ($\chi^2(4) = 9.45$, $2p = .051$, $V = .11$). In DS-F subtest, performance at posttest session was comparable between the groups ($\chi^2(4) = 5.85$, $2p = .21$, $V = .08$), and the training type did not impact performance in all digit span dimensions ($\chi^2_{DS-TOT}(1) = 1.17$, $2p = .28$, $V = .08$,

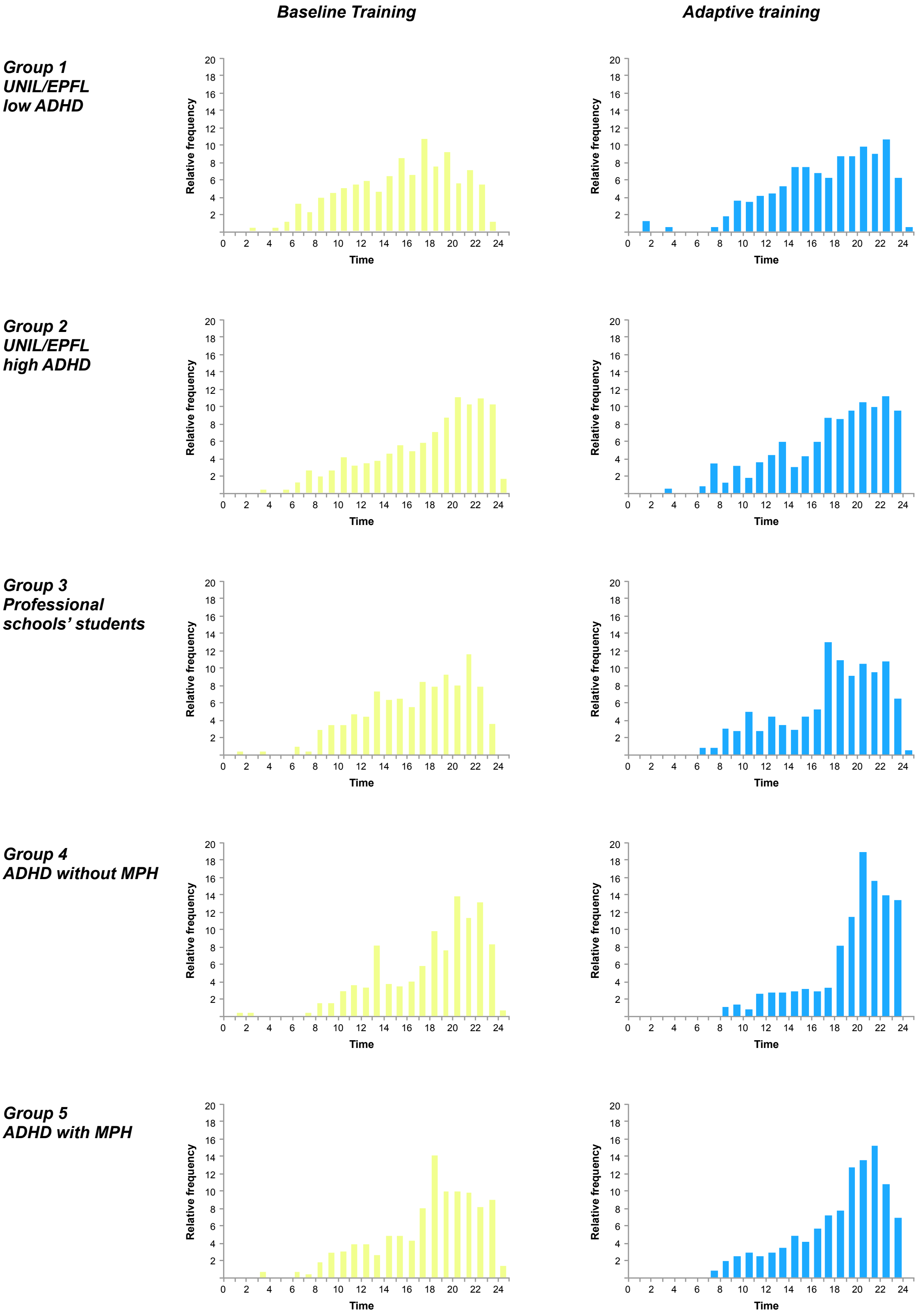

Figure 9: Time at which each participants' group performed the trainings at home

$\chi^2_{DS-F}(1) = 1.53$, $2p = .21$, $V = .09$, $\chi^2_{DS-B}(1) = 0.03$, $2p = .87$, $V = .01$, and $\chi^2_D S - A(1) = 0.03$, $2p = .86$, $V = .01$). Additionally, among the visuospatial dimension, we did not find neither significant group effect ($\chi^2(4) = 0.92$, $2p = .92$, $V = .04$), nor effect of the training type ($\chi^2(1) = 2.08$, $2p = .15$, $V = .11$).

3.3.3 Probabilistic Gambling Task

At the end of the posttest session, the UNIL/EPFL students with low and high ASRS score gained respectively in the PGT (median points ± SEM, more details are depicted in Table 4): 3672 ± 57.8, and 3900 ± 70.2 points, the students from professional schools earned 3844 ± 71 points, and the ADHD patients without and with MPH treatment, 3664 ± 54.7 and 3898 ± 50 points respectively. The *TotG* were not different from pretest session ($\chi^2(1) = 1.80$, $2p = .18$, $V = .06$), and were not affected by the outcomes' frequency of feedback ($\chi^2(1) = 1.99$, $2p = .16$, $V = .07$). However, the analysis revealed a significant effect of the group ($\chi^2(4) = 12.49$, $2p = .02$, $V = .0.12$), but when computing the contrasts, no pairwise comparison reached significance.

Index of risk (*IR*, as calculated in both papers) tended to be different from pretest session (see table 4, median ± SEM: 0.074 ±0.02 at pretest, and 0.109 ±0.03 at posttest session, $\chi^2(1) = 3.72$, $2p = .054$, $V = .09$), suggesting that individuals had the tendency to take a few more risks following the WMT. However, those indexes are really close to 0, and should be interpreted as an indication that all participants have used a variety of strategies in this task. We did not find any significant difference neither between the groups ($\chi^2(4) = 7.72$, $2p = .10$, $V = .10$), nor between the training type at the posttest session for both measures ($\chi^2_{TotG}(1) = 0.25$, $2p = .62$, $V = .03$, and $\chi^2_{IR}(1) = 0.23$, $2p = .63$, $V = .03$).

We also investigated the impact of training on the reaction time in this task, and the results highlighted a main effect of the testing session ($\chi^2(1) = 80.26$, $2p < .001$, $V = .43$), as well as a main effect of the feedback condition ($\chi^2(1) = 50.57$, $2p < .001$, $V = .33$), and a significant feedback condition x session interaction ($\chi^2(1) = 8.19$, $2p = .004$, $V = .19$). Together these effects indicate that reaction times were reduced in the LF condition, and that this effect was even more pronounced during the posttest session (Table 4). We did not find neither a group nor a training type effect at the posttesting session on reaction times ($\chi^2(4) = 5.43$, $2p < .24$, $V = .08$, and $\chi^2(1) = 2.10$, $2p < .15$, $V = .10$, respectively).

3.3.4 Symptoms evolution at follow-up

Participants that have completed the study were invited to fill in the CAARS-S:SV questionnaire after a period of three and six months following the end of the study, to investigate the evolution of ADHD symptoms. Four measures were analyzed, the DSM-IV Inattentive Symptoms (*TA*), DSM-IV Hyperactive-Impulsive Symptoms (*TB*), DSM-IV Total ADHD Symptoms (*TC*), and ADHD Index (*TD*).

At pretest session, all groups' score were significantly different on the four scales (see table 2 $\chi^2_{TA}(4) = 210.17$, $2p < .001$, $V = .49$; $\chi^2_{TB}(4) = 62.1$, $2p < .001$, $V = .27$; $\chi^2_{TC}(4) = 162.85$,

Table 3: Behavioral performance among the Digit span task and Corsi Bock Tapping Task

		Training	DS-F	DS-B	DS-A	DS-TOT	Corsi	DS-F	DS-B	DS-A	DS-TOT	Corsi
			Prestest session					*Posttest session*				
UNIL/EPFL	Low score	Baseline	10 10±0.6	12.4 12±0.6	12.9 13±0.5	12.2 12±0.6	64 60±7	11.4 12±0.6	12.5 13±0.6	12.6 13±0.7	13 13±0.7	78 80±5
		Adaptive	9.3 10±0.6	12.1 12±0.5	12.8 13±0.6	11.9 12±0.6	69 70±6	10.8 10±0.5	12.4 13±0.6	13.5 15±0.7	12.7 13±0.7	71 80±6
	High score	Baseline	10.4 10±0.6	10.8 11±0.6	12.3 12±0.6	11.5 12±0.6	71 80±6	11.7 11±0.8	11.8 12±0.5	14 14±0.5	13 13±0.6	73 85±8
		Adaptive	11.3 11±0.6	11.9 12±0.6	12.3 12±0.6	12.2 12±0.6	62 60±8	12.3 11±0.9	13 12±0.6	13.4 14±0.7	13.5 14±0.7	75 80±4
Prof.	School	Baseline	12 11±0.8	12.8 13±0.6	13.9 13±0.6	13.8 14±0.6	75 80±5	12.9 13±0.7	13.3 14±0.5	14.5 14±0.5	14.5 15±0.6	80 80±4
		Adaptive	11 11±0.5	10.8 11±0.5	12.5 12±0.5	11.7 11±0.5	75 80±4	10.6 11±0.5	11.9 12±0.5	13.2 13±0.6	12.3 13±0.4	74 80±5
ADHD	No MPH	Baseline	9.7 10±0.6	9.9 9±0.5	11.6 12±0.7	10.4 10±0.6	55 60±6	10.8 12±0.7	10.9 11±0.8	12.8 14±0.9	12.1 12±0.9	67 75±7
		Adaptive	10 10±0.5	9.8 11±0.6	10.3 10±0.5	9.7 10±0.5	63 80±6	10.5 10±0.7	10.8 11±0.6	11.6 12±0.8	11.2 11±0.7	75 80±4
	MPH	Baseline	9.5 9±0.5	9.9 9±0.7	10 11±0.7	9.8 10±0.6	62 60±5	10.6 10±0.6	10.9 11±0.6	11.3 10±0.7	11.4 10±0.7	68 80±6
		Adaptive	10.1 10±0.6	10 11±0.6	11.6 12±0.7	10.7 10±0.7	59 60±5	10.7 11±0.7	10.8 11±0.7	12.4 14±0.9	11.7 11±0.7	70 80±5

Mean, median ± SEM of Wais-IV Digit span task's subtests, and Corsi bock-tapping span task at pretest (left side) and posttest (right side) in each group. DS-F, Digit span Forward; DS-B, Digit span Backward; DS-A Digit span Ascending; DS-TOT, Digit span Total.

^{a} Standardized score; ^{b} Percentile.

Table 4: Behavioral performance among the PGT at pretest (left side) and posttest (right side) sessions

		Training type	Total Gains	Index Risk	Reaction Time (ms)	Total Gains	Index Risk	Reaction Time (ms)
			Prestest session			*Posttest session*		
UNIL/EPFL	Low score	Baseline	3775 3690±82	0.11 0.19±0.1	1198 1133±100	3767 3714±100	0.16 0.11±0.1	976 816±149
		Adaptive	3615 3536±72	-0-02 -0.04±0.1	1663 1356±193	3690 3636±57	0.19 0.12±0.1	1089 860±219
	High score	Baseline	3893 3880±90	0.25 0.33±0.1	1498 1367±177	3936 3920±87	0.23 0.24±0.1	1114 852±210
		Adaptive	3831 3688±114	0.14 0.13±0.1	1325 1235±144	3900 3842±114	0.27 0.41±0.1	849 675±109
Prof.	School	Baseline	3830 3786±73	0.16 0.12±0.1	1429 1262±158	3969 3904±98	0.18 0.02±0.1	906 871±88
		Adaptive	3727 3804±52	-0.05 -0.06±0.1	1976 1360±336	3894 3784±104	0.00 -0.01±0.1	1088 985±146
ADHD	No MPH	Baseline	3691 3652±61	0.08 0.18±0.1	1525 1531±124	3722 3672±75	0.05 0.12±0.2	1023 1063±98
		Adaptive	3813 3752±70	-0.06 0.03±0.1	1794 1485±183	3689 3656±83	-0.14 -0.27±0.1	1266 1047±181
	MPH	Baseline	3870 3806±66	0.06 0.14±0.1	1768 1472±237	3870 3876±73	-0.01 0.01±0.1	1067 1024±93
		Adaptive	3735 3742±91	0.08 0.06±0.1	1898 1512±258	3951 3916±69	0.11 0.16±0.1	1630 1110±329

Performance (Mean, median ± SEM) at the Probabilistic Gambling Task (PGT). NB: Total gains were evaluated in points earned among the whole task without distinction of feedback frequency of outcome conditions.

$2p < .001$, $V = .43$; $\chi^2_{TD}(4) = 105.53$, $2p < .001$, $V = .35$). Globally, UNIL/EPFL students with low levels of ASRS had lower scores than UNIL/EPFL students with high levels of ASRS on each measure. Their scores were also lower than the ones of both ADHD groups, but were not different from those of the professional schools' students. UNIL/EPFL students with high levels of ASRS did not differ compared to ADHD having MPH treatment on the Hyperactive-Impulsive subscale, but had reduced scores on all other measures compared with both ADHD groups. Nonetheless, they had higher scores than students from professional schools among all subscales. ADHD with and without MPH treatment did not differ from each other, but had higher scores than professional schools' students.

Participants who took part in the 3- and 6-month follow-up demonstrated a significant decrease of symptoms among the whole measures (see Table 5, $\chi^2_{TA}(2) = 44.37$, $2p < .001$, $V = .31$; $\chi^2_{TB}(2) = 32.04$, $2p < .001$, $V = .27$; $\chi^2_{TC}(2) = 40.60$, $2p < .001$, $V = .30$; $\chi^2_{TD}(2) = 45.99$, $2p < .001$, $V = .32$). The symptoms' reduction was appreciable at 3-months follow-up, compared to the pretest session, and stayed constant at 6-months, as indicated by similar range of scores between 3- and 6-months' evaluations. In spite of finding no effect of the training on the modification of the symptoms ($\chi^2_{TA}(1) = 1.99$, $2p = .16$, $V = .09$; $\chi^2_{TB}(1) = 2.22$, $2p = .14$, $V = .10$; $\chi^2_{TC}(1) = 2.26$, $2p = .13$, $V = .10$; $\chi^2_{TD}(1) = 2.44$, $2p = .11$, $V = .10$), we did found a main effect of group ($\chi^2_{TA}(4) = 145.26$, $2p < .001$, $V = .40$; $\chi^2_{TB}(4) = 54.36$, $2p < .001$, $V = .25$; $\chi^2_{TC}(4) = 54.37$, $2p < .001$, $V = .25$; $\chi^2_{TD}(4) = 101.48$, $2p < .001$, $V = .34$). In particular, UNIL/EPFL students having low levels of ASRS demonstrated a greater reduction compared to the other groups (mean decrease of 6 points ±1.67 SEM on the whole subscales), followed by the patients with ADHD without MPH treatment (5.5 ±2.33 points decrease), then UNIL/EPFL students having high levels of ASRS (4.3 ±2.14 points decrease), next the ADHD with MPH group (3.5 ±2.20 points decrease), and finally the students from professional schools (1.5 ±1.86 points decrease). Reductions were more considerable on the Inattentive subscale (TA, with a mean reduction of 5.6 ±2.25 points among all participants) compared to the Hyperactive-Impulsive (TB, with 5 ±2.17 points of diminution).

Table 5: Clinical assessment of participants after 3 and 6 months of follow-up

		Training type		CAARS A	CAARS B	CAARS C	CAARS D		CAARS A	CAARS B	CAARS C	CAARS D
			N	*3-months follow-up*				*N*	*6-months follow-up*			
UNIL/EPFL	Low score	Baseline	16	45 42±2	42 39±2.9	43 41±3	41 41±1.9	15	42 41±2	39 36±2	39 36±2	41 38±2.5
		Adaptive	15	41 39±2	39 35±1.9	38 37±2	39 40±1.3	17	46 40±3	43 36±3	44 36±4	40 40±2
	High score	Baseline	14	60 58±5	49 45±3.2	56 57±4	51 51±2.7	8	55 59±3	47 46±2	52 54±3	47 48±2.4
		Adaptive	12	62 63±4	50 48±3.2	58 60±4	53 57±3.1	17	65 63±4	56 56±4	63 67±4	54 53±2.6
Prof.	School	Baseline	13	55 53±4	50 48±4	53 49±4	48 47±2.5	11	53 53±3	45 49±3	50 52±3	47 49±2
		Adaptive	15	49 49±3	41 35±2.6	45 43±3	45 45±2.9	14	47 43±3	42 39±3	44 42±3	45 42±3.3
ADHD	No MPH	Baseline	10	63 66±4	60 61±4.9	64 67±5	53 53±3.4	7	71 74±7	64 59±8	71 77±8	56 50±6.2
		Adaptive	12	63 62±4	55 54±3.9	61 61±4	52 49±2.9	8	63 60±4	58 57±5	63 63±6	53 48±4.8
	MPH	Baseline	14	74 75±3	67 76±4.3	73 76±4	64 64±3.4	12	70 69±3	59 60±5	67 67±4	61 62±3.1
		Adaptive	17	64 66±4	53 53±3.3	60 58±4	58 57±2.7	9	66 65±4	52 52±5	61 57±5	56 55±3.9

Mean, median $\pm SEM$ measures of CAARS A–D indexes at 3-months follow-up (left side) and 6-months follow-up (right side) in each group. CAARS A, DSM-IV Inattentive symptoms; CAARS B, DSM-IV Hyperactive/impulsive symptoms; CAARS C, DSM-IV ADHD symptoms total; CAARS D, ADHD index. N, number of individuals.

4 Discussion

4.1 Gambling Behavior

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 regulation may constitute the primary neurochemical basis leading to ADHD symptoms, with anomalous interaction of the dopaminergic neuronal systems (Oades, 2008; Sharma and Couture, 2014). ADHD individuals are characterized by an increased likelihood to take more risks than age-matched controls in activities such as extreme driving and substance abuse (Barkley et al., 1996; Lee et al., 2011). It is recognized that childhood ADHD history has a strong influence on persistent pathological gambling (Breyer et al., 2009; Rodriguez-Jimenez et al., 2006). However, recent findings point out that pathological gambling in adulthood is associated with a comparable elevated level of impulsivity in ADHD and non-ADHD gamblers (Davtian et al., 2012).

Adult ADHD individuals were usually tested by implicit gambling tasks such as the IGT and the BART (Groen et al., 2013a). There is rather consensus among the studies to show no group effect neither in IGT (Agay et al., 2010; Ernst et al., 2003; Ibanez et al., 2012a; Malloy-Diniz et al., 2007), nor in BART (Mäntylä et al., 2012; Weafer et al., 2011). The GDT is an explicit task used for the assessment of risky decision making that could not reveal any salient difference in behavior between ADHD adults and controls (Wilbertz et al., 2012; Matthies et al., 2012). The Probabilistic Gambling Task (PGT) used in the current study is an explicit task with two conditions of feedback frequency of the outcome. Overall, we could not find any difference neither in total gains ($TotG$) earned by each group nor in the RI at pretest. However, we observed a very significant interaction with CAARS-S:SV score with the total earning: the lower the score the higher the gains in controls, but the lower the score the lower the gains in ADHD participants. This result shows that control and ADHD individuals sampled in this study behave in a complex and different way while executing of the task.

Personality

Individuals characterized by ADHD symptoms exhibit affective and motivational deficits in addition to cognitive impairments (Mäntylä et al., 2012; Sonuga-Barke, 2005; Toplak et al., 2005). Emotions are a primary driver of human actions and contribute to shape personality traits. Individuals' characteristics within usual pattern of behaviors that remain stable during adulthood served as the basis to personality traits theories. Basic personality traits described by the HEXACO model emerged from lexical studies of personality structure in several languages (Ashton et al., 2004; Lee and Ashton, 2004; Lee et al., 2005). This model includes six dimensions, i.e., Honesty-Humility (H), Emotionality (E), eXtraversion (X), Agreeableness (vs. anger) (A), Conscientiousness (C) and Openness to Experience (O). It is known that risky decision making is associated with personality traits (Weller and Tikir, 2011; Weller and Thulin, 2012) and that dopamine and serotonin are essential modulators of the expression of personality traits and decision making brain circuits (Carver and Miller, 2006; DeYoung, 2013), but the association between personality traits and risk taking has been investigated with contradictory results (Ashton et al., 2010; Vries et al., 2009). In fact, when it comes to financial risk taking, only the dimensions of Honesty-Humility, Emotionality and Conscientiousness appear to be associated with risky decision-making (Weller and Tikir, 2011; Weller and Thulin, 2012). ADHD patients have been recently characterized by specific personality traits, with lower scores on Conscientiousness, Emotionality and Agreeableness dimensions compared to control subjects (Gomez and Corr, 2014), but their relation with risk taking behavior has not been investigated in detail.

The present study is the first one, to our knowledge, to investigate the personality dimensions of ADHD individuals with the HEXACO Personality Inventory (Ashton and Lee, 2009). Analyses based on the Big Five model of personality have consistently characterized the personality traits of ADHD adults by lower scores of Conscientiousness and Agreeableness and higher score of Neuroticism (Jacob et al., 2007; Martel et al., 2010; Miller et al., 2008; Nigg et al., 2002b; Parker et al., 2004). Conscientiousness is defined in an identical way in the two models, whereas Agreeableness is only partially overlapping, and for both traits we observed significant lower scores in ADHD adults, fully in agreement with the previous studies. Inattention and disorganization are widely recognized to be strongly related to low Conscientiousness (Nigg et al., 2002b; Parker et al., 2004). In a structural equation modeling approach impulsivity was associated with lower Agreeableness while hyperactivity was associated with higher eXtraversion (Knouse et al., 2013). On the contrary to this model we observed a significant lower score for eXtraversion in the ADHD group. This difference may be interpreted by the fact that motor hyperactivity in adults is likely to represent a different symptom with distinct neural correlates compared to childhood and adolescence (Kessler et al., 2010). In fact a previous study reported lower scores for eXtraversion in ADHD adults (Jacob et al., 2007) and one more study reported such lower scores in particular in the inattentive ADHD group and that eXtraversion was positively correlated with agreeableness and Conscientiousness (Parker et al., 2004). It is important to notice that the control group was selected according to a strict criterion of CAARS-S:SV T-score < 56. This criterion may have introduced a bias with respect to other studies towards a group of control individuals characterized by a high score of eXtraversion. Openness and eXtraversion are two traits that overlap in the HEXACO and Big Five models. We observed a score to Openness higher in the ADHD group, while most of other studies did not report any significant result regarding this personality trait in ADHD individuals. It is noteworthy that there are studies not involving ADHD individuals showing an association of higher score of Openness with risk taking and sensation seeking behaviors (Lauriola and Levin, 2001; Vries et al., 2009).

In addition to significant lower Agreeableness score than controls, we observed that the lower the scores of Agreeableness the higher the values of the risk index RI in the ADHD group, thus showing a tendency to take more risk in PGT. Hence, our results support the model of a strong association between low levels of Agreeableness with impulsivity and gambling behavior. Indeed several recent studies performed in groups other than ADHD patients have highlighted an association between low Agreeableness and gambling behavior (Fang and Mowen, 2009; Hanss et al., 2014; Tackett et al., 2014), or risk taking (Vries et al., 2009; Weller and Tikir, 2011).

Effect of feedback frequency

Loss aversion, which refers to the individuals' tendency to be more affected by losses than by comparable gains, can be modified by manipulation of factors such as the feedback frequency of the outcome as in the original Gneezy and Potters' task (Gneezy and Potters, 1997), and in several other studies (Bellemare et al., 2005; Haigh and List, 2005; Langer and Weber, 2008; Sutter, 2007; Thaler et al., 1997). The overall main observation of these studies was the investment of higher stakes when outcomes were presented less frequently in accordance with the Myopic Loss Aversion (MLA) (Benartzi and Thaler, 1995). In the original version of the Gneezy Potters' task, 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 our PGT, the participants were given at each trial the possibility to select the amount to gamble regardless of the condition.

In our studies, we found differing results in the light of strategies adopted during the PGT in regard to the frequency of feedback conditions. In the first study, the results indicated that ADHD tended to take more risk in the *HF* condition, compared to *LF*, while the second study did not find any difference between both conditions. This dissimilarity might be due to the selection of individuals enrolled in the two studies. The ADHD participants were not screened in the same way; the second study focused on a much more rigorous selection in terms of the CAARS-S:SV' criteria and comorbid disorders, whereas the first study was more tolerant. Moreover, the control groups were not recruited in the same institutions, in the first paper, we selected UNIL/EPFL individuals, while in the second article, the controls were enrolled in professional schools. Nevertheless, in both studies, the behavioral results indicated 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. This result suggests that control participants were more likely to evaluate each trial separately in agreement with the Subjective Utility Theory (SEU) (Savage, 2012). Therefore, the results of the original task have not been replicated. 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 PGT. The fact that individuals of either group tended to express the same behavior in *LF* and *HF* conditions in the second study suggests that the feedback frequency of the outcome might have evoked a perception not comparable to the one evoked in the other studies. This hypothesis is supported by the fact that the reaction times during *LF* were faster than during *HF* condition, irrespective of the group. Moreover, during either condition the reaction times of the ADHD individuals tended to be larger than the controls. These findings further suggest that the decision making processes during PGT are indeed affected by the feedback frequency and differences in reaction times are likely to be associated with distinct brain network dynamics in ADHD and control participants.

4.2 Event-Related Potentials

In both studies, we were interested in investigating the electroencephalographic correlates surrounding decision making processes, to wit the self-paced Start of trial (Event S), and the gambling choice (Event I), as illustrated in the Figure 4. We consistently reported several ERP components, which were linked to personality factors in the first study, while the second report provided a more deeper examination of such components.

Start of trial

The current task is characterized by a free-operant behavior, given that the trial onset is associated with pressing the keyboard spacebar. In this goal-directed task, the participants are informed that they would play trials alternatively distributed in blocks of low and high feedback frequency of the outcome. At trial start it is likely that the participants develop their most adapted cognitive strategy by balancing the costs and benefits of making a decision regarding the amount to gamble (Balleine and Dickinson, 1998; Fantino, 1998; Shanks et al., 2002). Hence, the current task might be considered a kind of reinforcement learning in which each participant has to optimize the amount to gamble and the delay necessary to perform that choice (Niv et al., 2006).

Start of trial was characterized by a premotor activity appearing approximately 150 ms prior to stimulus onset. The spacebar pressing evoked a N2–P3a complex, which was followed by a P3b and further a slow negative wave usually referred as the CNV. N2 is a negative component that has been observed to peak between 180 and 325 ms after stimulus onset in several tasks, such as Oddball, Stroop, Go No-Go and Flanker tasks. Specific subcomponents of N2 have been associated with changes in the frequency of stimulus presentation and to the difference of target and non target items, and is usually followed by a P3a (Folstein and Van Petten, 2008; Garrido et al., 2009; Patel and Azzam, 2005). In the present PGT, clicking on the spacebar started the actual trial and raised the presentation of the the six possible amount to gamble. The participants reported to have some insights about the sum to invest during this stage, hence, the presentation of the gamble's options appeared as a target amount surrounded by flankers, a condition well known to evoke N2. We observed that N2 peak latencies were shorter at parietal locations in ADHD compared to controls, and that P3a latencies were also shorter in ADHD, in agreement with another study (Rodriguez and Baylis, 2007). The P3a component has been associated with stimulus-driven attention engagement and thus depending on an active orienting process (Polich, 2007; Squires et al., 1975), and frontal areas as well as the insula contribute mainly to P3a (Bledowski et al., 2004). We found indeed that differences in frontal areas activity were larger at this latency between the groups. No differences between groups were observed for the P3b component after trial start. These observations may suggest that ADHD individuals are characterized by the activation of a less extended brain network engaged in the stimulus-driven attention, thus resulting in shorter N2–P3a latencies.

Although we did not find any significant difference according the the outcomes' frequency of feedback conditions in the second study, *LF* condition was associated with shorter N2 latencies compared to *HF* condition in the first study. This effect was mainly driven by the fact individuals were chosen according to specific personality criteria. In addition, the CNV wave was also modulated by the feedback condition, the amplitude were larger in the *LF* condition, but only in the control group. Its reduced amplitude has been reported in children and adults with ADHD (Valko et al., 2009), suggesting that motor preparation to an imminent stimulus is impaired in ADHD. In line with this result, the lack of CNV enhancement within the patient group might imply that they did not recruit the necessary resources for the motor preparation in the *LF* condition, as it was the case in the control group.

It is interesting to notice that shorter N2 latencies were found in control individuals having higher Conscientiousness scores, and in highly Sincere (facet belonging to the Honesty/Humility dimension) ADHD participants in the *HF* condition, compared to individuals respectively with low scores. The lateral prefrontal cortex is likely to be associated with behavioral inhibition (Krämer et al., 2013), which can suggest that individuals with a high score of Conscientiousness are likely to inhibit response to flankers faster than low score individuals. Sincerity has been associated to ethical and to the health and safety aspects of risky decision making (Weller and Tikir, 2011). In control participants performing the PGT, N2 peaked earlier for individuals with lower scores of Sincerity only at the parietal sites, while, in ADHD participants, this effect was noticeable only at the fronto-central sites. This latter finding, along the same line of interpretation of N2 mentioned above, suggests that in these ADHD participants, the activity of the lateral prefrontal cortex was likely to inhibit the responses to flankers.

Differential wave analysis revealed in second paper a negative component located on fronto-central sites peaking at approximately 500 ms. This late component distinguished ADHD from controls, with a larger amplitude during *HF* condition. This may further suggest that this condition would be associated with a specific affective and motivational value in the ADHD group, somehow reflecting an emotional conflict revealed by N500 or N400-like ERP components in other studies (Chen et al., 2010; Williamson et al., 1991). Hence, at trial start the ADHD individuals, who are aware of playing a trial in the *HF* condition, are likely to engage less attentional resources and larger emotional stake.

Gambling Choice

Following the gamble selection onset we observed several ERP correlates of the executive functions that distinguished ADHD from the controls, namely a N2–P3a complex was characterized by larger peak latencies in ADHD compared to controls, in particular at fronto-central sites, followed by a P3b, which was evoked on fronto-central sites in with shorter peak latency in the ADHD sample, compared with the controls. If we assume that this ERP complex has always been associated with the brain network engaged in the stimulus-driven attention (Mennes et al., 2008; Yang et al., 2007), it is rationale to suggest that the build-up of a higher emotional percept of the gambling choice in the ADHD group is likely to be associated with an extension of the processing network, thus resulting in larger N2–P3a latencies. The executive attention network is responsible of error processing and conflict monitoring. The observation of shorter P3b latencies in the ADHD group suggests a dissociation between perceptual and response conflicts, in agreement with other studies (Yang et al., 2007). The behavioral outcome would result in higher levels of impulsivity revealed by shorter P3b latency.

In a decision making design, the P3a wave is likely to be generated by the cognitive processing that follows the feeling of "dissonance", the possibility of being wrong after taking a decision (Brehm, 1956). The effects of personality on the P3a latency was mainly visible for individuals with higher score of Conscientiousness in the control group and, to a lesser extent, only at fronto-central sites for the ADHD participants. Within high score individuals, this component was evoked earlier in comparison to the ones that had the lowest scores. Conscientiousness has been found to modulate the activation in the lateral prefrontal cortex, a region which is involved in planning as well as in the voluntary control of behavior (DeYoung et al., 2010). Thus, a possible explanation for these results is that individuals with high levels of Conscientiousness may have reached their decision's evaluation more rapidly than the least conscientious subjects. In the controls, this processes appears to involve posterior regions that are likely to be less activated in ADHD.

In addition, P3a peaked earlier for controls with lower score of Agreeableness, but in ADHD participants P3a peaked earlier in higher ranked individuals. Several studies have shown a negative relation between Agreeableness and decision making (Ashton et al., 2010; De Vries et al., 2009). Agreeableness has also been linked to dorsolateral prefrontal cortex, anterior cingulate cortex, and ventral striatum activations, as well as superior temporal sulcus, posterior cingulate cortex, and fusiform gyrus, regions involved in social interaction, and deliberation processes (Koelsch et al., 2013; DeYoung et al., 2010; Sonuga-Barke and Fairchild, 2012). Moreover, the P3a wave has been related to interpersonal conflict, and to susceptibility to framing (Graziano et al., 1996; Weber and Johnson, 2009). These results might therefore suggest that patients with ADHD used different circuits to implement decision making processes leading to choice deliberation and emotion regulation to evaluate interpersonal conflicts.

The last factor of personality that was examined was Sincerity, a facet that belongs to the Honesty/humility trait. This dimension, and in particular this facet has been found to correlate negatively with risk taking (Ashton et al., 2010; De Vries et al., 2009), and more specifically to ethical risk taking (Weller and Tikir, 2011). We found that participants characterized with low score of sincerity were more likely to evoke an earlier P3a wave in comparison to more sincere participants, leading to the interpretation that the evaluation of decision might be reached faster in the less sincere individuals. Hence, this component could represent a good marker being sensitive to the ethical aspect of gambling.

A differential feedback frequency-wave followed P3b. This event was qualified by a negative deflection that occurred at a latency centered on 490 ms, with a larger amplitude during the *LF* compared to the *HF* condition in the ADHD sample. It was located over the midline, more particularly at Cz, and was relevant in the frontal areas. This N400-like component, may be compared to a similar ERP component reported in studies assessing conflict (Chen et al., 2010; Polezzi et al., 2010; Yang et al., 2007; Yang and Zhang, 2011). This topographical distribution is compatible with a generator mainly located in the anterior cingulate cortex, an area associated with the detection of conflict (Botvinick and Carter, 2004; Mai et al., 2004; Van Veen and Carter, 2002). Recent data reported that N400-like amplitude was positively related to the level of impulsivity, in line with the previous neural correlates discussed here (Checa et al., 2014).

4.3 Working Memory Training's effects

Cognitive remediation has been hypothesized to reduce neuropsychological impairments and to reduce ADHD symptomatology. Therefore, this approach was proposed with the aim to complement, or even eliminate a drug treatment that can be both costly and troublesome for these patients. Those training programs have usually employed computerized programs, such as Cogmed Working Memory Training, Pay Attention!, or Captain's Log, which focuses on attentional and WM processes, or mixed WM and attentional tasks programs (Chacko et al., 2014; Cortese et al., 2015; Egeland et al., 2013; Green et al., 2012; Hovik et al., 2013; Johnstone et al., 2010a, 2012; Klingberg et al., 2005; van Dongen-Boomsma et al., 2014). More particularly, the Cogmed method allows to train WM processes, and has been used to decrease attentional problems caused by poor WM. This method has become increasingly utilized and has shown its beneficial effects not only on untrained WM tasks, but also among components of executive functions, such as response inhibition and reasoning. In addition, academic achievement has been shown to take advantage of these training sessions, and some studies even reported a significant reduction of the ADHD symptomatology, as reported by parent and teachers' ratings. (Chacko et al., 2014; Egeland et al., 2013; Green et al., 2012; Hovik et al., 2013; Johnstone et al., 2012; Klingberg et al., 2005; van Dongen-Boomsma et al., 2014).

These cognitive trainings do not only target individuals with impaired skills, but may also be useful for all kinds of people. A currently popular method employs the Dual N-Back task as a WMT, which lasts about a month, and that can be practiced with a computer at home or even on transportable devices. Research conducted on healthy individuals were sometimes contradictory, some argued that an intensiveWMT can have beneficial effects on similar untrained tasks, but also on further domains, such as intelligence, cognitive control, or reading comprehension (Chein and Morrison, 2010; Jaeggi et al., 2008; Salminen et al., 2012). These findings have been strongly undervalued, on the basis of reports that could not detect any kind of improvements, neither on related constructs, nor on more distant material, such general fluid intelligence, episodic memory, verbal fluency, reasoning, and other cognitive abilities (Chooi and Thompson, 2012; Dahlin et al., 2008; Redick et al., 2013; Thompson et al., 2013).

4.3.1 Dual N-Back task

Results from the current study demonstrated a general improvement on the trained task, the Dual N-Back, in all groups. This effect appeared to be quite large ($V = .50$), and even stronger according to the training type ($V = .68$), (Cunha and De Oliveira, 2000; Gravetter and Wallnau, 2013), just as those in the original and other studies (Chooi and Thompson, 2012; Dahlin et al., 2008; Jaeggi et al., 2008; Lilienthal et al., 2013; Morrison and Chein, 2011; Oelhafen et al., 2013; Owens et al., 2013; Redick et al., 2013; Salminen et al., 2012; Thompson et al., 2013). In addition, it is interesting to notice that the participants assigned to the baseline training also improved their performance, result which is in line with other studies that had the same active control group (Jaeggi et al., 2008; Lilienthal et al., 2013). Jaeggi et al. (2008) argued that this gain was likely to be owed to a retest effect. This seems to be in agreement with the report of Lilienthal et al. (2013). In their study, the effects of the WMT was evaluated in three groups, an adaptive training group, a non adaptive training group, and finally a no contact control group. Their results demonstrated that the no contact group displayed also a positive gain at the posttest session on the trained task, suggesting that the insights of Jaeggi et al. (2008) were suitable. However, this enhancement has been reported to be the result of an increase of activation within the prefrontal and parietal areas of the brain, systems that underlie WM, indicating that other untrained tasks should benefit from the effects of the training (Olesen et al., 2004).

None of the studies conducted on children with ADHD used the Dual N-Back as main training task. In fact each study was based on a cognitive program using more than 2 tasks. However, the present project exploited only the Dual N-Back, and was able to demonstrate that adults with ADHD could improve significantly their performance on this task. The results are comparable with the ones reported on trainings solely based on WM in children with ADHD, suggesting that WM can be enhanced regardless of the task and of ADHD patients' age (Chacko et al., 2014; Egeland et al., 2013; Green et al., 2012; Hovik et al., 2013; Johnstone et al., 2012; Klingberg et al., 2005; van Dongen-Boomsma et al., 2014).

4.3.2 Near transfer effects

Near transfer effects were evaluated using the WAIS-IV digit span task Forward, Backward and Ascending order, as well as the Corsi Block-Tapping task Forward only. Following the training, we found that all groups improved their performance on both auditory and visual span tasks. These effects can be qualified as medium ($V = .37$) and rather small ($V = .17$) (Cunha and De Oliveira, 2000; Gravetter and Wallnau, 2013) for the digit span and Corsi, respectively, which implies that the effects of an intensive WMT can be transferred to other untrained WM tasks, in accordance with the work of Jaeggi et al. (2008) in healthy controls, and in ADHD individuals (Chacko et al., 2014; Green et al., 2012; Johnstone et al., 2012; Klingberg et al., 2005). Unfortunately, we did not find any effect related to the type of training. By looking more closely at the results, we observed differences for the digit span Backward subtest between the participants with ADHD and both students from professional school and UNIL/EPFL students with low ASRS scores, while the other subtests did not yield significant difference between the groups. These results may seem surprising, but can be explained in several ways. Nowadays, the effects of motivation on learning are no longer questioned (Nicholls, 1984). Thus, ADHD individuals were more likely to be much more involved and motivated than the control groups in this project, because this training might have a direct effect on their daily functioning, which is not the case for other groups. In addition, the intensity of the current motivation corresponds to the level of subjective difficulty, as long as the demand is considered to be possible and useful to face a challenge (Brehm and Self, 1989). Therefore, untrained subtests (digit span task Forward and Ascending order, and the Corsi Forward) could have been exercised more successfully than the most difficult subtest (digit span task Backward), which may have be perceived as too difficult for the ADHD patients. Moreover, the UNIL/EPFL students have long been accustomed to experimentations. We decided further not to include students belonging to Psychology (SSP) and Economics (HEC) faculties to limit these side effects, but they are still very familiar with the experimental processes. Nevertheless, most of them have participated in this project for financial reasons (they were compensated with 350 CHF at the end of the experimental testings), and not for research. A second control group enrolled in professional schools allowed us to have a group which was naive to experiments, none of them had previously participated in any project. These facts have been reflected in the behavioral performance within these near transfer tasks, we were expecting to see higher differences between the UNIL/EPFL students and the ADHD patients, but finally, the results were truly comparable between these groups.

4.3.3 Far transfer effects

Human behavior is far from economically rational theories and humans failed to reproduce the Homo Economicus's behavior (Thaler, 2000). The perspective of the "rational agent" was investigated by Kahneman and Tversky on "bounded rationality" by emphasizing heuristics and bias in decision making under uncertainty and choice under risk (Kahneman and Tversky, 1979). They analyzed how a rational agent would behave in those various contexts and they demonstrated that contrary to the expected utility theory, the value function (which assigns a value to an outcome) is not symmetrical. Indeed, the value function is steeper than the gain function, meaning that a loss is much more painful as an equivalent gain is pleasurable, a phenomenon called loss aversion.

At the beginning of each trial, the individuals were endowed with 20 points to gamble in a risk project. The gains were not placed back in the game following the gamble, therefore, the participants could not be faced to losses at the end of the game. The most effective strategy would have been to bet the maximum of points at each trial, as demonstrated by the following equations (7), (8), (9), (10), (11), (12), (13):

$$\overline{G}_{(x)} = p_{(Gain)} + p_{(Loss)}, \text{ where } p_{(Gain)} = 1/3 * 4x + (20 - x) \text{ and } p_{(Loss)} = 2/3 * (20 - x) \quad (7)$$

$$\overline{G}_{(20)} = [(20 * 4 + 0) + 2 * (0)]/3 = 26.7 \tag{8}$$

$$\overline{G}_{(16)} = [(16 * 4 + 4) + 2 * (4)]/3 = 25.3 \tag{9}$$

$$\overline{G}_{(12)} = [(12 * 4 + 8) + 2 * (8)]/3 = 24 \tag{10}$$

$$\overline{G}_{(8)} = [(8 * 4 + 12) + 2 * (12)]/3 = 22.7 \tag{11}$$

$$\overline{G}_{(4)} = [(4 * 4 + 16) + 2 * (16)]/3 = 21.3 \tag{12}$$

$$\overline{G}_{(0)} = [(0 * 4 + 20) + 2 * (20)]/3 = 20 \tag{13}$$

At pretest, the risk index were close to 0, indicating that the individuals did not think as rational agents, they were rather driven by their unwillingness to take high risks in order to avoid losses. However, the results of this study suggests that working memory training resulted in a increase of risky behavior in our PGT among the participants, suggesting that the training caused a unification of the strategies towards a more rational behavior. These effects were neither selective to the training type, nor to the group, and did not affect the total gains. Nonetheless, we observed a large decrease in reaction time in this task after the training irrespective of the training condition or of the group. This result indicates that the repetition of trials has allowed the individuals to become more experienced, therefore to select an amount to gamble much faster at posttest.

To our knowledge, there is only one study that assessed the effects of a WMT on decision making (Bickel et al., 2011). This research was able to demonstrate that stimulant-dependent individuals displayed a decrease in discounting of delayed rewards after the training, which did not affect the heathy controls, indicating that these changes resulted from the enhancement of WM. A delay discounting task is a game where individuals have to choose between a small immediate, and a large delayed amount of money, a task designed to measure the degree of impulse control. It is important to stress that in the latter study, the authors did not find any transfer effect on the BART task, a game which is more representative of the gambling behavior assessed in our study. Therefore our results appeared to be in line with those results, in addition to the other studies that could not find any far transfer effect either in controls or in the ADHD population (Chacko et al., 2014; Chooi and Thompson, 2012; Dahlin et al., 2008; Redick et al., 2013; Thompson et al., 2013; van Dongen-Boomsma et al., 2014).

4.3.4 Changes in ADHD symptomatology

ADHD is a neurodevelopemental disorder usually diagnosed during childhood. It is generally assumed that it affects more than 4% of the children, with a greater representation of boys (Brown et al., 2001; Faraone et al., 2003; Polanczyk et al., 2007; Willcutt, 2012). Individuals living with this condition manifest attentional impairments, such as daydreaming, distractibility, difficulties in concentrating and maintaining focused attention, high degree of impulsivity, as well as excessive level of activity and talking. Disturbance associated with ADHD during childhood may also include learning difficulties that can lead to academic failure and social issues, thus increasing the risk of substance abuse and low self-esteem (Biederman, 2005). ADHD has long been regarded as a childhood disease, but in recent years, scientific proofs have demonstrated that the symptoms did not decrease during adolescence, on the contrary, it can persist into adulthood (Avisar and Shalev, 2011; Biederman et al., 2007a; Hervey et al., 2004). The Conners' Adult ADHD Rating Scale is a multidimensional instrument that can help to assess the presence and severity of ADHD in adults. It allows to investigate several symptomatic dimensions, to wit, the DSM-IV Inattentive Symptoms (*TA*), DSM-IV Hyperactive-Impulsive Symptoms (*TB*), DSM-IV Total ADHD Symptoms (*TC*), and ADHD Index (*TD*) (Conners et al., 1999). Participants completed the self-assessment form, but it would also have been possible to ask their relatives to fill-in the adapted forms, in order to have complementary data. The particular issue of this intensive WMT could involve a possible improvement of ADHD symptoms, which could result in a complementary therapy or even as a substitute to a drug treatment for these patients.

In the present project, all participants filled this questionnaire prior to the beginning of the testing period. We also got back in contact with them three and six months after the end of the study to ask them to fill in again this evaluation form in order to evaluate any changes in ADHD symptomatology. Overall the results indicated a significant reduction of the symptoms on each subscale at 3-months follow-up. The effect size were in between .27 and .49, which can be considered as large (Cunha and De Oliveira, 2000; Gravetter and Wallnau, 2013). These reductions were not affected by the training type, indicating that the WMT had a positive impact on inattentive and hyperactive/impulsive symptoms in all training conditions. Although one study did not find any significant effect of the training (van Dongen-Boomsma et al., 2014), some other reports on children with ADHD could also detect improvement on attentional and hyperactive/impulsive symptoms, based on parents' and/or teachers' ratings (Chacko et al., 2014; Green et al., 2012; Klingberg et al., 2005; Stevens et al., 2015). Even if the training program was not the same in the latter studies, they all used the Cogmed cognitive remediation's program. This divergence of methodology provides evidence that WM is a key system acting in the phenotype of ADHD impairments (Barkley, 1997; Barkley and Murphy, 2011; Brown et al., 2009). In addition, we did not notice any changes between 3- and 6-months follow-up, which suggests that the symptoms' improvement could last over the long term.

An interesting discovery is that this effect was modulated by the groups. Indeed, we found that not only ADHD participants had benefited from these effects, but also the healthy controls demonstrated a decrease of inattention and hyperactive/impulsive scores on the CAARS-S:SV' scales. This result implies that the effects of the training are not limited to populations with specific deficits such as ADHD, and present a great interest for public health arguments against self-administration of alcohol or drugs to enhance the performance or reduce stressors in the context of high pressure and work overload (Frone, 2008; Newbury-Birch et al., 2000; Webb et al., 1996).

4.4 Experimental limitations

4.4.1 Control tasks

It is important to state the limitations of the span tasks. First, these tasks had a limited number of trials, for instance, in the digit span task Forward, we observed that some students reached the maximum level already at pretest, thus it did not allow to assess the improvements of such students at the posttest session. If the levels were more numerous, we would certainly have been able to demonstrate better effects of the training in this subtest.

Second, the effects of the training could have been biased by the fact that the protocol was very long. The results of the span tasks have also shown that the easiest subtest (digit span task Forward) was often less well practiced at posttest by some participants than the other subtests, indicating that following the break, the participants were completely distracted. The individuals were all very tired by the training and wanted to finish the study as fast as possible, thus did not optimally execute these last tasks. We could have avoided this bias by shifting the tasks at the beginning of the testing sessions, or by separating the appointments. However the separation of the sessions would have been really difficult. It was already demanding to find two matching appointments for an individual, and would have been even more difficult to find four appointments for the same person.

4.4.2 Probabilistic Gambling Task

The PGT is a task which was rearranged from a task seeking to evaluate the risk taking modulators among investors. The way it was modified could have been more effective in this project. First, it is likely that the participants were not really motivated whilst gambling, as revealed by the index of risk close to zero. A possible solution could be the way of compensation, they earned 350 CHF for the whole procedure, but it is possible to imagine that they could have earned a fixed amount of 300 CHF plus the selection of two random trials played during the game. The method of administration could have been more attractive by handling the points differently. In our study, 20 points were attributed to the participants at the beginning of each trial, but it could be possible to endow them with a fixed amount within each block, in order to evaluate how the participants manage their money during the two conditions. Further, it would also have been possible to assess their preferences towards risk using a self-administrated questionnaire. Thus, the performances could have been controlled in light of each individual's scores.

Nevertheless, one strength of the PGT analyses is the time-frames defined to assess decision making with EEG. As a matter of fact, most studies have investigated reward or feedback processing, because ERP correlates are better understood and allow a better analysis of the results. The present investigation has enabled us to study the processes surrounding decision making, which are not yet fully assimilated, in particular in adult ADHD individuals. Moreover, putting in perspective the data with personality factors allowed us to show that some differences are specific to particular traits, not just at the behavioral level but also within the neural level.

4.4.3 Training session

The Dual N-Back is a task that has been recognized to properly assess the dimensions of working memory, a training on that basis is therefore very suitable. However, all individuals did not understand the task at first sight, in particular the patients with ADHD. It is possible to improve this point by adding a practice period prior to the test. We noticed that individuals evaluated the game as being relatively difficult, especially the patients. Many of them have reported to have lack of motivation to do the trainings each day, and we had to accompany some participants quite closely. Still, we had to exclude a number of participants due to their lack of discipline. The difficulty of the training and the involvement of the participants were key factors in the choice of the compensation of participants. This is why we chose a relatively high amount of 350 CHF. This amount attracted many students, because most of the studies that take place at the university of Lausanne do not offer this kind of money. We observed that the majority of the UNIL/EPFL students were only motivated by the financial compensation, which was evident in regard to their Dual N-Back performance (among other facts). This is one of the reasons we chose to add another control group to the study. Therefore, we decided to select individuals that were naive to experimentations to avoid this bias. Another way to escape this side effect could have been to eliminate the financial compensation to prevent from poor performance (Gneezy and Rustichini, 2000). We can not dismiss the fact that it could have been possible for the individuals to ask other people to complete the training for them, or, on the contrary, to have increased the number of practice with the smartphone application.

It is important to notice that the ADHD patients that have withdrawn from the study were the ones that had the higher rates of comorbidity. In addition, we noticed that there was a positive correlation between those patients and the number of major artifacts in the EEG signals, which were excluded from the ERP analyses. In spite of these exclusions, individuals who completed the study, especially the patients, have expressed their enthusiasm in respect to this game, and noticed some behavioral changes in their daily functioning. We were really pleased to have such feedback.

4.5 General conclusions

ADHD is a neuropsychiatric disorder that evolves continuously between childhood and adulthood. Yet, each individual presents a specific profile, making the diagnosis difficult to establish.

Most common negative symptoms being reported are attention deficit, which may be accompanied by hyperactivity and impulsivity. Inattention problems are also frequent and can lead to many difficulties in daily life, such as academic failure, social isolation, and emotional troubles. The administration of a drug treatment is an effective way to fight against these symptoms. The effects are fast, but require several administrations per day depending on the intensity of the disorder. Other therapies have started to become more attractive, namely, cognitive remediation. These methods have have allowed to reduce the symptoms and to improve some deficient aspects, such as working memory functions on more extended periods.

The aim of the present study was to examine the effects of an intensive working memory training conducted with the Dual N-back task in a population of young adults with ADHD and match-controls through various measures including electroencephalography.

In opposition to most other studies assessing decision making, our work was interested in events surrounding decision making processes. Overall, the results indicated that spacebar pressing evoked a N2–P3a complex, which was followed by a P3b and further a slow negative wave usually referred as the CNV. Following the gamble selection onset, another N2–P3a complex was evoked. These components appeared to be different in both groups, N2 and P3a were shorter in the ADHD sample after the start of trial, while this complex was evoked at longer latencies in the ADHD at the second stage of decision making.

Further, we observed that specific traits of personality were associated with risky decision making, not only at the behavioral level, but also in regard with neurocognitive processes. In particular, Conscientiousness, Agreeableness and Sincerity modulated the latencies of the negative wave occurring at around 200ms (N2) and of the positive deflection peaking at around 250ms (P3a) components at decision stages. N2 peaked earlier in individuals with high levels of Conscientiousness, controls with low score of Sincerity and highly sincere patients with ADHD following the appearance of the gamble choices. Furthermore, after selecting the chosen amount, 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.

In addition, we found that the working memory training had a spillover effect on near constructs, as assessed by untrained working memory span tasks in all groups, independently of the training type. However, these effects were rather absent on decision making behaviors. Nonetheless, an interesting discovery is that the CAARS-S:SV scores in all participants were reduced following the training. Together, these results suggest that selected differences characterizing ADHD might be enhanced by a cognitive training solely based on working memory.

4.5.1 Future directions

The aim of the present study was to examine the effects of an intensive working memory training conducted with the Dual N-Back task in a population of young adults with ADHD and with age-matched healthy controls. This study took place at the University of Lausanne with the interdisciplinary collaboration of diverse departments, namely the Department of Information

Systems, and the Department of Economics, from the Faculty of Business and Economics (HEC), and the Department of Child and Adolescent Psychiatry (SUPEA), from the Faculty of Medicine.

This project lasted over three years: the first year was spent with the elaboration of the tasks, the set-up of the laboratory, and the pilot studies that have allowed to validate the protocol. The second and third years were dedicated to the recruitment and to the experimental sessions that included more than 430 testing periods in the laboratory. During this period, we also intended International meetings and published one peer-reviewed article, while another one is in preparation.

An important issue for future research would be the examination of all the data we have collected. At the beginning of the project, we planned to study the effects of this training on attention, as measured by the Attentional Network Test (ANT), and to evaluate the brain responses that resulted following the training not only for trained task but also on decision making. Unfortunately, the data collection and their examination took much longer than expected, especially because of the addition of a third control group. Nevertheless, it is possible to make some assumptions regarding these unexploited data.

It has been reported that the N-Back/Dual N-Back task evoked a N2 and P3 waves following the presentation of the stimuli (Stroux et al., 2015; Watter et al., 2001). These studies were more interested in the behavior of the P3 component and found that the increase of the cognitive load resulted in its amplitude decrease, as well as a diminution of its peak latency. This component was also larger for non-match stimuli, compared to those that matched, and appeared to be maximal at parietal sites, compared to central and frontal areas (Oelhafen et al., 2013; Watter et al., 2001). However, in ADHD, cognitive load did not modulate the P3 as it was the case in the control group, suggesting a deficient interference control in these patients (Stroux et al., 2015).

A recent study showed that brain activity within frontal, parietal and temporal regions was increased following an intensive training using the Cogmed program, in addition to enhancements of WM performance and symptomatology in an ADHD population (Stevens et al., 2015). These results appear to be similar to those found in healthy populations (Olesen et al., 2004). Moreover, the P3 has been hypothesized to be generated within the temporal parietal junction and to be modulated by the activity of the locus coeruleus norepinephrine system (Nieuwenhuis et al., 2005a). According to these facts and to the behavioral results found in the present project, it is possible to consider that the WMT would modify both latency and amplitude of the P3 component following the stimulus presentation in the Dual N-Back task. We would expect an increase latency in both groups, and more especially a normalization of the P3 amplitude in ADHD.

The ANT is a test assessing attentional capacity of individuals within three different constructs: alerting, orienting, and conflict networks. It has been shown that adults with ADHD present accuracy impairments and reaction time fluctuations compared to healthy controls (Lundervold et al., 2011). Although some studies did not find any far transfer effects following a WMT, others have found more positive results (Chacko et al., 2014; Klingberg et al., 2005).

Thus we would expect an enhancement of ADHD performance in regard to the ANT, more particularly in regard with the reaction times.

The main aim of this project was to assess the neural changes following this intensive training on decision making using a gambling task. Although we do not currently have published any data, some preliminary results have been presented last year in the annual meeting of the Society for Neuroeconomics. These preliminary results highlighted selected differences in the activity triggered by both time frames investigated during the PGT. We observed that the amplitude of the P3a was larger in all trained individuals in both *LF* and *HF* conditions. In addition, the activity evoked by the selection of the invested amount was larger in all trained participants in the *LF* condition. Moreover, in the *HF*, similar observations were measured in the controls on parietal sites, while these differences were mostly perceptible on the frontal site in the ADHD participants. These results might highlight that the early brain activity was indeed affected by the training.

We hope to expand these results and generalize them to all the participants of our study. We would expect not see no difference between the three control groups, however, it may be possible that N2–P3a peak latencies in ADHD individuals become normalized following the training, with a higher improvement in the adaptive group.

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6 Annexes

6.1 List of publications

Mesrobian, S. K., Lintas, A., Bader, M., Götte, L., & Villa, A. E. P. (In preparation to be submitted to Biological psychiatry). Decision Making Processes in Young Adults Affected by Attention-Deficit/Hyperactivity Disorder Revealed by Event-Related Potentials During a Gambling Task.

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Mesrobian, S. K., Lintas, A., Bader, M., Götte, L., & Villa, A. E. P. (2014). Working Memory Training and Risky Decision-Making: An ERP Study in ADHD and Control Participants. *Society for Neuroeconomics Annual Meeting.* Miami, 26–28.09 2014.

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6.2 Paper presented at the section 3.1

Mesrobian, S. K., Bader, M., Götte, L., Villa, A. E.P., & Lintas, A. (2015). Imperfect Decision Making and Risk Taking Are Affected by Personality. In *Decision Making: Uncertainty, Imperfection, Deliberation and Scalability.* (pp. 145-184). Springer International Publishing.

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

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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)

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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].

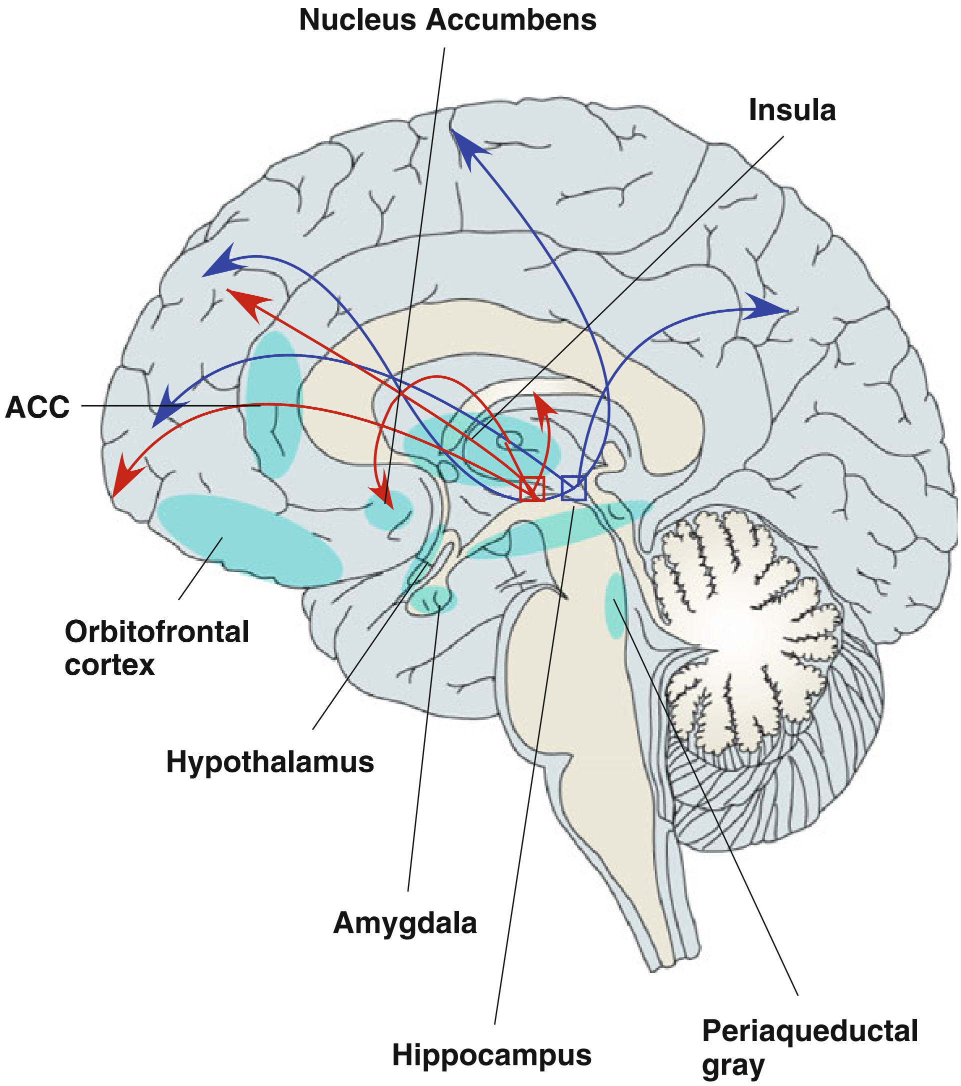

Fig. 6.1 Human brain illustration of medial surface of the left cerebral hemisphere (modified from [46]). The principal areas involved in decision-making are labeled in turquoise. The *blue arrows* show the main modulatory projections of the nuclei using the serotonin transmitter to cortical areas. The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

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

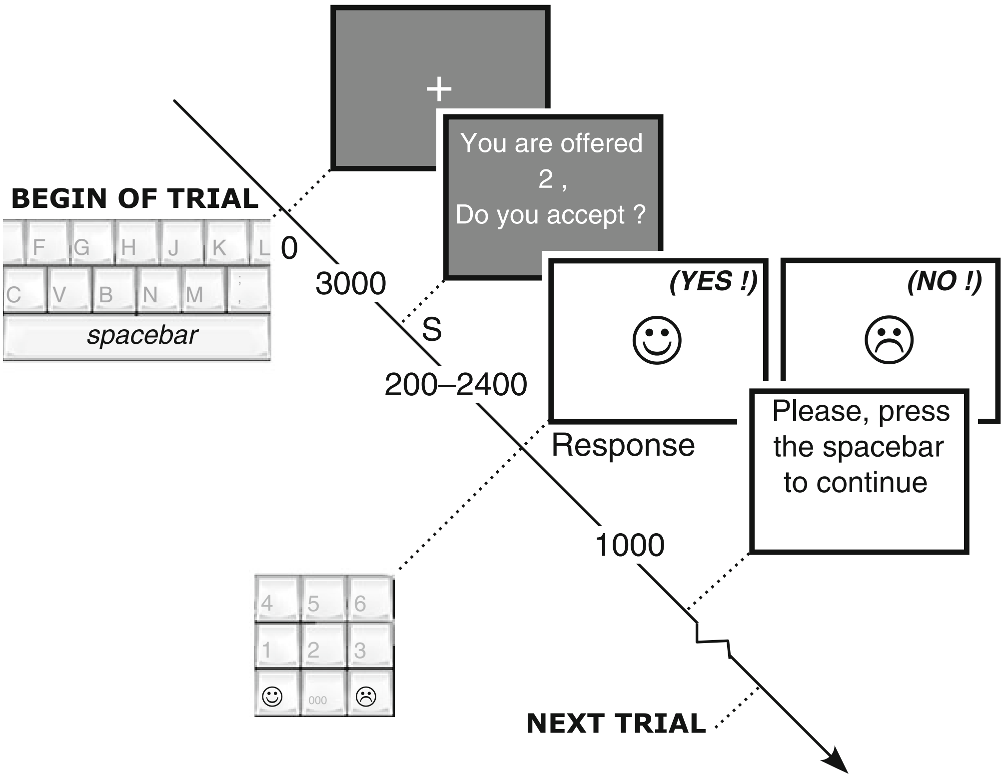

Fig. 6.2 Illustration of the Ultimatum Game task with the participants acting as responders. Event (S) indicate the stimulus onset

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 $p < 0.01$

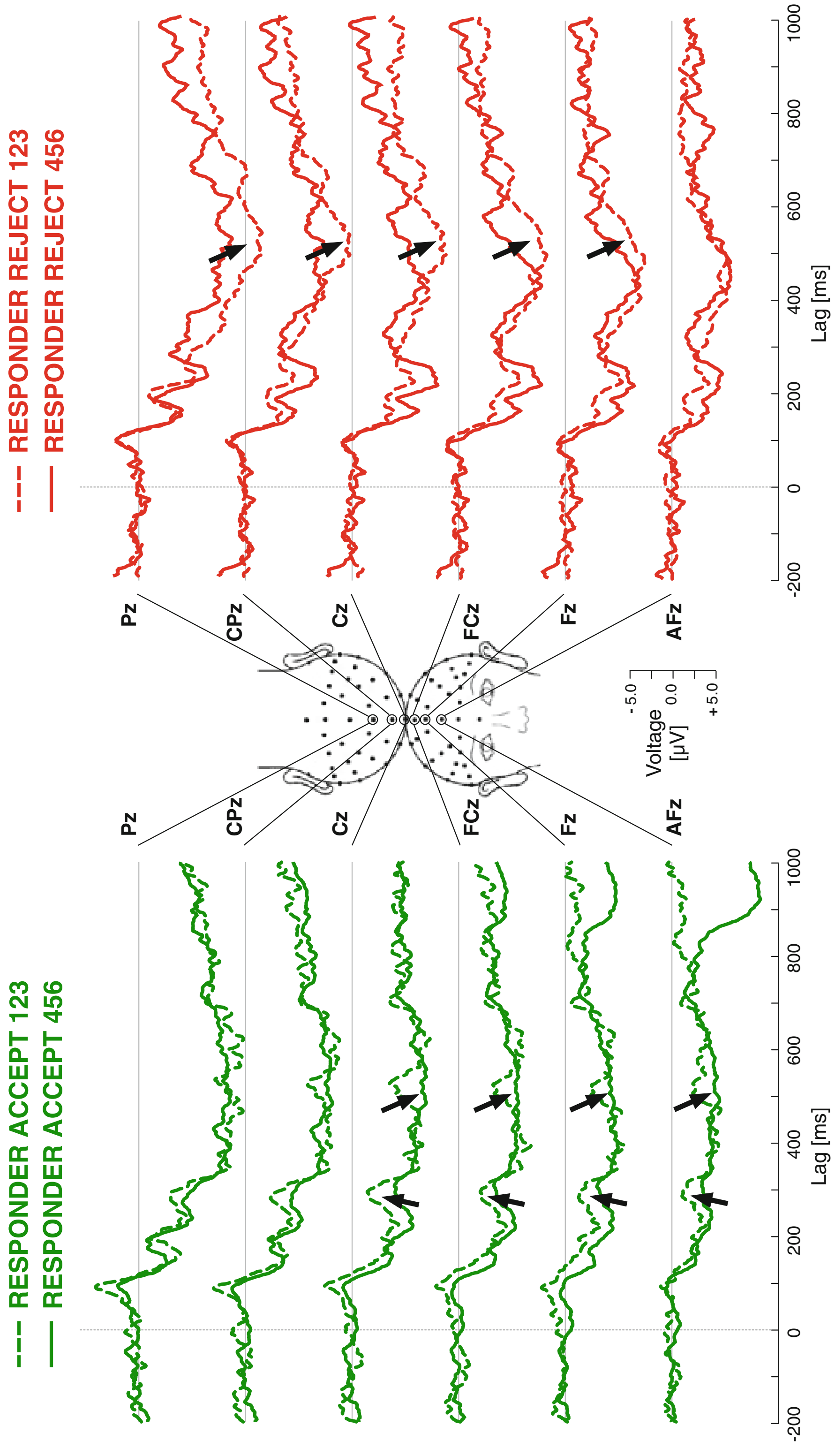

Fig. 6.3 Event related potentials during the Ultimatum Game. Grand-average ERPs at electrode sites AFz, Fz, FCz, Cz, CPz and Pz following the acceptance (*green lines*) or rejection (*red lines*) of an offer. *Dashed lines* refer to the decision following wretched offers (123) and *solid lines* following 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

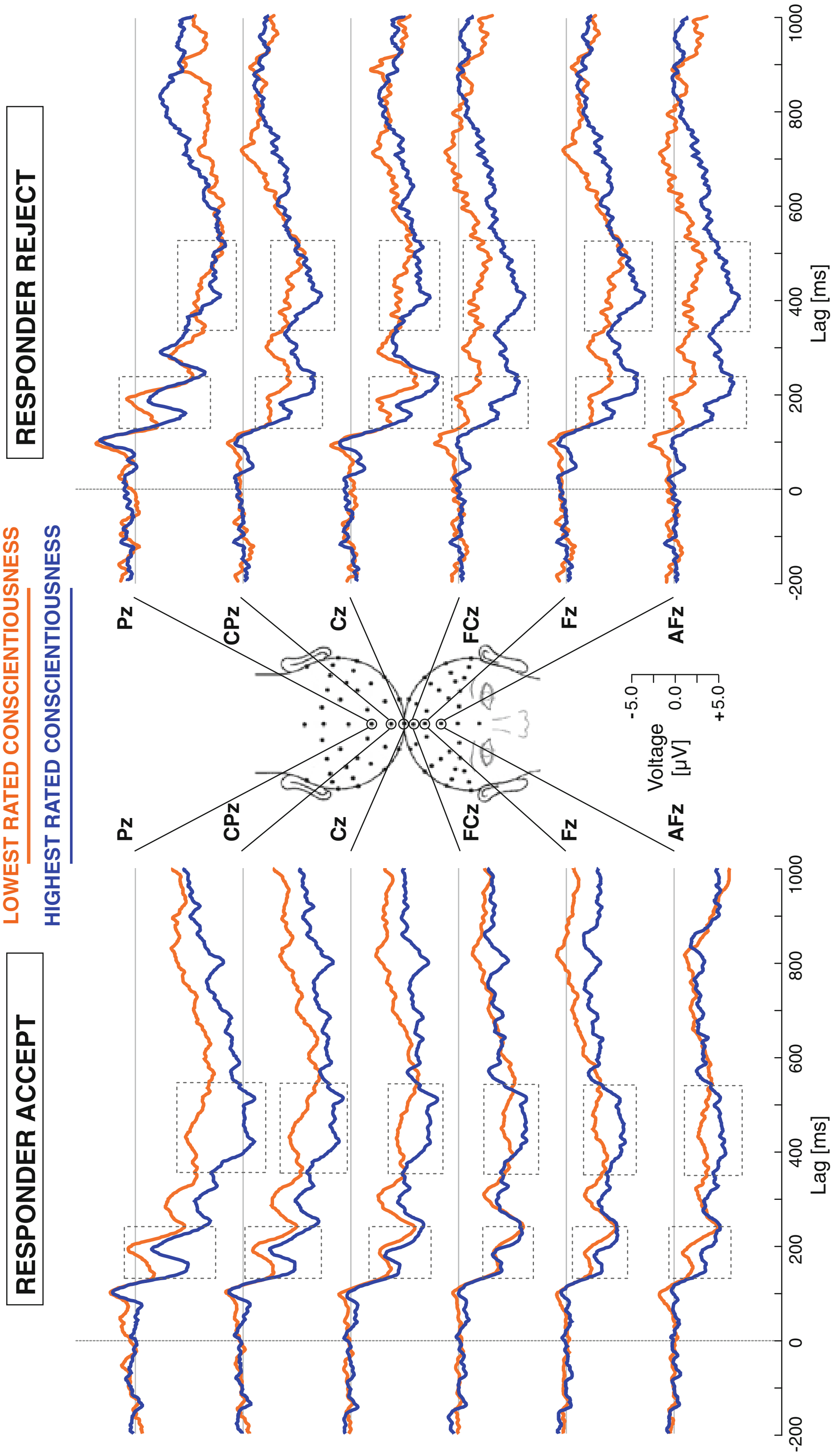

Fig. 6.4 Event Related Potentials during the Ultimatum Game. Grand-average ERPs at electrode sites AFz, Fz, FCz, Cz, CPz and Pz following the acceptance (*left panel*) or rejection (*right panel*) of any kind of offer (wretched, fair and prodigal pooled together). Participants are subdivided in two groups 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

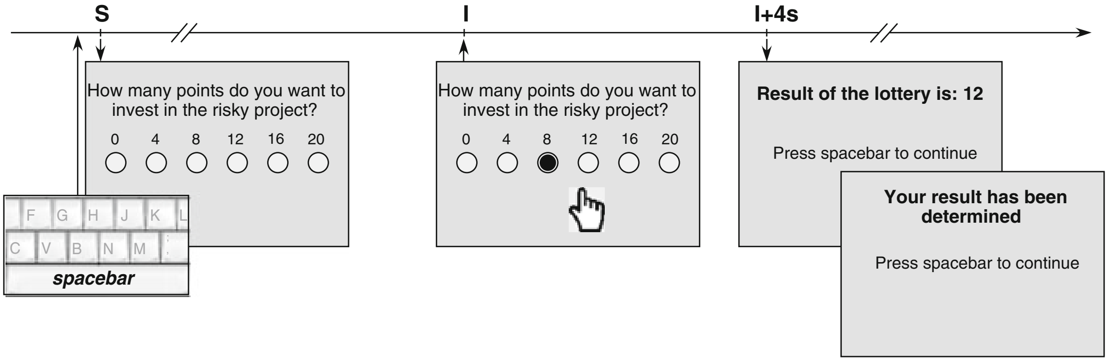

Fig. 6.5 Experimental protocol of the Investment Game. Participants started the task by pressing the spacebar (S) and then were asked to invest a certain amount of points in a risky project. The decision making process was not limited in time. Once the investment option selected (I), participants could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

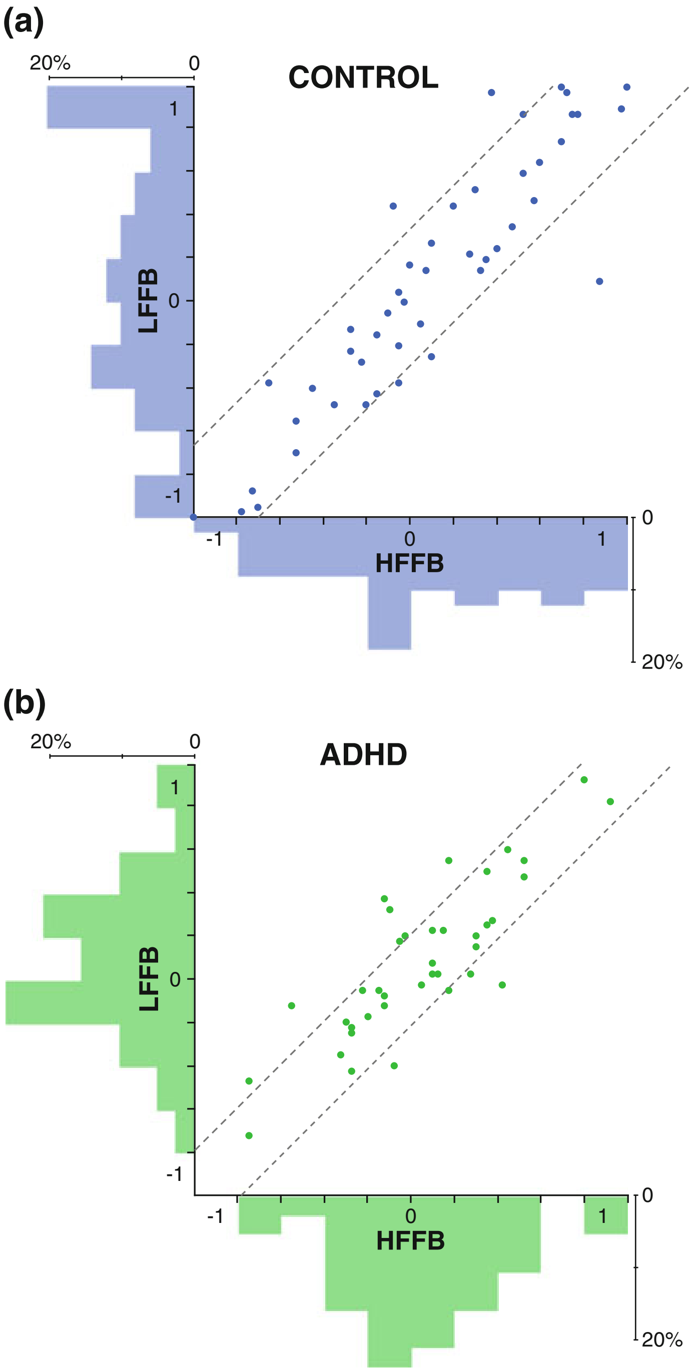

Fig. 6.6 Scatter plot of the investment risk index IRi during 'high frequency feedback' (HFFB) and 'low frequency feedback' (LFFB) conditions for control (panel **a**) and ADHD (panel **b**) participants. Each dot represents the data from one participant. *Dashed lines* represent the 95 % confidence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

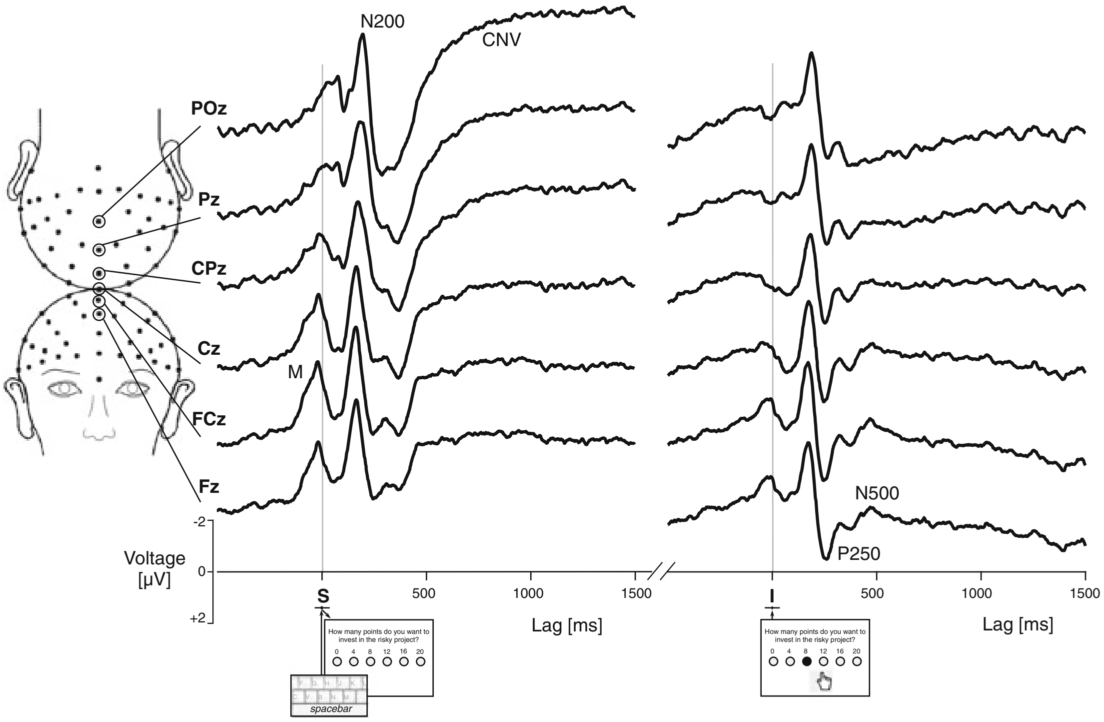

Fig. 6.7 Event related potentials during the Investment Game. Grand average at Fz, FCz, Cz, CPz, Pz and POz sites for all participants and all conditions pooled together. *Left side*: ERPs triggered by event S corresponding to the self-paced start of trial. *Right side*: ERPs triggered by event I corresponding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

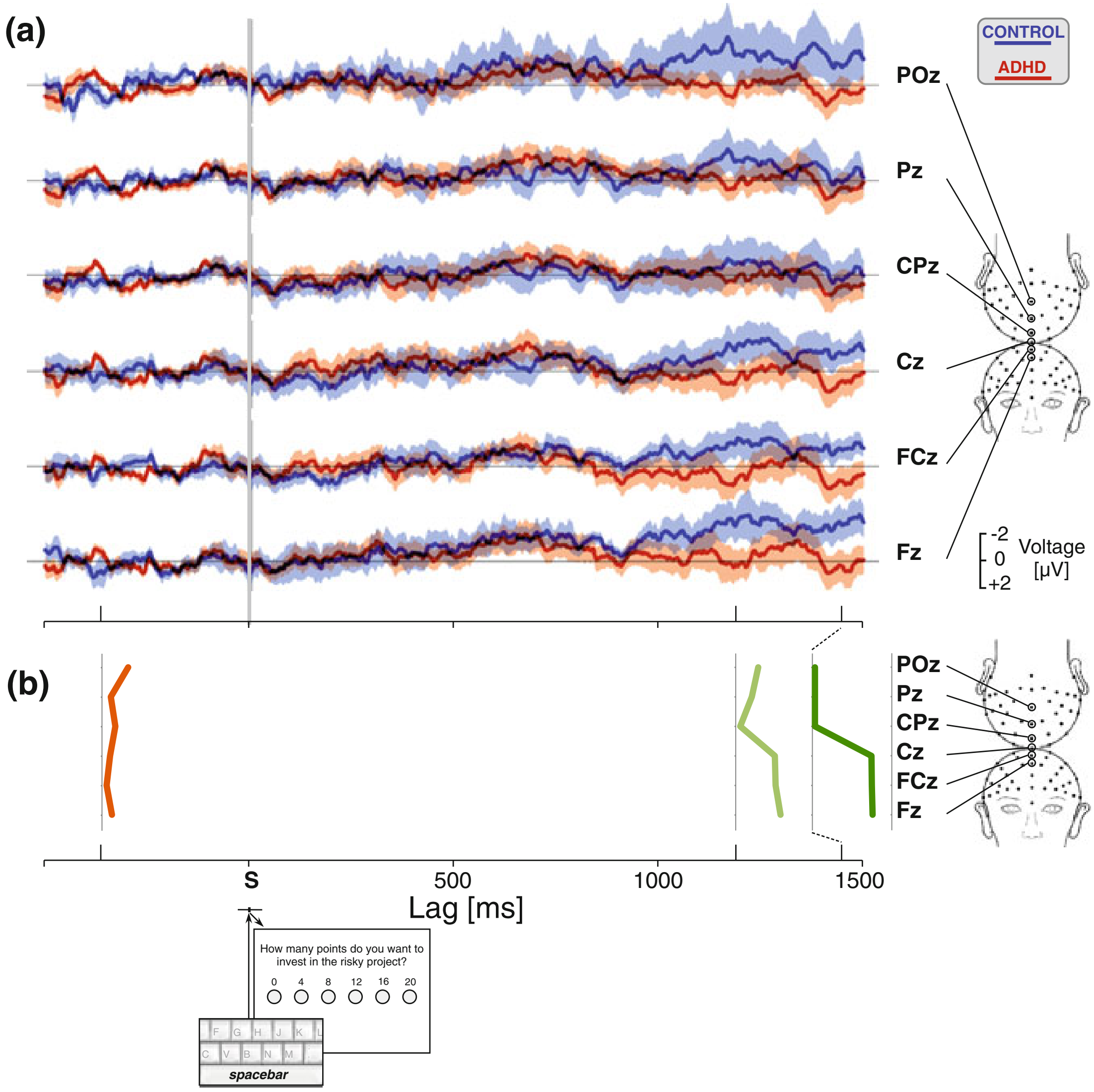

Fig. 6.8 Investment Game: brain activity triggered by self-paced trial onset (event S, Fig. 6.5). **a** Feedback-related differential activities showing the effects of feedback frequency for controls (*blue lines*) and ADHD participants (*red lines*). These feedback-related differential activities were 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.

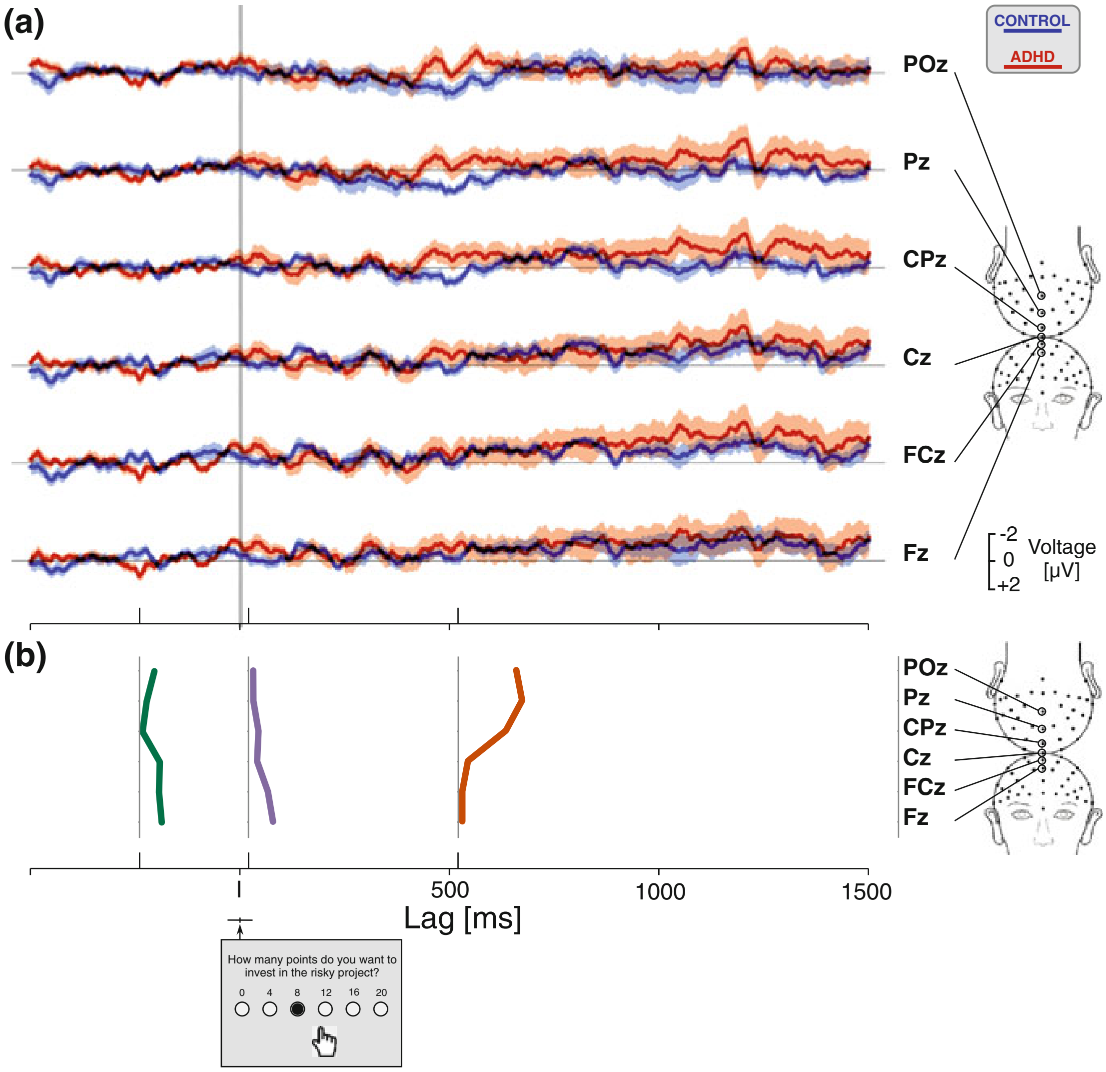

Fig. 6.9 Investment Game: brain activity triggered by the investment choice (event I, Fig. 6.5). **a** Feedback-related differential activities showing the effects of feedback frequency for controls (*blue lines*) and ADHD participants (*red lines*). These feedback-related differential activities were 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.

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6.3 Paper presented at the section 3.2

Mesrobian, S. K., Lintas, A., Bader, M., Götte, L., & Villa, A. E. P. (Under review). Decision Making Processes in Young Adults Affected by Attention-Deficit/Hyperactivity Disorder Revealed by Event-Related Potentials During a Gambling Task.

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Abstract: BACKGROUND: Attention-deficit hyperactivity disorder (ADHD) is characterized by deficits of executive functions and decision making during childhood and adolescence. Contradictory results exist whether altered event-related potentials (ERPs) in adults are associated with the tendency of ADHD patients towards risky behavior.

METHODS: Clinically diagnosed ADHD patients (n = 18) and healthy controls (n = 18), aged less than 30 years, were screened with the Conners' Adult ADHD Rating Scales and assessed by the Mini-International Neuropsychiatric Interview, adult ADHD Self-Report Scale, and by the 60-item HEXACO Personality Inventory. All participants performed a probability gambling task (PGT) with two frequencies of the feedback information of the outcome. For each trial ERPs were triggered by the self-paced trial start and by the gamble selection.

RESULTS: ADHD patients tended to express impulsivity associated with lower values of the agreeableness personality dimension. The latency of the first N2-P3a ERP component, associated with the attentional load, was shorter in the ADHD group. In the ADHD, a N500 component after trial start related to the feedback frequency condition suggested a large affective stake of the decision making and a N400-like component after gamble selection suggested an emphasized postdecisional evaluation of the choice made. ERP markers showed the build-up of a frontoparietal activity related to the emotional percept accompanying the motor response.

CONCLUSIONS: Our results indicate that in young adult ADHD patients ERP analyses provide a more sensitive tool than classical behavioral markers to assess the neural dynamics involved in decision making processes.

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Opposed Reviewers:

Event-Related Potentials During a Gambling Task in Young Adults with Attention-Deficit/Hyperactivity Disorder

Decision Making Processes and ERPs in young ADHD adults

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Abstract

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METHODS:. Clinically diagnosed ADHD patients ($n = 18$) and healthy controls ($n = 18$), aged less than 30 years, were screened with the Conners' Adult ADHD Rating Scales and assessed by the Mini-International Neuropsychiatric Interview, adult ADHD Self-Report Scale, and by the 60-item HEXACO Personality Inventory. All participants performed a probability gambling task (PGT) with two frequencies of the feedback information of the outcome. For each trial ERPs were triggered by the self-paced trial start and by the gamble selection.

RESULTS:. ADHD patients tended to express impulsiveness associated with lower values of the agreeableness personality dimension. The latency of the first N2-P3a ERP component, associated with the attentional load, was shorter in the ADHD group. In the ADHD, a N500 component after trial start related to the feedback frequency condition suggested a large affective stake of the decision making and a N400-like component after gamble selection suggested an emphasized postdecisional evaluation of the choice made. ERP markers showed the build-up of a frontoparietal activity related to the emotional percept accompanying the motor response.

CONCLUSIONS:. Our results indicate that in young adult ADHD patients ERP analyses provide a more sensitive tool than classical behavioral markers to assess the neural dynamics involved in decision making processes.

INTRODUCTION

Decision making is the most essential phase in volitional act, that follows problem analysis, deliberation and evokes execution. The operations involved in the cognitive control of this process must necessarily require the ability to evaluate external demands and internal goals, to perform a value-based action selection among several alternatives depending on the perceived or estimated costs and benefits of each choice translated into an expected reward to the final choice (1, 2). These cognitive abilities are generally referred to as executive functions (3). The integrity of a monitoring system capable, on the short-term, to compare the actual and expected outcomes and, on the long-term, to build-up and maintain the repertoire of response alternatives is necessary to achieve a correct decision making process (4). Behavioral determinants such as vigilance, motivation and emotions exert a powerful influence on the overall cognitive framework of decision making (5, 6). Impaired decision making is among the characteristic symptoms of patients affected by Attention Deficit/Hyperactivity Disorder (ADHD). This behavioral disorder of childhood and adolescence is characterized by primary deficits of executive functions and clinical symptoms including excessive inattention, hyperactivity and impulsiveness that persist into adulthood in a vast proportion of the diagnosed adolescents (7–11). Adult ADHD patients tend to shift their actions towards oppositional conducts affecting their social lives (12–14) including alcohol or drugs abuse (15, 16). Their difficulties in making decisions lead ADHD patients to choose riskier options with unfavorable outcomes in economic and financial settings (14, 17, 18). In addition to cognitive impairments these patients exhibit affective and motivational deficits with an independent effect on their social problems (19, 20). ADHD patients were characterized by specific personality traits based on the 'Big Five' model (BF) with lower scores on conscientiousness, emotionality and agreeableness (21, 22). Failure to learn from emotionally negative feedback is one of the characteristics of impulsive individuals, thus leading to choices in favor of immediate gains and problem gambling in ADHD adults (23, 24).

Event-related potentials (ERPs) are transient electric signals obtained as averaged brain activity triggered in time by a repeating physical or mental stimulus (25). Controversial results were reported for ERP differences between healthy individuals and ADHD patients, partly due to differences in protocols and to patients' selection with respect to comorbid disorders (26–28). Despite these differences in the experimental studies, early sensory processing is likely to be altered in ADHD patients, as suggested by reduced P1 and N2 and enhanced P2 components evoked by non-target stimuli, accompanied by changes in response inhibition associated with altered N2-P3 components (27, 29–32).

The aim of the current study is to investigate which are the behavioral and neural correlates of decision making in young adults affected by ADHD during completion of a Probabilistic Gambling Task

(PGT). For this purpose, we recorded behavioral and ERP data with a strict control of the age-range and clinical and personality assessment of the participants. We used a modified version of the Gneezy-Potters' task (33) with a manipulation of the feedback information frequency aiming at assessing the ERP components associated with the anticipatory processing of the target stimulus, attentional priming, cognitive workload, and response selection.

METHODS AND MATERIALS

Participants' demography and assessment

Ninetysix clinically referred young adult ADHD patients were recruited either in the Psychiatric Department of the University Hospital of Lausanne or at a psychiatrist's practice in collaboration with the University Hospital after an initial screening appointment to ensure that they were fulfilling the criteria defined by the DSM-IV-TR for inattentive, hyperactive/impulsive or mixed subtypes (34). Subjects with presence of motor tics, suicidal behavior, chronic medical conditions, and drug or alcohol abuse or co-morbidity of psychiatric disorders, i.e. acute mood/anxious disorder, bipolar disorder, psychosis, autism or Asperger's syndrome, antecedent of Tourette's syndrome, were excluded from this study. Subjects taking psychostimulants were required to stop medication 24 hours prior to testing. All subjects taking any other psychotropic agents such as anti-depressants, mood stabilizers, non-stimulant medications for ADHD, or dopamine receptor-blocking agents were also excluded from this study. Control subjects were screened prior to the experimental session to ensure that they would not report any neuropsychiatric disorders or any other exclusion criteria and none were taking any psychoactive medications.

Two weeks prior the experimental session, all participants were requested to fill the Conners' Adult ADHD Rating Scales-Self Report (Screening Version, CAARS-S:SV) (35) and the adult ADHD Self-Report Scale (ASRS) (36). The CAARS-S:SV include the ADHD Index, referred to as CAARS in the text, the DSM-IV Inattentive Symptoms Subscale (CAARS-A), the DSM-IV Hyperactive-Impulsive Symptoms Subscale (CAARS-B) and the DSM-IV Total ADHD Symptoms Subscale (CAARS-C). CAARS was used because of its robust psychometric statistics and content validity in comparison to other scales (37). A normalized T-score of CAARS > 60 for the ADHD group and a T-score of CAARS < 56 for the control group were set as inclusion criteria. All participants completed the 60-item HEXACO Personality Inventory (38). On the day of the experimental session, the participants were welcomed, then requested to complete the Edinburgh Handedness Inventory (EHI) (39) and underwent the Mini-International Neuropsychiatric Interview (MINI) (40) under the supervision of a trained clinical psychologist. Table 1 shows the main descriptive statistics of patients' demographics and behavioral assessment. Further information on statistical analyses is provided in Supplement 1.

Probabilistic Gambling Task and Behavior

In the Probabilistic Gambling Task (PGT), each participant was endowed with an amount of 20 points at the beginning of each trial. The participants had to select the amount of points (among the values of 0, 4, 8, 12, 16, 20 points) to gamble in a trial (as illustrated by Figure 1). Two events, trial start (S) and gambling choice (I), delimited a time interval, the termination of which corresponds to a voluntary action, i.e. the choice of a selected amount to gamble. The outcome of the gambling was either to win four times the selected value, with a probability $P_{win} = 1/3$, or to loose the entire amount with a probability $P_{loose} = 2/3$ with a uniformly distributed probability (e.g., if the participant selected 8 points, the outcome would be $12 = (20 - 8)$ in case of loss, or $44 = (20 - 8) + (8 \times 4)$ in case of win). For each trial in the "high frequency feedback" condition (*HF*) the participant was informed, 4 seconds after the choice, about the amount of points held after gambling. In the "low frequency feedback" condition (*LF*) the participant was just informed that the outcome of the gambling was determined. Participants' performance was assessed by the total gains earned after the end of playing the whole task ($TotG$), by a risk index (RI) and by reaction times (RT). Detailed information on the behavioral task and risk indexes is provided in Supplement 1.

EEG recording and analyses

Upon completion of the MINI all participants included in the study were guided to a sound and light-attenuated room for the preparation of the EEG recordings. Detailed information is provided in Supplement 1.

RESULTS

Personality traits and behavioral performance

HEXACO scores within each dimension of personality were determined for each subject and robust correlations were computed for each group (Supplemental Table S1). The robust mixed effects model with one factor within-subject (*personality*: H, E, X, A, C, O) and one factor between-subject (*groups*: controls and ADHD) revealed a significant interaction between the factors for openness (t(34) = 5.96, *p* < .001, *r* = .71), conscientiousness (t(34) = 3.89, *p* < .001, *r* = .55), extraversion (t(34) = 3.27, *p* < .01, *r* = .49) and emotionality (t(34) = 2.10, *p* < .05, *r* = .34). The agreeableness factor in the ADHD was lower than in controls (Table 1) and was correlated with higher risk indexes irrespective of the feedback frequency of the outcome (Supplemental Table S2). We observed also significant lower scores in ADHD for conscientiousness and extraversion (Table 1).

The amount of points gained by the ADHD participants at the end of PGT was not different from controls (Table 2), but CAARS was positively correlated in ADHD, and negatively correlated in controls, with the cumulated amount of points gained during both conditions (Figure 2). In particular, in ADHD the risk index was positively correlated with CAARS-B, the hyperactive-impulsive symptoms subscale (Supplemental Table S2). The participants of either group tended to keep the same risk-taking attitude in both feedback conditions (Supplemental Figure S1). The ADHD group was characterized by faster reaction times during *LF* than during *HF* (Table 2) and reaction times of ADHD tended to be generally slower than controls. Further results are presented in the Supplement S1.

Event Related Potentials

Four ADHD patients were discarded from the electrophysiological analyses because of excessive movements artifacts. The build-up of a premotor related brain activity (*M*) appeared about 150 ms before pressing the spacebar (the trigger event *S*), with largest amplitude on FCz and Cz electrode sites (Figure 3). An early visual event-related component C1, reflecting the initial response of the primary visual cortex, peaked near 70 ms after event S on POz and Pz. Both *S* and *I* triggering events evoked a negative-positive complex of peaks (N2-P3a) at approximately 175 and 250 ms. Immediately following P3a there was a second positive component (P3b), usually associated with a cognitive workload, at a latency near 340 ms. During the time interval between the events *S* and *I* a slow negative deflection (CNV, contingent negative variation) was evoked after P3b. The CNV component is usually elicited by situations in which two events delimit a time interval, the termination of which reflects preparation for a voluntary action.

After the trial start, the latencies of P3a at frontocentral locations (Fz, FCz and Cz pooled together) during the *LF* condition were shorter in the ADHD group than in controls (Table 3). A significant effect of frequency feedback on P3a latency was observed in both groups at frontocentral and at centroparietal locations as well, thus suggesting that this ERP component is generated by a neural circuit associated with processing the frequency feedback outcome. In the ADHD group exclusively we observed a between condition effect at centroparietal sites for N2 and at frontocentral sites for P3b components (Table 3). These results show that the neural activity in the ADHD is affected by the frequency feedback condition of the protocol since the trial start (*S*), when the participant elaborates the gambling strategy.

No within groups effect of the frequency feedback outcome was observed after the gambling choice for N2 and P3a in either group (Table 3). After pooling together the latencies from all six midline sites and for both *HF* and *LF* conditions, the latencies of N2 ($U = 22557$, $2p < .001$, $r = .21$) and P3a ($U = 20624$, $2p < .05$, $r = .12$) were larger in the ADHD compared to controls. After the gambling choice, P3b latencies were shorter in ADHD (after pooling all electrodes and both conditions: $U = 14374$, $2p < .001$, $r = .18$), in particular during the *HF* condition (Table 3). Further analyses are in the Supplement S1 and supplemental Table S3 reports the latencies for the N2, P3a and P3b peaks pooled across the two feedback conditions.

Differential waveform analysis

For each participant we calculated separately the ERPs for *HF* and *LF* trials. The feedback related differential ERPs were obtained by subtracting the ERP recorded during *LF* from the ERP recorded during *HF* condition, as illustrated by the dark grey lines in Figure 4. In order to assess the group factor we compared the feedback related differential ERPs for controls and ADHD participants triggered by the trial start (Figure 5) and by the gambling choice (Figure 6). After the trial start, the differences between groups appeared for an interval centered at a latency of 80 ms lasting 45 ms, corresponding to the C1 wave, and for an interval centered on 260 ms lasting 120 ms, corresponding to the N2-P3 complex (Figure 5A). For such N2-P3 component we observed that controls were characterized by greater amplitude of N2 wave in *LF* versus *HF*, whereas the opposite effect occurred in ADHD participants. Notice that the difference between ADHD and controls became increasingly significant towards the frontal locations, peaking at site Fz (Figure 5B, red relative density curve). A third significant feedback related differential interval was observed at a latency of 500 ms lasting 70 ms following a spatial pattern similar to N2-P3 (Figure 5B, orange curve).

Further significant between groups difference in feedback frequency related activities appeared centered at 440 ms before making the gambling choice (trigger *I*) along the frontocentral sites (Figure 6B, yellow curve). In ADHD this component was characterized by greater amplitude of ERP during *HF* trials, likely to be associated with the motivation and selection of a risky goal-directed behavior. The differences between groups in movement initiation, towards the button associated with the selected gamble, was revealed in the ADHD by larger feedback frequency related activity at the parietal site Pz approximately 140 ms before the gambling choice (Figure 6B, brown curve). The differential waveform analysis showed two more intervals characterized by a sharp frontocentral scalp distribution and by greater amplitudes during the *LF* condition in the ADHD group (Figure 6B, cyan and blue curves). These components occurred at latencies centered on 490 ms and 850 ms after event *I* and lasted

270 ms and 170 ms, respectively. In particular, notice at sites CPz, Cz and FCz the opposite trend of the feedback frequency differential ERP curves (Figure 6A) for ADHD (blue lines, mainly towards positive values) and controls (green lines, mainly towards negative values).

DISCUSSION

The present study was aimed at investigating the behavior and the ERPs elicited by a probability gambling task in young adults with ADHD and age-matched controls, in the context of personality assessed by the HEXACO-Personality Inventory. We showed characteristic ERP components triggered by trial start and by gamble selection. The neural correlates appear as valuable markers to distinguish ADHD from controls. The manipulation of outcomes' feedback frequency showed that at trial start the latency of the N2-P3a components, associated with expectation-association-orienting processing, were shorter in the ADHD. The reaction times till the gambling choice were larger in the ADHD, as well as the latencies of the N2-P3a complex after the choice was made. On the contrary, the P3b component after gambling occurred earlier in the ADHD .

Personality

We observed lower conscientiousness, agreeableness and extraversion scores in ADHD than in controls, generally confirming previous studies based on the 'Big Five' model (BF). Those studies reported ADHD patients characterized by low scores of conscientiousness and agreeableness and high score of neuroticism (41–44). Several studies performed in groups other than ADHD patients have highlighted an association between low agreeableness and gambling behavior or risk taking (45–47). Notice that conscientiousness and extraversion are defined in the same way in both BF and HEXACO models, but agreeableness is only partially overlapping. Low conscientiousness was reported being strongly related with inattention and disorganization (43, 44) and low extraversion with ADHD inattentive subjects (41, 44). In our study the CAARS index of ADHD was correlated with extraversion (Table S1). These results are coherent with the fact that our ADHD group was strongly characterized by inattentive symptoms, with an average T-score of 79.6 (Table 1), a high score comparable only with the ADHD group reported by another study (48). A one-tail test showed that the score to openness-to-experience in ADHD was higher than in controls, while most of other studies did not report any significant result regarding openness, whose definition overlaps in HEXACO and BF models. The association of high scores of openness with risk taking and sensation seeking behaviors was reported in studies not involving ADHD patients (47).

Risk taking and gambling behavior

The Iowa Gambling Task, the Balloon Analogue Risk Task, and the Game of Dice Task could not reveal any salient group effect between ADHD adults and controls (24, 31) and in agreement with behavioral data reported from ADHD children and adolescents (49). The Probabilistic Gambling Task (PGT) used in the current study is an explicit task with two conditions of feedback frequency of the outcome. Overall, and in each condition separately, we could not find any significant difference between groups neither in total gains nor in the risk index. However, we observed an interaction of CAARS score with the total earning: the lower the score the lower the gains in ADHD participants, but the lower the score the higher the gains in controls.

ADHD patients are characterized by an increased likelihood to take greater risks than age-matched controls in activities such as extreme driving and substance abuse (12, 14, 16). It is recognized that childhood ADHD history has a strong influence on persistent pathological gambling (50). Moreover, recent findings point out that pathological gambling in adulthood is associated with a comparable elevated level of impulsiveness in ADHD and non-ADHD gamblers (23). In our ADHD group we observed a correlation between CAARS-B score, associated with impulsiveness and hyperactivity, and the risk index RI. However, our ADHD group was characterized by inattentiveness rather than impulsiveness, which may explain why the between groups comparison could not immediately reveal a significant difference in risk taking behavior between ADHD and controls.

Both risk strategy evaluated by RI in the current study and the total gains were not significantly affected by feedback frequency in either group of participants. However, the investment of higher stakes associated with low frequency presentation of the outcomes was observed in the original Gneezy and Potters' (33), and other tasks (51, 52). In the original task (33) the participants had to choose one bet per block in the *LF* condition, whereas the participants of the current study were allowed to gamble independently at each trial. Hence, differences in experimental design and protocol may contribute to explain our result.

Neural dynamics and Event Related Potentials

The manipulation of the feedback frequency of the outcome necessarily affects how individuals tend to evaluate each transaction in combination and not separately to the previous ones. The PGT is characterized by a free-operant (self-paced) behavior given that the trial onset is associated with pressing the keyboard spacebar. In this goal-directed task the participants are informed that they play trials alternatively distributed in blocks of low and high feedback frequency of the outcome. Hence, it is likely that the participants develop their most adapted cognitive strategy at trial start, by balancing the costs and benefits of making a decision regarding the amount to gamble (53, 54). The interval between the trial start and the time of choosing the amount to gamble may be interpreted as a cue-target interval, given that the selected gamble is a target of a self-paced movement. The ADHD group was characterized by faster reaction times during *LF* than during *HF*. We observed only for the ADHD group a feedback frequency effect on the reaction times, thus suggesting that the decision making processes during PGT are likely to be associated with distinct brain network dynamics in ADHD and controls. These differences might be due to inhibitory control deficits in ADHD, as suggested in the literature (31, 32, 55, 56).

Most ERP components recorded in the ADHD were affected by the feedback frequency right after the trial start. We observed an effect already on the C1 wave, which is known to be related with the initial response of the primary visual cortex to an attended stimulus modulated by affective perception (57). The next ERP component, N2, had a shorter latency at centroparietal locations in ADHD during the *HF* condition. During *HF* P3a latency was overall shorter in both groups at all sites. The P3a component is associated with stimulus-driven attention engagement (58) and its latency is likely to increase with an increased demand of an active orienting process associated with a low feedback frequency of the outcome. Frontal areas and the insula contribute mainly to P3a (59) and during *LF* we found differences between groups restricted to the frontocentral sites. Shorter P3a latencies in ADHD are in agreement with another study (60). During *HF* the P3b latency was shorter and a later component centered on 490 ms with larger amplitude characterized the ERP at frontocentral sites of ADHD. The topographical distribution and latency of such N500 component is in agreement with the wave related to emotional tension-resolution patterns and response selection in risky decision making in gambling tasks (61–64). Later in the cue-target interval, during movement initiation towards reaching the target (i.e., clicking on the selected amount to gamble), the ADHD were characterized during *LF* by a frontocentral wave at -440 ms and a centroparietal wave at -140 ms. The neural dynamics responsible of shorter reaction times during *LF* in the ADHD might be associated with the generation of these ERP components, in particular with the frontostriatal network supporting inhibitory control (65–67) and the centroparietal processing of memory related emotional cues (68, 69). These observations may suggest that at trial start an ADHD individual is characterized by the activation of a less extended brain network engaged in stimulus-driven attention followed by the build-up of larger emotional stake of response conflict.

Following the gamble selection the N2-P3a component was characterized by peak latencies larger in ADHD compared to controls, in particular at frontocentral locations. If we assume that this ERP complex is associated with the brain network engaged in the stimulus-driven attention it is likely that a higher emotional percept of the gambling choice in the ADHD (62, 63) may involve an extension of the processing network resulting in larger N2-P3a latencies. After P3b, a negative deflection centered on 490 ms with larger amplitude during *LF* than *HF* was characteristic of ADHD. This feedback frequency related activity peaked over Cz and is likely to be associated with a N400-like ERP component related to a contextual mismatch (70). In the present task this internal event is represented by the conceptual processing of the gambling outcome expectation, in agreement with other observations of N400-like waves peaking over central areas (71, 72). The last feedback frequency related event that distinguished ADHD and controls occurred at centroparietal sites at latencies in the range 760–930 ms after gambling selection. This component could be identified with the late positive potential (LPP) detected in various experimental designs related to the processing of affective content (73, 74). In ADHD participants, the low feedback frequency of the outcome produced an emotional reaction and a greater conflict towards the outcome of the choice. The time course of N400-like and LPP might be associated with the difficulty for the participants to know the accuracy of their choice until a feedback stimulus occurred at the end of the trial. This difference with controls appears in agreement with the characteristic posterror behavior reported in ADHD adolescents (49). By the time feedback occurred, any response conflict had dissipated, which suggests to consider these two ERP components being associated with postdecisional evaluation of the choice made.

In conclusion, Event Related Potentials elicited by a probability gambling task are valuable markers of decision making deficits related to ADHD, more sensitive than classical behavioral markers based on the total gain, gambling amount and risk taking indexes. We used two conditions characterized by low and high frequency of feedback information of the outcome. The low feedback frequency condition generated stronger emotional response in the ADHD. In both groups the risks taking strategies varied greatly between individuals and were not affected by the feedback frequency of the gambling outcome. ERPs analyses provide a sensitive tool to assess the dynamics of the neural circuits involved in the decision making processes of young adults affected by ADHD.

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Figure legends

Figure 1: Experimental design of the Probabilistic Gambling Task. Each trial began by pressing the spacebar (S), which was immediately followed by a message on the computer-controlled monitor with the request to choose a selected amount of points to gamble in a game. The reaction time (RT) was determined by the lag until the selection of the amount to gamble (I). After an additional fixed interval of 4 seconds (I+4s) the participant was informed about the outcome of the gamble (*HF Loss* or *HF Win*) in the *HF* condition or simply informed about the determination of the gamble in the *LF* condition.

Figure 2: Scatter plot of the total gain $TotG$, cumulated during both feedback frequency conditions, as a function of CAARS, the normalized ADHD Index *T*-score. The robust regression equations for controls and ADHD are equal to $y = 4800 - 24.7x$ (F(1,16)=6.43, $p = .02$, $R^2 = .294$) and $y = 1541 + 33.2x$ (F(1,16)=6.74, $p = .02$, $R^2 = .307$). All points were included for the robust regression. Each point represents the data from one participant. Dashed lines represents 95% confidence interval.

Figure 3: Event-Related Potentials (ERPs) during the Probabilistic Gambling Task. Grand average at Fz, FCz, Cz, CPz, Pz and POz sites for all participants (N=34) and at all conditions (*HF*, *LF*) pooled together. **A.** ERPs triggered by event S, corresponding to the trial start. **B.** ERPs triggered by event I, corresponding to the gambling choice. C1: visual evoked potential component; CNV: Contingent Negative Variation; M: premotor response; N2-P3a: complex of components associated with expectation-attention-orienting processing; P3b: positive peak associated with cognitive workload.

Figure 4: Effect of feedback condition on the grand-averaged ERPs. **A.** ERPs averaged for all participants $(N = 34)$ at electrodes sites POz, Pz, CPz, Cz, FCz and Fz across conditions *HF* (red lines) and *LF* (blue lines) after the trial start (S). **B.** ERPs after the gambling choice (I). Dotted lines correspond to the difference waves, computed by subtracting *LF* curves from *HF* curves.

Figure 5: Feedback related differential activities triggered by the trial start (S). **A.** The curves were computed by subtracting ERPs associated with *LF* from ERPs associated with *HF* for controls (green lines, $N = 18$) and ADHD participants (blue lines, $N = 14$). The confidence interval (mean curve $\pm$ SEM) is shown by the shaded areas. **B.** The relative density plot shows the spatial distribution of the amplitude of the differential curves integrated along three intervals emphasized by the grey stripes, centered at latencies 80 ms (dark grey), 260 ms (red) and 490 ms (orange).

Figure 6: Feedback related differential activities triggered by the gambling choice (I). **A.** The curves were computed in the same way as Figure 5A. **B.** The relative density plot shows the spatial distribution of the amplitude of the differential curves integrated along four intervals emphasized by the grey stripes, centered at latencies 440 ms (yellow) and 140 ms (brown) before the gambling choice and 490 ms (turquoise) and 850 ms (teal blue) after the gambling choice.

Table 1: Descriptive statistics (median, mean and SEM) of participants' demographics, DSM-IV ADHD Symptom subscales and personality traits.

	Controls	ADHD	*Between groups*	Effect size
N	18	18		
Age	22 22.0 (0.8)	22 22.3 (0.7)	$U = 175$ $2p = .69$	$r = .07$
Female / Male	10 / 8	11 / 7	$\chi^2 = .114$ $2p = .74$	$\Phi = .06$
Laterality quotient (EHI)	95 89.0 (5.5)	100 89.4 (5.5)	$U = 171.5$ $2p = .76$	$r = .05$
Conner's Adult ADHD Rating Scales-Self Report (Screening Version) CAARS-S:SV (T-score)				
DSM-IV Inattentive Symptoms	52.5 51.7 (2.2)	79.5 79.6 (1.4)	$U = 323^{***}$ $2p < .001$	$r = .85$
DSM-IV Hyperactive-Impulsive Symptoms	44.5 43.9 (2.2)	63.5 64.8 (2.6)	$U = 304.5^{***}$ $2p < .001$	$r = .75$
DSM-IV Total ADHD Symptoms	50.0 47.9 (2.3)	77.0 76.5 (2.0)	$U = 323^{***}$ $2p < .001$	$r = .85$
ADHD Index	46.0 44.9 (1.4)	68.0 69.3 (1.3)	$U = 324^{***}$ $2p < .001$	$r = .86$
Adult ADHD Self-Report Scale (ASRS)	48.0 45.7 (2.2)	67.0 66.3 (1.9)	$U = 312^{***}$ $2p < .001$	$r = .79$
HEXACO Personality factors				
$[H]$ Honesty-Humility	35.5 36.5 (1.5)	37.0 35.1 (1.5)	$U = 150.5$ $2p = .72$	$r = .07$
$[E]$ Emotionality	33.5 32.7 (1.6)	34.0 32.3 (2.1)	$U = 165$ $2p = .93$	$r = .02$
$[X]$ Extraversion	37.0 36.4 (1.1)	30.5 31.2 (1.7)	$U = 87.5^{*}$ $2p < .05$	$r = .39$
$[A]$ Agreeableness	30.5 31.8 (1.2)	27.5 27.9 (1.5)	$U = 96.5^{*}$ $2p < .05$	$r = .35$
$[C]$ Conscientiousness	35.0 35.4 (1.0)	28.5 29.6 (1.5)	$U = 65.5^{**}$ $2p < .01$	$r = .51$
$[O]$ Openness to Experience	31.0 33.0 (1.6)	38.0 37.1 (1.6)	$U = 220.5$ $2p = .06$	$r = .31$

Table 2: Descriptive statistics (Median, mean and SEM) of participants' behavioral performance during the probability gambling task.

	Controls	ADHD	*Between groups*
N	18	18	
Total Gain (points)			
Within condition			
• High Frequency Feedback	1852	1914	$U = 187.5$
$TG(HF)$	1843 (43)	1899 (60)	$2p = .43$ $r = .13$
• Low Frequency Feedback	1840	1938	$U = 197.5$
$TG(LF)$	1861 (43)	1935 (46)	$2p = .27$ $r = .19$
Within groups	$Z = 0.07$	$Z = 0.74$	
Between conditions	$2p = .96$ $r = .01$	$2p = .48$ $r = .12$	
Normalized Risk Index			
Within condition			
• High Frequency Feedback	-0.03	0.24	$U = 186$
$RI(HF)$	0.06 (0.10)	0.13 (0.10)	$2p = .46$ $r = .13$
• Low Frequency Feedback	-0.06	0.25	$U = 196.5$
$RI(LF)$	-0.01 (0.12)	0.11 (0.12)	$2p = .28$ $r = .18$
Within groups	$Z = 1.18$	$Z = 0.26$	
Between conditions	$2p = .25$ $r = .20$	$2p = .81$ $r = .04$	
Reaction Time (ms)			
Within condition			
• High Frequency Feedback	1083	1544	$U = 204$
$RT(HF)$	1245 (146)	1595 (196)	$2p = .19$ $r = .22$
• Low Frequency Feedback	1032	1274	$U = 197$
$RT(LF)$	1136 (153)	1414 (200)	$2p = .28$ $r = .18$
Within groups	$Z = 1.13$	$Z = 2.33^{*}$	
Between conditions	$2p = .27$ $r = .19$	$2p < .05$ $r = .39$	

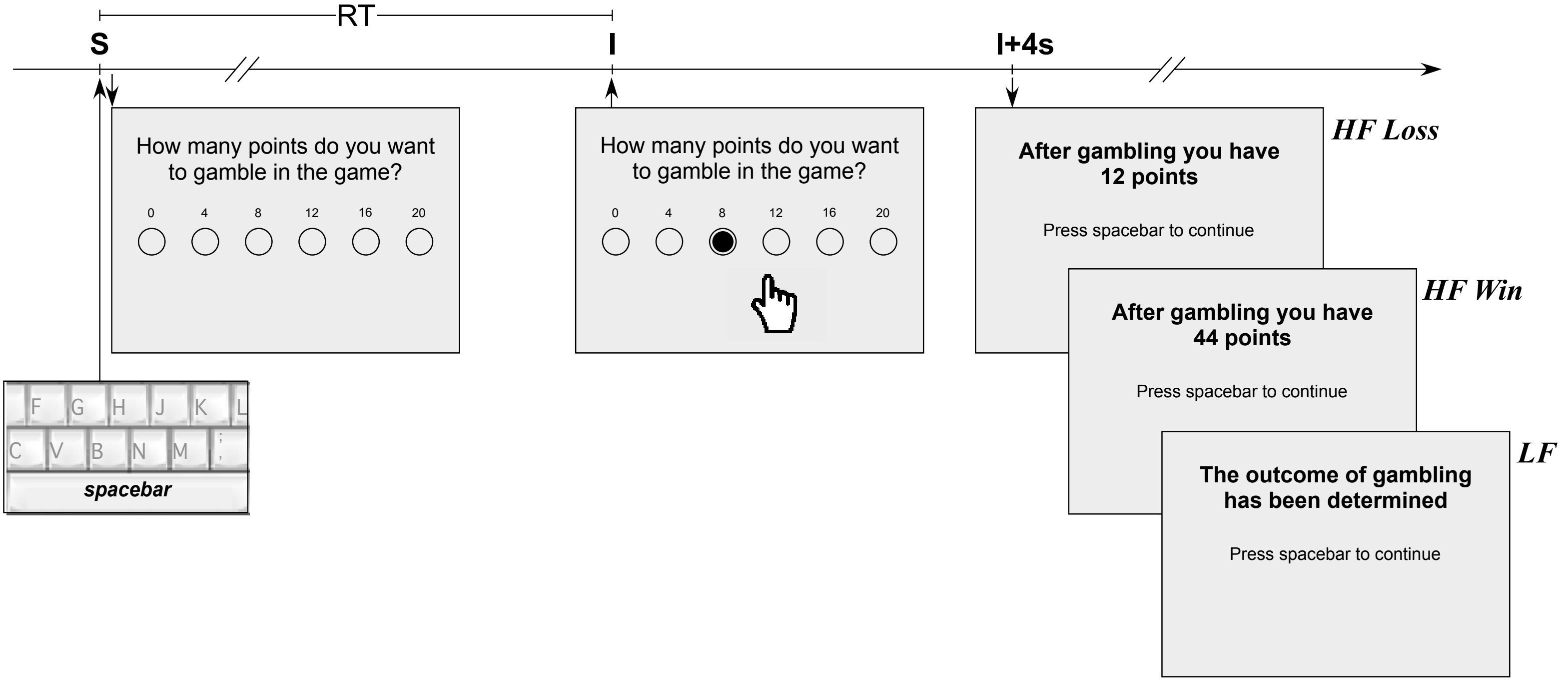
Between groups comparison is assessed by the unpaired Mann-Whitney Rank Sum Test and the statistics U is reported. Within group (between conditions) comparison is assessed by the paired Wilcoxon signed rank test and the statistics Z is reported. Two-sided p-value and effect size r are reported for both tests.

Table 3: Median and averaged ERPs latencies (ms) ± SEM at the frontocentral (Fz, FCz, CZ) and centroparietal (CPz, Pz, POz) sites during the high frequency feedback (*HF*) and low frequency feedback (*LF*) conditions after the trial start and after the gambling choice.

		Within condition High Frequency Feedback (*HF*)			Within condition Low Frequency Feedback (*LF*)			*Within groups Between conditions* (*HF vs. LF*)	
		Controls	ADHD	*Between groups*	Controls	ADHD	*Between groups*	Controls	ADHD
Trial start									
N2	frontocentral	164.0 170.1 (2.9)	173.5 169.5 (2.3)	$U = 1139$ $2p = .97$ $r = .00$	171.0 172.2 (2.1)	174.0 172.0 (2.5)	$U = 1180$ $2p = .74$ $r = .03$	$Z = 1.22$ $2p = .23$ $r = .12$	$Z = 0.84$ $2p = .41$ $r = .09$
	centroparietal	190.5 185.8 (3.4)	179.0 177.7 (3.4)	$U = 905$ $2p = .09$ $r = .18$	189.5 187.5 (2.8)	187.0 184.1 (3.4)	$U = 1052$ $2p = .55$ $r = .06$	$Z = 1.04$ $2p = .30$ $r = .10$	$Z = 2.58^{**}$ $2p < .01$ $r = .28$
P3a	frontocentral	246.5 247.8 (3.3)	243.0 242.1 (3.9)	$U = 1116$ $2p = .90$ $r = .01$	262.0 259.9 (3.7)	247.0 249.2 (3.2)	$U = 862.5^{*}$ $2p < .05$ $r = .20$	$Z = 3.48^{***}$ $2p < .001$ $r = .33$	$Z = 2.13^{*}$ $2p < .05$ $r = .23$
	centroparietal	251.0 258.3 (3.4)	255.5 248.9 (5.2)	$U = 1068.5$ $2p = .63$ $r = .05$	264.0 266.0 (3.2)	260.0 260.0 (3.4)	$U = 997$ $2p = .31$ $r = .10$	$Z = 3.31^{***}$ $2p < .001$ $r = .32$	$Z = 2.85^{**}$ $2p < .01$ $r = .31$
P3b	frontocentral	351.0 352.6 (3.7)	349.0 346.7 (3.4)	$U = 974$ $2p = .46$ $r = .08$	356.0 358.2 (2.7)	363.5 354.3 (4.3)	$U = 1121$ $2p = .95$ $r = .01$	$Z = 1.78$ $2p = .08$ $r = .17$	$Z = 2.90^{**}$ $2p < .01$ $r = .32$
	centroparietal	353.0 356.9 (3.8)	348.0 348.0 (3.7)	$U = 951.5$ $2p = .18$ $r = .14$	357.0 360.4 (3.4)	354.0 353.3 (4.6)	$U = 1054$ $2p = .56$ $r = .01$	$Z = 0.64$ $2p = .53$ $r = .06$	$Z = 1.86$ $2p = .06$ $r = .20$
Gambling choice									
N2	frontocentral	167.5 168.1 (2.2)	174.0 176.2 (2.4)	$U = 1414.5^{*}$ $2p < .05$ $r = .21$	165.0 167.5 (1.8)	174.5 176.0 (2.0)	$U = 1542.5^{**}$ $2p < .01$ $r = .31$	$Z = 1.40$ $2p = .16$ $r = .13$	$Z = 0.81$ $2p = .43$ $r = .09$
	centroparietal	178.5 177.7 (2.5)	181.0 183.3 (2.6)	$U = 1298.5$ $2p = .23$ $r = .12$	178.0 175.8 (2.6)	184.0 184.1 (2.6)	$U = 1425.5^{*}$ $2p < .05$ $r = .22$	$Z = 1.08$ $2p = .28$ $r = .10$	$Z = 60$ $2p = .55$ $r = .07$
P3a	frontocentral	235.0 239.3 (2.0)	242.0 245.1 (2.8)	$U = 1366$ $2p = .09$ $r = .18$	237.5 241.8 (2.0)	245.0 243.6 (2.7)	$U = 1228$ $2p = .49$ $r = .07$	$Z = 1.37$ $2p = .17$ $r = .13$	$Z = 0.51$ $2p = .61$ $r = .06$
	centroparietal	244.0 244.1 (2.4)	245.0 249.5 (3.3)	$U = 1223.5$ $2p = .51$ $r = .07$	239.5 242.7 (2.5)	251.5 247.7 (4.0)	$U = 1354.5$ $2p = .10$ $r = .17$	$Z = 0.55$ $2p = .59$ $r = .05$	$Z = 0.53$ $2p = .61$ $r = .06$
P3b	frontocentral	351.0 354.9 (3.2)	342.0 347.7 (3.1)	$U = 815.5^{*}$ $2p < .05$ $r = .23$	360.0 360.5 (3.3)	350.5 353.1 (3.6)	$U = 892.5$ $2p = .07$ $r = .18$	$Z = 1.42$ $2p = .16$ $r = .14$	$Z = 1.28$ $2p = .20$ $r = .14$
	centroparietal	360.0 365.1 (2.9)	350.5 353.8 (3.1)	$U = 768^{**}$ $2p < .01$ $r = .28$	370.5 364.6 (3.2)	362.0 363.5 (4.2)	$U = 1100$ $2p = .80$ $r = .03$	$Z = 0.52$ $2p = .61$ $r = .05$	$Z = 2.29^{*}$ $2p < .05$ $r = .25$

Between groups comparison is assessed by the unpaired Mann-Whitney Rank Sum Test and the statistics U is reported. Within group (between conditions) comparison is assessed by the paired Wilcoxon signed rank test and the statistics Z is reported. Two-sided p-value and effect size r are reported for both tests.

Figure 1



How many points do you want to gamble in the game?

How many points do you want to gamble in the game?

After gambling you have 12 points

Press spacebar to continue

After gambling you have 44 points

Press spacebar to continue

The outcome of gambling has been determined

Press spacebar to continue

Figure 2

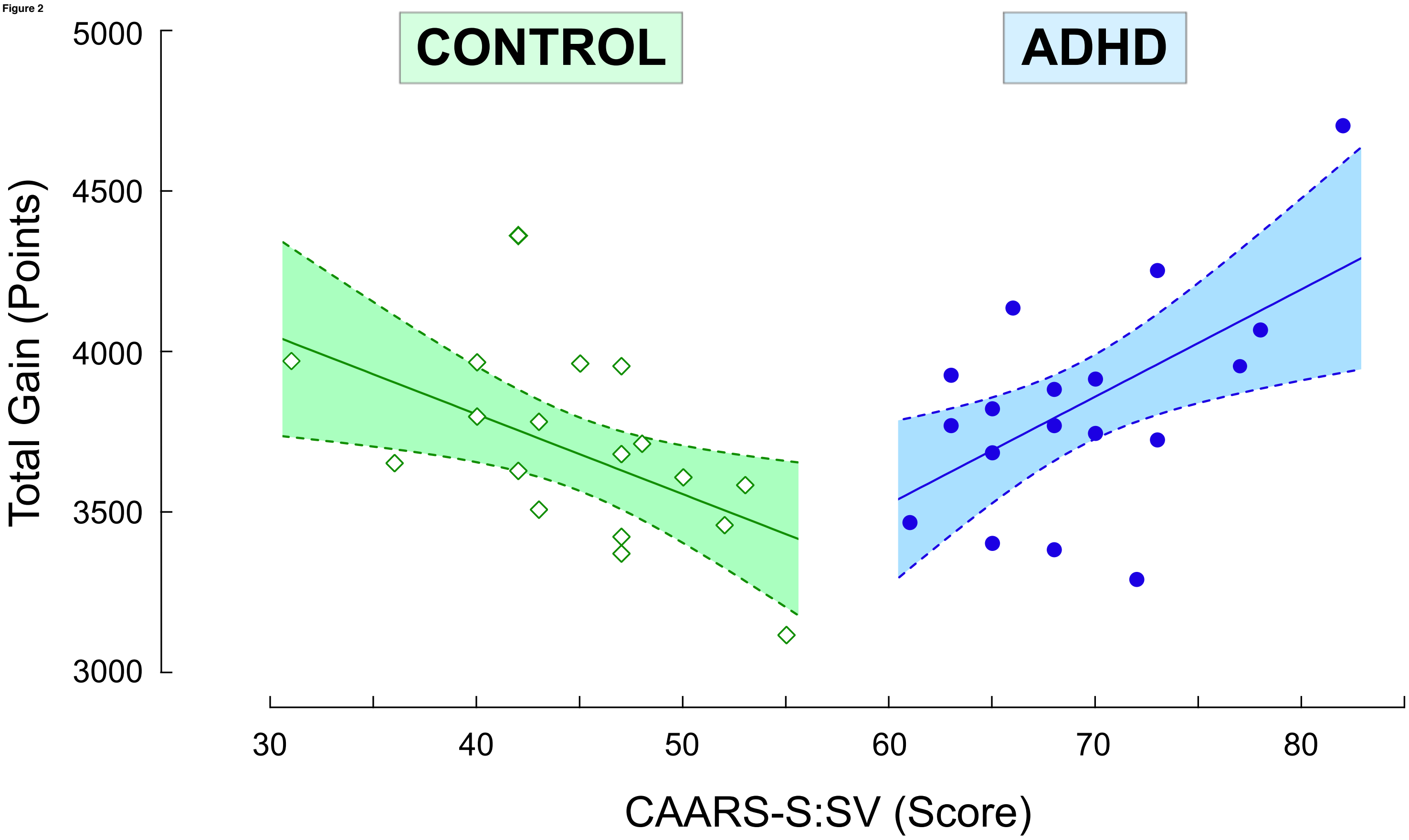

CONTROL
ADHD
Total Gain (Points)
5000
4500
4000
3500
3000
30
40
50
60
70
80
CAARS-S:SV (Score)

Figure 3

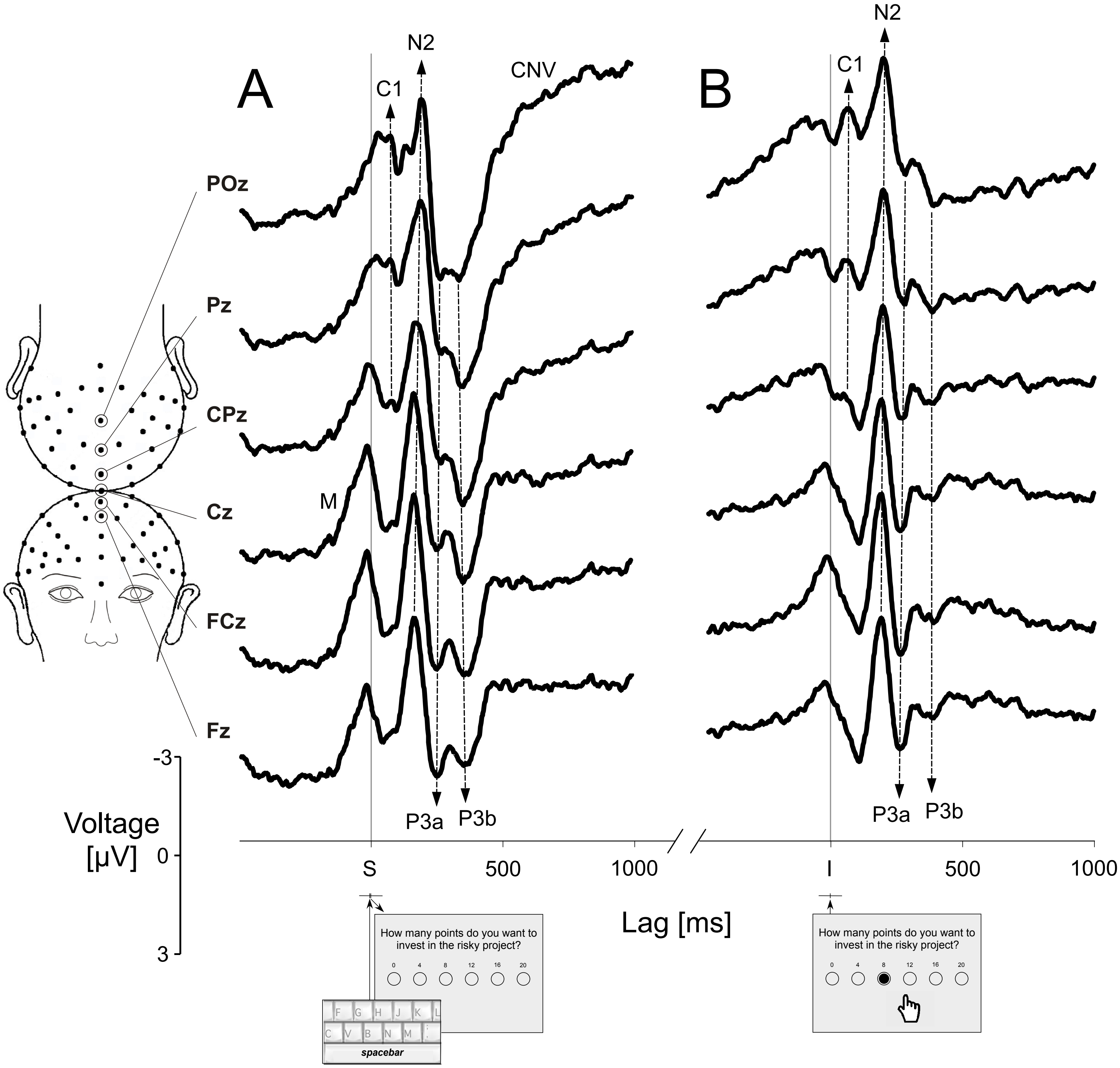

A
B
N2
C1
CNV
M
P3a
P3b
POz
Pz
CPz
Cz
FCz
Fz
Voltage
[µV]
-3
0
3
S
I
500
1000
Lag [ms]
How many points do you want to invest in the risky project?
0
4
8
12
16
20
F G H J K L
C V B N M
spacebar

Figure 4

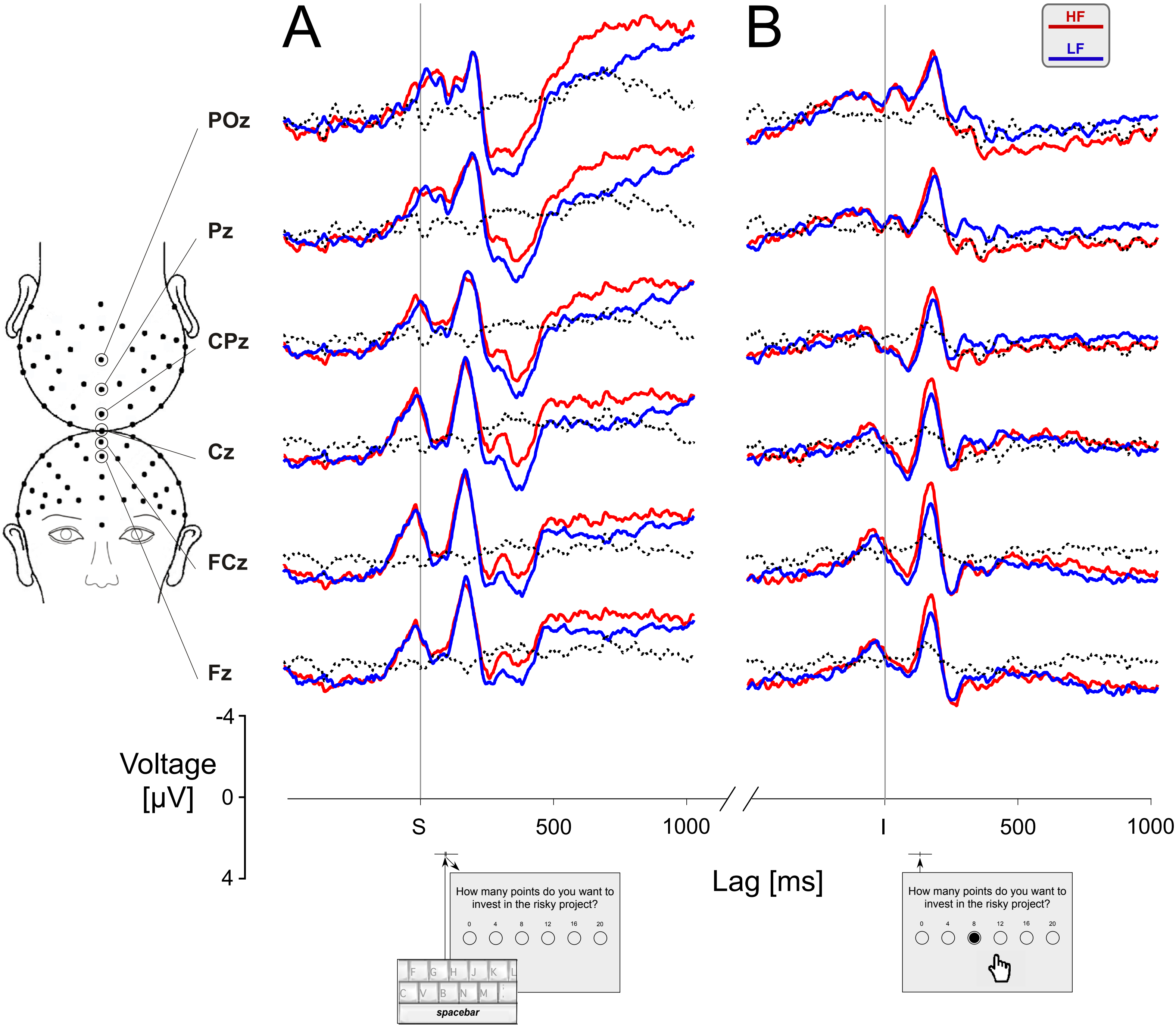
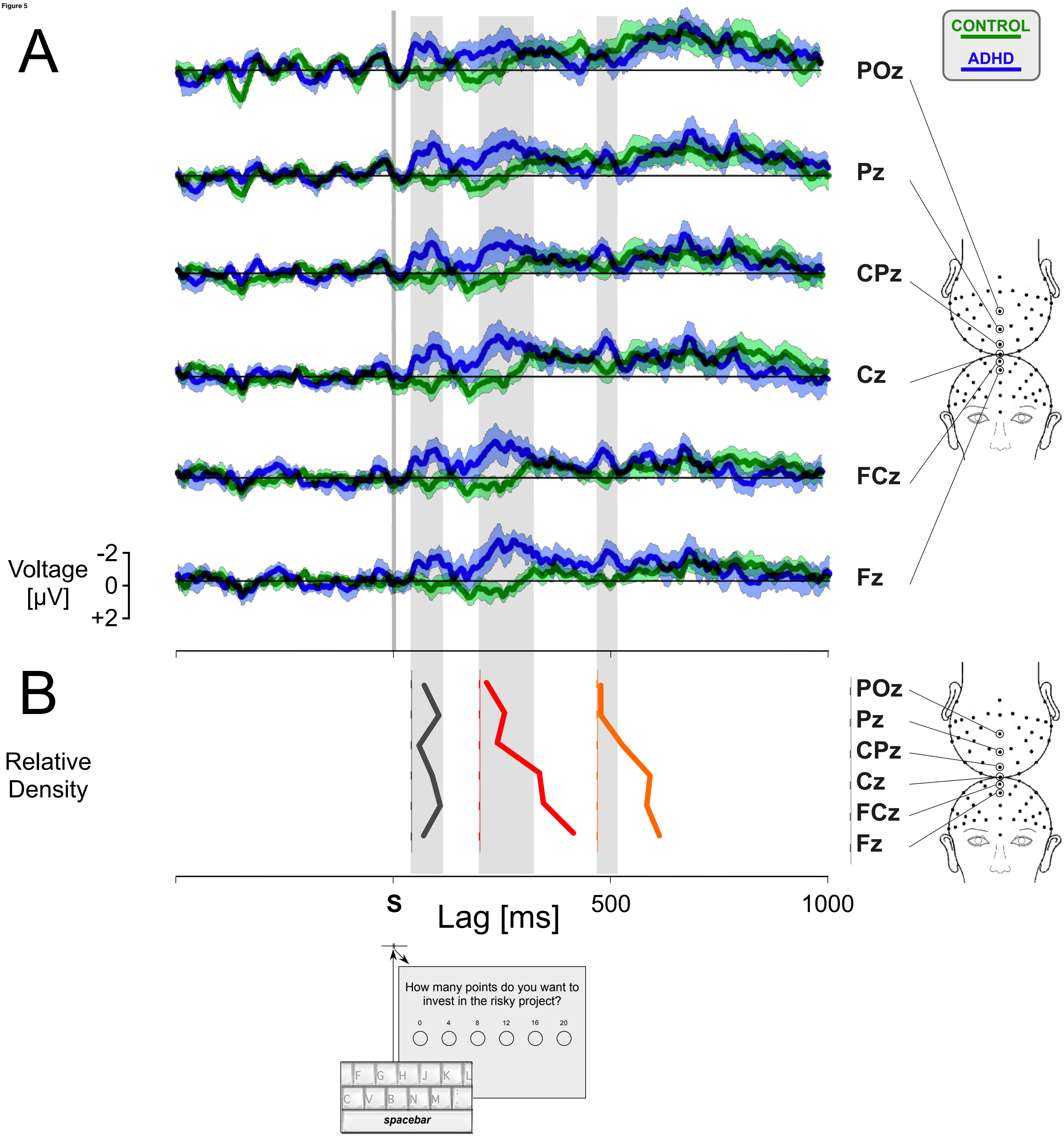
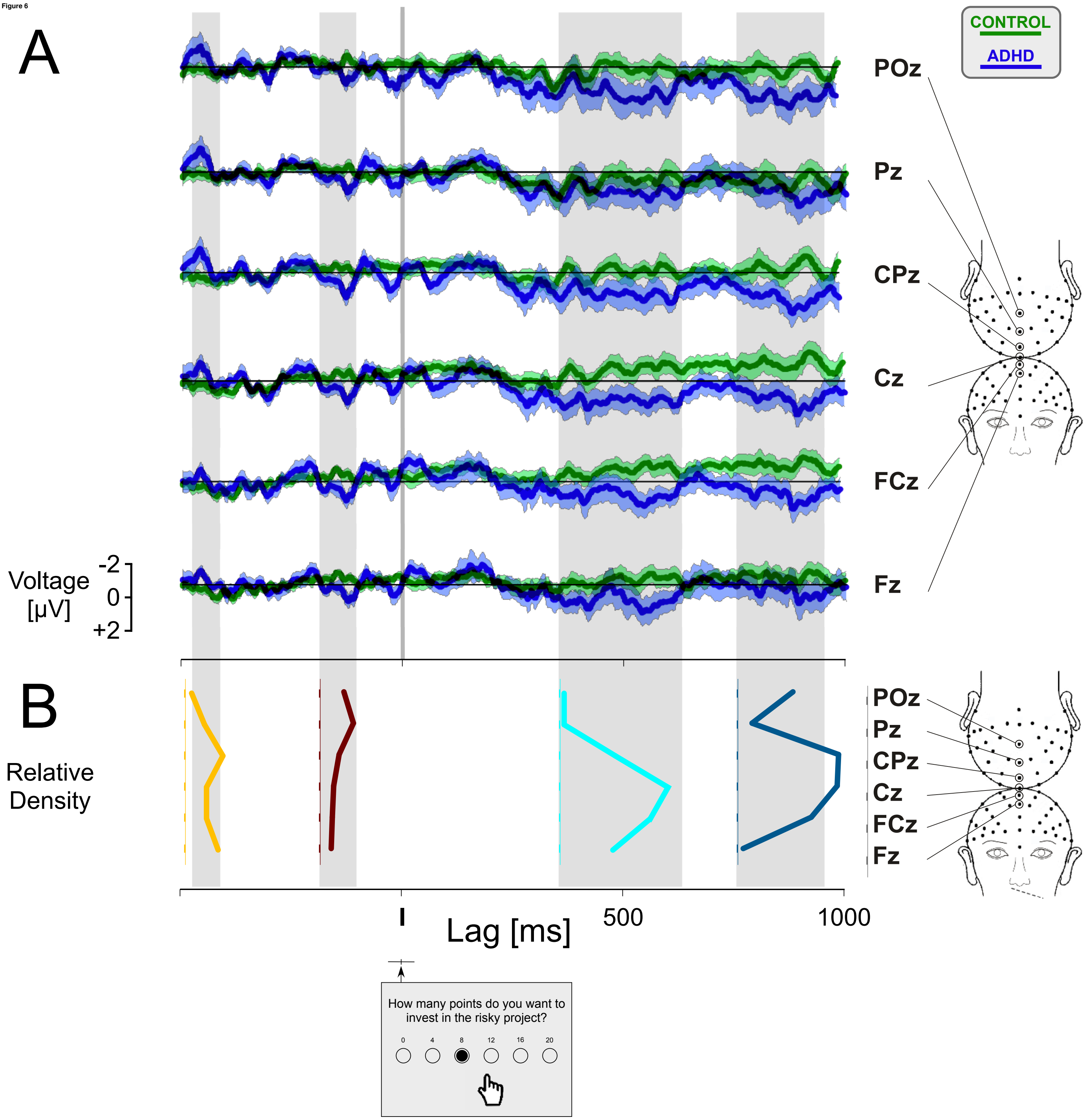

A
B
HF
LF
POz
Pz
CPz
Cz
FCz
Fz
-4
Voltage
[μV]
0
4
S
500
1000
I
500
1000
Lag [ms]
How many points do you want to invest in the risky project?
0
4
8
12
16
20
F G H J K L
C V B N M
spacebar
How many points do you want to invest in the risky project?
0
4
8
12
16
20

Figure 5



How many points do you want to invest in the risky project?

Figure 6



How many points do you want to invest in the risky project?

○ 0 ○ 4 ● 8 ○ 12 ○ 16 ○ 20

Event-Related Potentials During a Gambling Task in Young Adults with Attention-Deficit/Hyperactivity Disorder

(SUPPLEMENTAL INFORMATION)

Decision Making Processes and ERPs in young ADHD adults

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ARTICLE INFORMATION

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Supplemental information:

Number of figures: 1

Number of tables: 3

Supplemental Methods and Materials

Statistical analyses

Statistical analyses were performed with the R language and environment for statistical computing (1, 2). For most variables we report the median and the mean ±SEM. All statistical hypotheses were tested with a level of significance of $p = .05$, unless otherwise reported. For parametric comparisons of distributions we used Student's t-test and Cohen's d effect size. For Chi-squared tests the effect size is reported by Φ for 2 x 2 contingency tables, otherwise by Cramer's V (3). Nonparametric comparisons of sample distributions (4) were assessed by the Wilcoxon signed-rank test using the Z statistic for paired observations and by the Mann-Whitney U test for independent samples with effect size r. We used robust statistics throughout all the analyses (5–8), including the robust correlation indexes $\hat{\rho}_G$, the robust mixed effects model (9) and otherwise stated the linear mixed-effects models for within-subject factorial analyses (10).

Participants' demography and assessment

The study was carried out in accordance with the latest version of the Declaration of Helsinki (11) and approved by the Ethics Committees of the Faculty of Business and Economics of the University of Lausanne, and by the Cantonal Ethics Committee of Canton Vaud on behalf of the Swiss Federal Authorities. All participants had normal or corrected-to-normal vision, none reported a history of sustained head injury. The slight prevalence of females in the gender distribution was in agreement with other reports (12). In both groups CAARS and ASRS's total scores were positively correlated ($\hat{\rho}_G(16) = .513$, $p = .03$ for controls and $\hat{\rho}_G(16) = .464$, $p = .05$ for ADHD participants).

Probabilistic Gambling Task and Behavior

The graphical message with a grid corresponding to the possible choices was displayed on the computer-controlled monitor and the participant used the computer mouse to click on the selected amount of points to gamble. In order to reduce the saccadic eye movements the graphical message was displayed in a screen area corresponding to a vertical angle of 3 degrees and an horizontal angle of 8 degrees, hence falling within the range of the normal human parafoveal region in reading (13). In both conditions (i.e., ‘high frequency feedback” *HF* and “low frequency feedback” *LF*) the overall amount of points held by the participant was displayed every four trials. Each participant played the PGT in 10 alternated blocks of *HF* and *LF* 16 trials each, hence 80 trials for each condition.

The performance of the participants was assessed by the total gains earned after the end of playing the whole task ($TotG$), during low frequency feedback trials ($TG($*LF*$)$), during high frequency feedback trials ($TG($*HF*$)$), and by three risk indexes. The relative number of trials a participant gambled 0, 4, or 8 points defined a low risk index LR. A high risk index HR was defined for gambling amounts of 12, 16, or 20 points. A risk index RI centralized within the range [-1, +1] was calculated as $RI = (HR - LR)/(HR + LR)$. Then, a RI towards -1 is characteristic of a risk-averse strategy, an index towards +1 for a risk-seeking participant, and $RI \approx 0$ being associated with a risk-neutral attitude. Each participant could be further characterized with the corresponding RIs calculated following the feedback frequency trials, i.e. $RI($*LF*$)$ and $RI($*HF*$)$. The behavior of the participants was also assessed by measuring the reaction times (RT) in ms. The trials with $RT < 250$ ms and $RT > 10$ seconds were discarded. Additional trials detected as outliers on the basis of a robust analysis (14) were also discarded from further analyses.

EEG recording and analyses

Electrophysiological signals were recorded using 64 scalp Ag/AgCl active electrodes (ActiveTwo MARK II Biosemi EEG System, BioSemi B.V., Amsterdam, The Netherlands), mounted on a headcap (extended international 10/20 layout, NeuroSpec Quick Cap) and referenced to the linked earlobes. Vertical and horizontal ocular movements were recorded using two pairs of bipolar electrodes placed beneath and above each eye next to the lateral canthi. The data acquisition (DC amplifiers and software by Biosemi, USA) was set with a sampling rate of 1024 Hz at 24 bits resolution and band-passed filtered with lower cutoff at 0.05 Hz and upper cut-off at 200 Hz, Electrode impedances were checked and kept always below $20\ k\Omega$ for all channels before starting the continuous recording of the EEG (15). The final checkup of the electrophysiological equipment and of the quality of brain signals was completed in about 30 minutes. The participants were instructed to maintain their gaze on a white fixation cross at the center of a 19-inch computer screen at a viewing distance of about 70 cm. At the begin of the recording session the EEG was recorded during two minutes while the participants kept the eyes closed and during two minutes while they fixated a cross on the center of the computer screen.

The brain signals were preprocessed and analyzed with BrainVision Analyzer 2.0.4 (Brain Products, Gilching, Germany). Visual inspection of the EEG was performed to remove immediately those trials containing high amplitude muscle activity related noise, large eye blinks and other easily identifiable artifacts. Saccade-related eye movements were corrected using Infomax Independent Component

Analysis (*ICA*) (16). Markers were used off-line to segment the continuous EEG data into epochs triggered by pressing the spacebar (event S) and by clicking on the selected amount to gamble (event I), as illustrated in Figure 1 of the main article. The epochs were further scanned and inspected visually for contamination by residual minor artifacts. After removing all artifacts the number of usable epochs for the event-related potentials (ERPs) analysis had to be more than twenty in order to include the participant's record in the analyses. For ERPs the trials were cut into epochs lasting 1500 ms ranging from -500 to +1000 ms around the trigger events of interest (i.e., events S and I). ERP analyses were performed on the artifact-free trials, band-pass filtered between 0.1 and 30 Hz (-12dB/octave). Subsequently the trials were baseline corrected to the interval 500 ms prior to trigger onset and averaged for both conditions *LF* and *HF*.

Supplemental Results

Personality traits and performance to PGT

In controls, openness was negatively correlated with CAARS (Supplemental Table S1) and positively correlated with the total gains (Supplemental Table S2). Honesty-humility was positively correlated with conscientiousness ($\hat{\rho}_G(16) = .514$, $p = .03$) (Table S1) and positively correlated with reaction times (Supplemental Table S2). In ADHD, the robust mixed effects model confirmed the effect of agreeableness on the risk index irrespective of the feedback frequency ($t(16) = 2.61$, $p = .02$, $d = .10$). In this group agreeableness was positively correlated with honesty-humility ($\hat{\rho}_G(16) = .512$, $p = .03$). The interaction between the group factor and the CAARS index on $TotG$, the cumulated amount of points during both feedback frequency conditions, illustrated in the main text by Figure 2, was also confirmed by the factorial analysis ($\chi^2(4) = 15.23$, $p < .001$, $V = .46$).

Event Related Potentials

We considered the linear mixed effects model with two within-subject factors (*recording sites*: POz, Pz, CPz, Cz, FCz, and Fz; *conditions*: *HF* and *LF*) and one between-subject factor (*groups*: controls and ADHD). After the trial start, the model revealed a significant main effect of the electrode factor for N2 ($\chi^2(5) = 54.60$, $p < .001$, $V = .17$) and P3a peak latencies ($\chi^2(5) = 20.26$, $p < .01$, $V = .10$). A significant main effect of the feedback condition, without interaction with the electrode factor, was observed only for P3a peak latencies ($\chi^2(1) = 10.75$, $p = .001$, $V = .17$). No main effect of the electrode factor was observed for P3b peak latency after trial start ($\chi^2(5) = 2.33$, $p = .80$, $V = .03$) and no difference between

P3b latencies for ADHD and controls after pooling all electrodes together (354.0 ms, 350.6±2.0 and 354.0 ms, 357.1±1.7, respectively).

After the gambling choice, the model revealed a significant main effect of the electrode factor for N2 (χ^2(5) = 46.58, $p < .001$, $V = .16$), but not for P3a peak latencies (χ^2(5) = 6.74, $p = .24$, $V = .06$). A main effect of the electrode factor was observed for P3b peak latency (χ^2(5) = 54.79, $p < .001$, $V = .17$).

Supplemental Figure

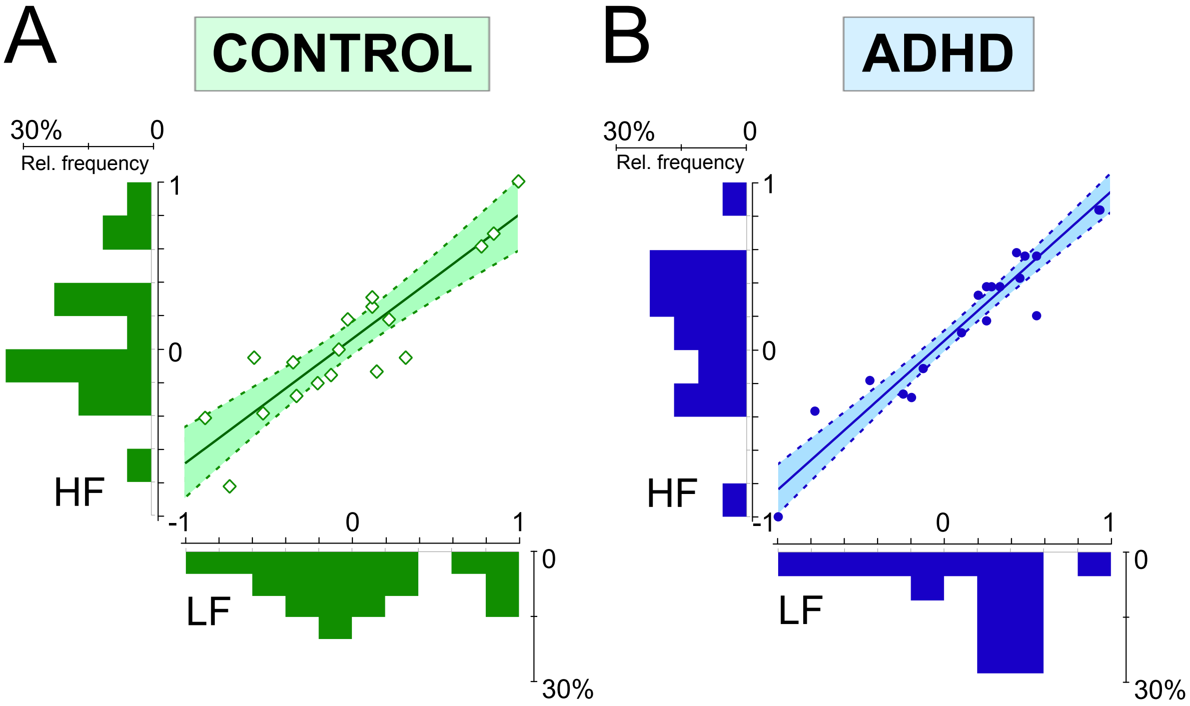

Figure S1: Individual strategies during outcome frequency feedback conditions. **A.** Control participants. Scatter plot of the risk index during high frequency feedback, RI(*HF*), as a function of the risk index during low frequency feedback, RI(*LF*). The robust regression equation is $y = 0.075 + 0.728x$ (F(1,16)=61.18, $p < .001$, $R^2 = .796$). **B.** Same scatter plot for ADHD patients. The robust regression equation is $y = 0.035 + 0.875x$ (F(1,16)=142.39, $p < .001$, $R^2 = .906$). Each point represents the data from one participant. Dashed lines represents 95% confidence interval. Histograms represents the marginal distributions of RI.

Supplemental Table

Table S1: Robust correlations among personality traits and ADHD assessment scales.

		ADHD ($N = 18$)									
		H	E	X	A	C	O	CAARS	CAARS-A	CAARS-B	ASRS
Controls ($N = 18$)	H	.	.270	−.012	.512*	.263	−.160	−.085	.047	.211	.148
	E	.124	.	−.052	.108	.344	.296	.479*	.292	−.097	.088
	X	.024	−.321	.	−.146	−.047	.363	−.079	−.193	.128	.082
	A	.333	.257	.057	.	.024	.170	−.278	−.200	−.245	−.132
	C	.514*	.146	.120	.073	.	−.267	.018	−.023	.096	.264
	O	.215	−.070	.400	.271	−.249	.	.256	−.021	−.325	−.031
	CAARS	−.136	.291	−.327	.035	−.029	−.478*	.	.195	.052	.464*
	CAARS-A	−.102	.123	−.151	.390	−.426	−.023	.587*	.	.391	.396
	CAARS-B	−.432	.085	−.328	−.009	−.194	−.560*	.786**	.550*	.	.431
	ASRS	−.301	.218	−.197	.048	−.209	−.299	.513*	−.373	.570*	.

Personality traits: [H]onesty-Humility, [E]motionality, e[X]traversion, [A]greeableness, [C]onscientiousness, and [O]penness to experience). CAARS: ADHD Index; CAARS-A: DSM IV Inattentive Symptoms Subscale; CAARS-B: DSM IV Hyperactive-Impulsive Symptoms Subscale.

Robust correlation coefficients $\hat{\rho}_G$ following the Gaussian rank correlation estimators (5).

(*) level of significance of *2p*$<$.05 ; (**) level of significance of *2p*$<$.01.

Supplemental Table

Table S2: Robust correlations between personality traits with measures of performance to PGT.

		H	E	X	A	C	O	CAARS	CAARS-A	CAARS-B	ASRS
Controls ($N = 18$)	$TotG$	$.168$	$-.188$	$-.057$	$.197$	$.157$	$.502^{*}$	$-.655^{**}$	$-.383$	$-.648^{**}$	$-.368$
	$TG(HF)$	$.012$	$-.067$	$-.229$	$.117$	$-.132$	$.519^{*}$	$-.504^{*}$	$-.133$	$-.442$	$-.317$
	$TG(LF)$	$.065$	$-.274$	$.070$	$.146$	$.218$	$.236$	$-.391$	$-.293$	$-.410$	$-.244$
	RI	$.139$	$-.332$	$.041$	$.055$	$.197$	$.245$	$-.280$	$-.045$	$-.196$	$-.161$
	$RI(HF)$	$.168$	$-.289$	$.119$	$.158$	$.124$	$.339$	$-.232$	$-.089$	$-.155$	$-.075$
	$RI(LF)$	$-.004$	$-.373$	$-.009$	$-.113$	$.215$	$.049$	$-.231$	$-.231$	$-.130$	$-.098$
	RT	$.435$	$.395$	$-.070$	$.011$	$-.062$	$.103$	$.054$	$.126$	$-.124$	$.319$
	$RT(HF)$	$.462^{*}$	$.335$	$.021$	$-.058$	$-.031$	$.157$	$.001$	$.039$	$-.180$	$.222$
	$RT(LF)$	$.584^{*}$	$.214$	$-.163$	$-.007$	$-.082$	$.010$	$-.011$	$-.091$	$-.263$	$.178$
ADHD ($N = 18$)	$TotG$	$.143$	$-.062$	$.021$	$.153$	$-.303$	$.113$	$.433$	$.014$	$-.062$	$.192$
	$TG(HF)$	$.073$	$-.179$	$.083$	$-.008$	$-.020$	$-.074$	$.227$	$.256$	$-.095$	$.419$
	$TG(LF)$	$.109$	$.173$	$.009$	$.044$	$-.414$	$.247$	$.530^{*}$	$-.228$	$-.049$	$-.060$
	RI	$-.263$	$-.257$	$.312$	$-.567^{*}$	$.072$	$-.130$	$.294$	$.090$	$.498^{*}$	$.244$
	$RI(HF)$	$-.259$	$-.293$	$.394$	$-.563^{*}$	$.081$	$-.136$	$.290$	$.070$	$.534^{*}$	$.364$
	$RI(LF)$	$-.221$	$-.215$	$.281$	$-.542^{*}$	$.011$	$-.080$	$.295$	$.110$	$.459$	$.139$
	RT	$.030$	$-.297$	$.004$	$-.099$	$.179$	$-.206$	$-.290$	$-.104$	$-.093$	$-.407$
	$RT(HF)$	$.085$	$-.266$	$.068$	$-.044$	$.171$	$-.221$	$-.283$	$-.116$	$-.040$	$-.441$
	$RT(LF)$	$.151$	$-.337$	$-.026$	$-.078$	$.232$	$-.326$	$-.310$	$-.156$	$-.115$	$-.319$

Robust correlation coefficients $\hat{\rho}_G$ following the Gaussian rank correlation estimators (5).

(*) level of significance of *2p*$<$.05 ; (**) level of significance of *2p*$<$.01.

Supplemental Table

Table S3: Median and averaged ERPs latencies (ms) ± SEM in both feedback frequencies conditions pooled together for N2, P3a and P3b components over Fz, FCz, CZ, CPz, Pz and POz sites, after the trial start and after the gambling choice.

	Onset event	ERP	Latencies at recording sites (ms)					
			Fz	FCz	Cz	CPz	Pz	POz
Controls ($N = 36$)	Trial Start	N2	165.0 170.5±3.0	164.0 170.0±3.1	170.5 172.9±3.1	186.0 183.3±3.4	189.5 187.4±3.9	192.0 189.2±4.0
		P3a	255.5 254.3±4.3	253.5 253.9±4.5	248.5 253.4±4.4	257.5 263.2±4.4	260.0 264.3±4.1	257.0 259.0±3.8
		P3b	352.0 355.4±4.0	353.0 356.7±4.1	351.0 354.2±3.9	353.5 356.1±4.2	354.5 359.2±4.4	358.5 360.6±4.6
	Gambling choice	N2	174.5 172.6±2.8	166.0 168.1±2.2	168.0 167.5±2.7	177.5 176.1±3.3	176.5 175.8±3.0	184.0 178.4±3.1
		P3a	237.0 241.8±2.5	236.0 241.1±2.3	235.5 238.7±2.7	240.0 243.8±2.8	241.0 243.7±3.1	243.5 242.5±3.2
		P3b	356.0 357.9±3.6	357.0 357.0±4.0	358.0 358.2±4.3	357.0 358.9±3.6	369.0 366.5±3.9	370.5 369.2±3.6
ADHD ($N = 28$)	Trial Start	N2	174.5 172.6±2.8	174.0 171.1±3.0	169.5 168.5±3.0	180.0 179.5±3.7	183.0 181.2±4.1	187.5 182±4.9
		P3a	243.0 246.1±4.2	241.0 242.7±4.4	253.0 248.2±4.5	254.0 251.2±4.8	260.0 256.2±5.4	258.5 255.9±6.2
		P3b	356.5 349.2±5.0	356.5 351.4±4.9	352.0 350.9±4.5	355.0 352.4±5.0	352.0 350.2±5.2	350.0 349.3±5.4
	Gambling choice	N2	174.0 176.7±2.5	175.0 176.5±2.7	174.0 175.1±2.9	177.0 180.6±3.1	182.0 184.3±3.3	186.5 186.1±3.0
		P3a	246.0 245.2±3.1	241.0 244.7±3.5	243.5 243.2±3.6	249.5 247.0±4.3	246.0 247.5±4.3	252.5 251.2±4.8
		P3b	347.0 350.1±3.7	343.0 348.8±4.0	346.0 352.3±4.6	352.0 355.3±4.5	357.0 359.4±4.6	361.0 361.1±4.6

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6.4 Questionnaires

6.4.1 ASRS

UNIL/EPFL students were screened according to the their answers on the six first questions. The 6-item screener has proven some validity. It consists in giving one point for each answer greater than 1 in the first three items, and one point for any answer greater than 2 in each next three items. Participants that had responded positively to a minimum of 4 of those items (within the 6-item screener criteria) were considered as having ADHD symptoms, whereas those that have responded to less than 4 items were considered as having no ADHD symptoms. Then, for such individuals, the score on these 6-item screener was calculated, those having a score greater than 22 were selected to participate as UNIL/EPFL students with high ADHD symptoms, and the ones having a score lower than 10 were selected to participate as UNIL/EPFL students with low ADHD symptoms. These criteria were chosen according to the score's distribution of the participants.

Adult Self-Report Scale (ASRS-1.1) Symptom Checklist

INSTRUCTIONS

Les questions figurant au verso ont pour but de favoriser le dialogue entre vous et vos patients, et de vous aider à confirmer les éventuels symptômes d'un Trouble d'Hyperactivité avec Déficit de l'Attention (THADA).

Description : La liste des symptômes est un instrument qui reprend les 18 critères du DSM-IV-TR. Parmi ceux-ci, six sont les plus prédictifs du THADA. Ces six items composent l'ASRS v1.1 Screener et se retrouvent dans la partie A de la liste des symptômes. La partie B regroupe les 12 items restants.

Instructions :

Symptômes :

1. Demandez au patient de remplir les parties A et B de la liste des symptômes en cochant la case qui correspond le mieux à la fréquence de chacun des symptômes.
2. Cotation de la partie A. Si au moins quatre croix apparaissent dans la zone ombrée de la partie A, le patient présente des symptômes très évocateur de THADA, ce qui recommande une évaluation plus poussée.
3. Les scores de fréquence de la partie B apportent des éléments additionnels et peuvent donner des indices sur la symptomatologie du patient. Attachez une attention particulière aux crois figurant dans la zone ombrée. La réponse en terme de fréquence est plus sensible pour certaines questions. Aucun score total ou probabilité diagnostic n'est attaché à ces 12 questions. Il a été démontré que les 6 questions de la partie A étaient les plus prédictives du diagnostic et doivent être utilisées comme outil de dépistage.

Gêne :

1. Parcourez la totalité de la liste des symptômes avec votre patient et évaluez le niveau de gêne associé à chaque symptôme.
2. Prenez en compte les situations scolaires/professionnelles, sociales et familiales.
3. La liste des symptômes peut aider à l'évaluation de la gêne occasionnée car la fréquence des symptômes est souvent associée à leur sévérité. Si la fréquence des symptômes est très élevée, vous pourrez demander à votre patient de décrire comme ils impactent sa capacité à travailler, à prendre soin des choses à sa maison, ou à s'entendre avec d'autres personnes comme l'époux/épouse.

Histoire :

1. Evaluez la présence dans l'enfance de ces symptômes ou d'autres similaires. L'ADHD des adultes n'a pas été forcément diagnostiqué dans l'enfance. Cherchez dans l'histoire du patient les problèmes précoces ou persistants liés à l'attention ou au contrôle de soi. Certains symptômes doivent avoir été présents dans l'enfance, mais pas tous nécessairement.
2. Demandez à consulter les bulletins scolaires. Mais souvenez-vous que de nombreux adultes étaient scolarisés alors que le THADA et ses symptômes n'étaient pas familiers. Plus qu'aux notes, accordez de l'importance aux commentaires des enseignants. Si vous ne pouvez pas avoir accès à ces bulletins, posez des questions comme « si j'étais un enseignant, comment est-ce que je décrirais votre attitude en classe ? » et « si je lisais vos bulletins scolaires, qu'est-ce que j'y trouverais ? »

Nom :……………………………………………….. **Sexe :** **H / F** **Date :** **……/……/20….**

Répondez aux questions suivantes en vous auto-évaluant sur chacun des critères à l'aide de l'échelle à droite de la page. Pour répondre aux questions, cochez la case qui décrit le mieux vos sentiments ou vos comportements au cours des six derniers mois. Rendez ensuite le questionnaire entièrement rempli au professionnel de santé qui vous la remis avec lequel vous pourrez en discuter.

		Jamais	Rarement	Parfois	Souvent	Très souvent
1.	Avec quelle fréquence avez-vous des difficultés à finaliser les derniers détails d'un projet une fois que le plus intéressant a été fait?	○	○	○	○	○
2.	Avec quelle fréquence avez-vous des difficultés à mettre les choses en ordre lorsque vous devez faire un travail qui demande une certaine organisation?	○	○	○	○	○
3.	Avec quelle fréquence avez-vous des difficultés pour vous souvenir de vos rendez-vous ou de vos engagements?	○	○	○	○	○
4.	Avec quelle fréquence avez-vous tendance à éviter ou à remettre à plus tard un travail qui demande beaucoup de réflexion?	○	○	○	○	○
5.	Avec quelle fréquence avez-vous la bougeotte ou agitez-vous vos mains ou vos pieds lorsque vous devez rester assis pendant un long moment?	○	○	○	○	○
6.	Avec quelle fréquence vous sentez-vous trop actif ou obligé de faire des choses, comme si vous étiez actionné par un moteur?	○	○	○	○	○
7.	Avec quelle fréquence faites-vous des erreurs d'étourderie lorsque vous travaillez sur un projet ennuyeux ou difficile?	○	○	○	○	○
8.	Avec quelle fréquence avez-vous des difficultés à rester attentif lorsque vous faites un travail ennuyeux ou répétitif?	○	○	○	○	○
9.	Avec quelle fréquence avez-vous des difficultés à vous concentrer sur ce que les gens vous disent, même lorsqu'ils vous parlent directement?	○	○	○	○	○
10.	Avec quelle fréquence avez-vous tendance à égarer ou du mal à retrouver des choses à la maison ou au travail?	○	○	○	○	○
11.	Avec quelle fréquence êtes-vous distrait par de l'activité ou du bruit autour de vous?	○	○	○	○	○
12.	Avec quelle fréquence vous levez-vous pendant des réunions ou d'autres situations dans lesquelles vous êtes censé rester assis?	○	○	○	○	○
13.	Avec quelle fréquence avez-vous la bougeotte ou vous sentez-vous agité?	○	○	○	○	○
14.	Avec quelle fréquence avez-vous des difficultés à vous détendre et à vous relaxer pendant votre temps libre?	○	○	○	○	○
15.	Avec quelle fréquence avez-vous remarqué que vous étiez trop bavard lorsque vous étiez en compagnie d'autres personnes?	○	○	○	○	○
16.	Avec quelle fréquence vous surprenez-vous terminant les phrases des autres dans une discussion avant qu'ils aient pu le faire eux-mêmes?	○	○	○	○	○
17.	Avec quelle fréquence avez-vous des difficultés à attendre votre tour dans une file d'attente?	○	○	○	○	○
18.	Avec quelle fréquence interrompez-vous les autres lorsqu'ils sont occupés?	○	○	○	○	○

6.4.2 HEXACO PI-R

The scoring keys are shown following the questionnaire. Reversed items (R) were changed (1 → 5; 2 → 4; 3 → 3; 4 → 2; 5 → 1) and the sum of points was calculated according to the scoring keys.

CODE:

Inventaire de personnalité HEXACO

DIRECTIONS

Dans les pages suivantes, vous trouverez une série d'énoncés qui vous décrivent. Veuillez lire chaque énoncé et décider à quel point vous êtes d'accord ou en désaccord avec son contenu. Ensuite, écrivez le chiffre approprié, en vous fondant sur l'échelle suivante :

5 = tout à fait d'accord
4 = d'accord
3 = neutre (ni d'accord, ni en désaccord)
2 = pas d'accord
1 = pas du tout d'accord

Veuillez répondre à tous les énoncés, même si vous n'êtes pas tout à fait certain(e) de votre réponse.

1 = pas du tout d’accord 2 = pas d’accord 3 = neutre (ni d’accord, ni en désaccord) 4 = d’accord 5 = tout à fait d’accord

1 _____ Visiter une galerie d’art m’ennuierait.

2 _____ J’organise et je prévois à l’avance afin d’éviter de tout bousculer à la dernière minute.

3 _____ Je garde rarement rancune, même contre les personnes qui m’ont causé de graves préjudices.

4 _____ Je me sens raisonnablement satisfait avec moi-même dans l'ensemble.

5 _____ J’ai peur de voyager en cas d’intempéries.

6 _____ Je n’aurais pas recours à la flatterie pour obtenir une augmentation de salaire ou une promotion, même si je crois que cela ait d’excellente chance de réussir.

7 _____ Apprendre l’histoire et les politiques d’autres pays m’intéresse.

8 _____ Je me donne au maximum afin d’atteindre un but.

9 _____ Les gens me disent parfois que je juge trop les autres.

10 _____ Je fais rarement part de mes opinions pendant des réunions de groupe.

11 _____ Parfois, je ne peux m’empêcher de m’inquiéter pour des incidents sans importance.

12 _____ Si j’avais la certitude de ne jamais me faire prendre, je volerais volontiers un million d’euros.

13 _____ J’aimerais bien créer une œuvre d’art comme un roman, une chanson ou une peinture.

14 _____ Lorsque je travaille, je me soucie peu des petits détails.

15 _____ Les gens disent parfois que je suis une personne têtue.

16 _____ Je préfère les emplois qui exigent une interaction sociale active à un emploi où il faut travailler seul.

17 _____ Lorsqu’une expérience douloureuse m’afflige, j’ai besoin de quelqu’un pour me sentir mieux.

18 _____ Avoir beaucoup d’argent n’est pas particulièrement important pour moi.

19 _____ Porter attention aux idées radicales est une perte de temps.

20 _____ Lorsque je prends des décisions, je me fie à mon intuition du moment plutôt que de prendre le temps d’évaluer rationnellement la question.

21 _____ Les gens trouvent que je suis une personne qui se fâche facilement.

22 _____ La plupart du temps, je suis jovial(e) et optimiste.

23 _____ Voir quelqu’un pleurer me donne envie de pleurer moi-même.

24 _____ Je crois mériter plus de respect qu’une personne moyenne.

25 _____ Si j’en avais la chance, j’aimerais bien assister à un concert de musique classique.

26 _____ Au travail, mon désordre me cause parfois des problèmes.

27 _____ J’ai l’attitude de « pardonner et oublier » envers ceux qui m’ont traité injustement.

28 _____ J’estime que je suis une personne peu populaire.

29 _____ Les dangers physiques me font très peur.

30 _____ Pour obtenir quelque chose de quelqu’un en particulier, je rirais de ses blagues même si elles sont plates.

Veuillez continuer…

1 = pas du tout d’accord   2 = pas d’accord   3 = neutre (ni d’accord, ni en désaccord)   4 = d’accord   5 = tout à fait d’accord

31 _____ Je n’ai jamais vraiment aimé feuilleter une encyclopédie.
32 _____ Je ne fais que le strict minimum de mon travail.
33 _____ Je juge souvent les autres avec indulgence.
34 _____ Dans des situations sociales, je suis la personne qui fait généralement les premiers pas.
35 _____ J’ai tendance à beaucoup moins m’inquiéter que la plupart des gens.
36 _____ Je n’accepterais jamais de pot-de-vin, aussi gros soit-il.
37 _____ On me dit souvent que j’ai beaucoup d’imagination.
38 _____ Je fais toujours mon travail avec minutie, même lorsque cela exige plus de temps.
39 _____ Je suis plutôt flexible dans mes opinions lorsque les gens ne sont pas d’accord avec moi.
40 _____ Me faire des amis est ma priorité quand je suis dans un nouvel environnement.
41 _____ Je peux gérer les situations difficiles sans le soutien moral de qui que ce soit.
42 _____ Posséder des articles de luxe me ferait très plaisir.
43 _____ J’aime bien les gens qui sont capables d’une vision non conventionnelle des choses.
44 _____ Je fais beaucoup d’erreurs, parce que je ne pense pas avant d’agir.
45 _____ La plupart des gens se fâchent plus rapidement que moi.
46 _____ La plupart des gens sont plus optimistes et dynamiques que moi.
47 _____ Je me sens très émotif(ve) quand une personne qui m’est proche s’en va pour une longue période.
48 _____ Je veux que les gens sachent que je suis une personne importante et supérieure.
49 _____ Je ne me considère pas comme une personne artistique ou créative.
50 _____ On me qualifie souvent de perfectionniste.
51 _____ Même lorsque les gens commettent de nombreuses erreurs, j’émets rarement des commentaires négatifs.
52 _____ J’estime parfois que je suis une personne sans valeur.
53 _____ Même en cas d’urgence, je ne panique pas.
54 _____ Je ne ferais pas semblant d’aimer une personne dans le seul but d’obtenir une faveur d’elle.
55 _____ Parler de philosophie m’ennuie.
56 _____ Je préfère être spontané(e) que de m’en tenir à un plan.
57 _____ Lorsqu’on me dit que j’ai tort, ma réaction première est de défendre mon point.
58 _____ Lorsque je suis en groupe, je suis souvent le ou la porte-parole.
59 _____ Je reste impassible même dans des situations où la plupart des gens deviennent très émotifs.
60 _____ Je serais tenté(e) d’utiliser de la fausse monnaie si j’étais certain(e) de ne jamais me faire prendre.

Scoring Keys for the 60-Item Version

Honesty-Humility	
Sincerity	6, 30R, 54
Fairness	12R, 36, 60R
Greed-Avoidance	18, 42R
Modesty	24R, 48R
Emotionality	
Fearfulness	5, 29, 53R
Anxiety	11, 35R
Dependence	17, 41R
Sentimentality	23, 47, 59R
Extraversion	
Social Self-Esteem	4, 28R, 52R
Social Boldness	10R, 34, 58
Sociability	16, 40
Liveliness	22, 46R
Agreeableness	
Forgiveness	3, 27
Gentleness	9R, 33, 51
Flexibility	15R, 39, 57R
Patience	21R, 45
Conscientiousness	
Organization	2, 26R
Diligence	8, 32R
Perfectionism	14R, 38, 50
Prudence	20R, 44R, 56R
Openness to Experience	
Aesthetic Appreciation	1R, 25
Inquisitiveness	7, 31R
Creativity	13, 37, 49R
Unconventionality	19R, 43, 55R

6.4.3 CBS

This questionnaire was not scored.

UNITE DE RECHERCHE DU SUPEA (CHUV)
ETUDE SUR LE SYNDROME D'HYPERACTIVITE AVEC DEFICIT D'ATTENTION

QUESTIONNAIRE POUR LES ADULTES

Nom, Prénom : ____________________________________ Date : _________
Date de naissance : _________________

CURRENT BEHAVIOR SCALE (Russel A. Barkley, PhD)[1]

Cochez s'il vous plaît la case qui décrit le mieux votre comportement.

		Durant les 6 derniers mois			
		Jamais, Rarement	Parfois	Souvent	Très souvent
1	J'ai de la difficulté à attendre; je suis impatient/e.				
2	Je prends des décisions de manière impulsive.				
3	Je suis incapable de contrôler mes réactions ou mes réponses face à un évènement ou toute autre situation.				
4	J'ai de la difficulté à arrêter mes activités ou mon comportement quand cela est nécessaire.				
5	J'ai de la difficulté à changer ma manière de faire lorsque je reçois un feedback sur mon erreur.				
6	Je suis facilement distrait(e) par des pensées non pertinentes quand je dois me concentrer.				
7	Je suis enclin à la rêverie alors que je devrais me concentrer sur une tâche.				
8	J'ai tendance à remettre les choses au lendemain ou à retarder ce que je dois faire jusqu'à la dernière minute.				
9	Je fais des commentaires de manière impulsive sur les autres.				
10	J'ai tendance à faire des pauses dans mon travail et à ne pas faire tout ce que je suis supposé(e) faire.				
11	J'ai tendance à interrompre un travail rapidement s'il est ennuyeux ou déplaisant.				
12	Je suis incapable d'envisager l'obtention d'une récompense non-immédiate ou de suspendre une activité dans le but d'obtenir une récompense ultérieure.				
13	J'ai tendance à faire des choses sans prendre en considération leurs conséquences.				
14	Je change de programme à la dernière minute ou sur un coup de tête.				

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[1] In Biederman J. et al. (2008). Journal of Psychiatric Research 42, 304-310. Traduction de Michel Bader, Sarah Leopizzi et Coralie Voumard avec l'autorisation de Russel A. Barkley, mai 2008.

		Durant les 6 derniers mois			
		Jamais, Rarement	Parfois	Souvent	Très souvent
15	Je commence un projet ou une tâche sans lire ou écouter attentivement les directives.				
16	J'ai une mauvaise perception du temps.				
17	J'ai de la difficulté à gérer mon temps.				
18	Je ne prends pas en considération les évènements passés pertinents ou mes expériences personnelles antérieures avant de répondre à des situations.				
19	Je ne pense pas au futur autant que les autres personnes de mon âge semblent le faire.				
20	Je ne me prépare pas pour le travail ou pour les tâches qui me sont assignés.				
21	Je ne réussis pas à respecter les échéances fixées.				
22	J'ai de la difficulté à planifier ou à préparer des événements à venir.				
23	J'oublie de faire des choses que je suis supposé(e) faire.				
24	J'ai des difficultés avec le calcul arithmétique mental.				
25	J'ai plus de peine que je ne le devrais à comprendre ce que je lis ; je dois relire le texte pour comprendre sa signification.				
26	Je semble ne pas me souvenir de ce que j'ai entendu ou lu précédemment.				
27	Je semble incapable d'atteindre les objectifs que je me suis fixés.				
28	Je suis en retard au travail ou aux rendez-vous				
29	J'ai de la difficulté à organiser mes pensées ou à clarifier mes idées.				
30	Je n'ai pas conscience de ce que je dis ou fais.				
31	Je suis incapable de garder en mémoire les choses dont je dois me souvenir.				
32	J'ai de la difficulté à être objectif(ve) à propos des choses qui m'affecte.				
33	J'ai de la difficulté à prendre en considération le point de vue des autres sur un problème ou une situation.				
34	J'ai de la difficulté à garder en tête l'importance ou le but des activités.				
35	J'ai tendance à perdre le fil de la discussion en parlant avec les autres.				
36	Lorsqu'on m'explique quelque chose de compliqué à faire, je ne peux pas retenir les informations nécessaires pour reproduire ou faire correctement la tâche.				

		Durant les 6 derniers mois			
		Jamais, Rarement	Parfois	Souvent	Très souvent
37	Je porte une attention limitée aux détails en travaillant.				
38	Je trouve difficile de ne pas perdre de vue l'objectif lors de la réalisation simultanée de plusieurs activités.				
39	Je ne peux pas faire les choses avant d'être confronté(e) au dernier délai.				
40	Je n'apprécie pas le travail ou les activités scolaires demandant un effort plus marqué.				
41	J'évalue difficilement le temps nécessaire pour faire quelque chose ou pour aller quelque part.				
42	Je me motive difficilement pour commencer à travailler.				
43	Je me mets facilement en colère ou deviens facilement contrarié(e).				
44	Je suis facilement frustré(e).				
45	Je réagis de manière excessive.				
46	Je manque de motivation pour poursuivre mon travail et le terminer.				
47	Je suis incapable de persister dans les tâches que je trouve inintéressantes.				
48	Je ne m'investis pas autant dans mon travail que je le devrais ou autant que les autres.				
49	J'ai de la difficultés à rester vigilant(e) ou éveillé(e) dans des situations monotones.				
50	Je suis facilement excité(e) par des activités qui se déroulent autour de moi.				
51	Je ne suis pas motivé(e) à me préparer à l'avance pour réaliser ce qui doit être fait.				
52	Je suis incapable de rester concentré(e) lors de lectures, de tâches administratives ou en travaillant.				
53	Je m'ennuie facilement.				
54	Les autres me disent que je suis paresseux (se) ou que je manque de motivation.				
55	Je dépends de l'aide des autres pour terminer mon travail.				
56	Les tâches doivent apporter une récompense immédiate, sinon je suis incapable de les faire.				
57	J'ai de la peine à terminer une activité avant d'en commencer une nouvelle.				
58	Je résiste mal à l'envie de faire quelque chose de plus amusant ou de plus intéressant lorsque je suis supposé(e) travailler.				

		Durant les 6 derniers mois			
		Jamais, Rarement	Parfois	Souvent	Très souvent
59	Je suis incapable de maintenir des amitiés ou des relations proches aussi longtemps que d'autres personnes.				
60	Je suis inconstant(e) dans la qualité ou dans la quantité de mon travail.				
61	Je ne me préoccupe pas des évènements futurs autant que les autres .				
62	Je ne réfléchis pas de manière critique avant d'entreprendre quelque chose.				
63	Je ne suis pas capable de travailler aussi bien que d'autres, sans supervision ou sans instructions fréquentes.				
64	Je réalise difficilement ce que j'avais l'intention de faire.				
65	J'ai de la peine à tenir les promesses ou les engagements faits aux autres.				
66	Je manque d'autodiscipline.				
67	J'ai de la difficulté à raisonner de manière adéquate dans des situations problématiques ou stressantes.				
68	J'ai de la difficulté à suivre les règles dans un contexte donné.				
69	Je ne suis pas très flexible dans mes comportements ou dans l'approche d'une situation; je suis extrêmement rigide dans ma manière de faire les choses.				
70	J'ai de la difficulté à organiser mes pensées.				
71	J'ai de la difficulté à exprimer mes pensées de manière claire.				
72	Je suis incapable de proposer ou de trouver des solutions à des problèmes, alors que les autres en sont capables.				
73	Souvent je ne trouve pas les bons mots quand j'aimerais expliquer quelque chose aux autres personnes.				
74	J'ai de la difficulté à mettre par écrit mes pensées aussi bien ou aussi vite que les autres.				
75	Je ne pense pas être aussi créatif(ve) ou inventif(ve) que mes pairs.				
76	Lorsque j'essaie d'atteindre mes objectifs ou de faire mes devoirs, je trouve que je ne suis pas capable d'envisager autant de solutions que les autres.				
77	J'ai plus de difficulté que les autres à apprendre des activités nouvelles ou complexes.				
78	J'ai de la difficulté à expliquer les choses dans le bon ordre ou de manière chronologique.				

		Durant les 6 derniers mois			
		Jamais, Rarement	Parfois	Souvent	Très souvent
79	Je ne vais pas à l'essentiel dans mes explications aussi vite que les autres.				
80	J'ai des difficultés à faire les choses de manière ordonnée ou chronologique.				
81	Je suis incapable de penser par moi-même ou de faire face aussi efficacement que les autres à des évènements inattendus.				
82	Je suis maladroit(e); J'ai plus de problèmes de coordination de mouvements que les autres.				
83	Mon écriture est médiocre ou peu soignée.				
84	J'ai de la difficulté à organiser ou réaliser mon travail en fonction des priorités ; je n'arrive pas bien à établir les priorités.				
85	Je suis plus lent/e que les autres à réagir à des événements inattendus.				
86	Je fais des blagues, je m'amuse, ou j'agis de manière irréfléchie alors que je devrais être sérieux (se).				
87	Je suis incapable de me souvenir aussi bien que les autres, de ce que j'ai fait ou des lieux où je suis allé(e).				
88	Je suis sujet(te) aux accidents.				
89	J'ai tendance à conduire à une vitesse excessive plus facilement que les autres.				
90	J'ai de la peine à gérer l'argent ou les cartes de crédits.				
91	J'ai plus de difficultés à me souvenir des événements de mon enfance que les autres.				
92	Je perds mon sang-froid.				
93	Je me dispute avec les autres.				
94	Je défie ou je refuse activement d'obéir aux demandes ou de me conformer aux règles des autres.				
95	J'agace de manière délibérée les gens.				
96	J'accuse les autres pour mes propres erreurs ou pour ma mauvaise conduite.				
97	Je suis susceptible ou facilement agacé(e) par les autres.				
98	Je suis en colère ou plein(e) de ressentiment.				
99	Je suis malveillant(e) ou vindicatif(ve)				

6.4.4 CAARS-S : SV

The response scale was adapted according to the technical manual's instructions to range from 1 to 5 (instead of 0 to 4 points). Raw scores were calculated within each sub category: The TA subscale (DSM-IV Inattentive symptoms) was composed of the following items: 1, 9, 13, 14, 19, 21, 26, 29, and 30. The TB subscale (DSM-IV Hyperactive/impulsive symptoms) was composed of the following items: 2, 4, 6, 8, 16, 18, 22, 25, and 27. The TC subscale (DSM-IV ADHD symptoms total) was composed the TA and TB items. The TD subscale (ADHD index) was composed of the following items: 3, 5, 7, 10, 11, 12, 15, 17, 20, 23, 24, and 28. If an item was missing, the subscale's score was corrected ((score*total number of items)/valid number of items, for instance a score of 13 with one missing value becomes 15, (13*9)/8)). However, if a subscale contained more than 2 missing values, the subscale was considered as invalid. These 4 scores were then compared to a standardized table according to the age and gender of each participants, allowing the comparison of individuals having different age and sex.

ECHELLE D'EVALUATION DE CONNERS POUR LES ADULTES ATTEINTS DE TDAH (CAARS-S : SV) (C. K. Conners, Ph.D., D. Erhardt, Ph.D., and E. P. Sparrow, Ph.D.)

Voici une liste de propositions concernant des comportements ou problèmes parfois rencontrés chez les adultes. Lisez attentivement chaque proposition et indiquez dans quelle mesure ou à quelle fréquence elle peut s'appliquer à votre situation récente. Entourez le chiffre correspondant à votre réponse. Pour cela, utilisez l'échelle suivante : 0 = pas du tout, jamais ; 1 = Un peu, de temps à autre ; 2 = plutôt, souvent et 3 = beaucoup, très fréquemment.

		Pas du tout, jamais	**Un peu, de temps à autre**	**plutôt, souvent**	**beaucoup, très fréquemment**
1.	Je perds les objets dont j'ai besoin pour des tâches ou des activités (p. ex., pense-bête, crayons, livres ou outils).	0	1	2	3
2.	Je parle trop.	0	1	2	3
3.	Je suis toujours en train de faire quelque chose, comme si j'étais monté(e) sur ressorts.	0	1	2	3
4.	J'éprouve des difficultés à m'occuper calmement.	0	1	2	3
5.	Je suis irascible/colérique.	0	1	2	3
6.	Je me lève alors que je devrais rester assis(e).	0	1	2	3
7.	Je fais toujours des caprices.	0	1	2	3
8.	J'éprouve des difficultés à faire la queue ou à attendre mon tour.	0	1	2	3
9.	J'ai du mal à rester concentré lorsque je travaille.	0	1	2	3
10.	J'évite les nouveaux défis par manque de confiance en moi.	0	1	2	3
11.	Je ressens une agitation intérieure, même si j'ai l'air calme.	0	1	2	3
12.	Les choses que j'entends ou que je vois me distraient de ce que je fais.	0	1	2	3
13.	Je suis distrait(e) dans mes activités quotidiennes.	0	1	2	3
14.	J'éprouve des difficultés à écouter ce que les autres disent.	0	1	2	3
15.	Je n'exploite pas tout mon potentiel.	0	1	2	3
16.	Je ne tiens pas en place.	0	1	2	3
17.	Je ne parviens pas à mener les tâches à bien, sauf en cas d'absolue nécessité.	0	1	2	3
18.	J'agite les mains ou les pieds ou je remue sur ma chaise.	0	1	2	3
19.	Je fais des fautes d'inattention ou j'ai des difficultés à faire attention aux détails.	0	1	2	3
20.	Je perturbe les activités des autres.	0	1	2	3
21.	Je n'aime pas les tâches ou les activités professionnelles qui demandent beaucoup de réflexion.	0	1	2	3
22.	Je suis agité(e) ou trop actif(ve).	0	1	2	3
23.	Parfois, je suis tellement concentré(e) que j'en oublie tout le reste ; à d'autres moments, je suis tellement inattentif(ve) que je me laisse distraire facilement.	0	1	2	3
24.	Je n'arrive pas à me concentrer sur un sujet, sauf s'il est vraiment intéressant.	0	1	2	3
25.	Je réponds avant d'attendre la fin de la question.	0	1	2	3

In the USA, P.O Box 950, North Tonawanda, NY 14120-0950. (800) 456-3003.
In Canada, 3770 Victoria Park Ave. Toronto. ON M2H 3M6. (0800) 268-6011.
International. +1-416-492-2627. Fax. +1-416-492-3343

26.	J’éprouve des difficultés à finir mon travail ou mes tâches.	0	1	2	3
27.	J’interromps les autres lorsqu’ils travaillent ou se divertissent.	0	1	2	3
28.	Mes erreurs passées ne me permettent pas d’avoir confiance en moi.	0	1	2	3
29.	Je me laisse distraire par ce qui se passe autour de moi.	0	1	2	3
30.	J’éprouve des difficultés à organiser mes tâches et activités	0	1	2	3

6.4.5 EHI

A laterality quotient (LQ) was calculated for each participants according to the following formula:

$$LQ = 100 * \frac{\sum x(i,R) - \sum x(i,L)}{\sum x(i,R) + \sum x(i,L)}$$

where $\sum x(i,R)$ and $\sum x(i,L)$ are the number of "+" for an item in the right and left columns respectively (meaning that if a participant responded "habituellement", it was scored with one "+", and if the participant responded "toujours" it was scored with two "+" in both columns), providing a score in between [-100,+100], -100 corresponding to a left handed participant, +100 to a right handed participant, and 0 to an ambidextrous individual.

QUESTIONNAIRE DE LATERALISATION :

Pour dix gestes quotidiens à réaliser, indiquez quelle main vous utilisez par une croix dans l'une des colonnes du tableau :

Action	Toujours à gauche	Habituellement à gauche	Sans préférence	Habituellement à droite	Toujours à droite
Écrire	☐	☐	☐	☐	☐
Dessiner	☐	☐	☐	☐	☐
Lancer un objet	☐	☐	☐	☐	☐
Utiliser des **ciseaux**	☐	☐	☐	☐	☐
Tenir sa **brosse à dents**	☐	☐	☐	☐	☐
Utiliser un **couteau** (sans la fourchette)	☐	☐	☐	☐	☐
Utiliser une **cuillère**	☐	☐	☐	☐	☐
Balayer (main qui est au-dessus sur le manche)	☐	☐	☐	☐	☐
Craquer une **allumette**	☐	☐	☐	☐	☐
Dévisser un bouchon (main sur le bouchon)	☐	☐	☐	☐	☐
Total					

Oldfield, R.C. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia. 9(1):97-113, 1971.

6.4.6 MINI

The MINI was rated according the scoring instructions in the questionnaire (p.3), based on the presence or absence of the symptoms in each module.

M.I.N.I.

Mini International Neuropsychiatric Interview

French Version 5.0.0

DSM-IV

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University of South Florida - Tampa - USA.

NOM DU PATIENT :		***PROTOCOLE NUMERO :***	
DATE DE NAISSANCE:		***Heure de Début :***	
ENTRETIEN REALISE PAR :		***Heure de Fin :***	
DATE DE L'ENTRETIEN :		***DUREE TOTALE :***	

M.I.N.I. 5.0.0 / French version / DSM-IV / current

MODULES	PERIODES EXPLOREES	
A. EPISODE DEPRESSIF MAJEUR	Actuelle (2 dernières semaines) + Vie entière	
A'. EDM avec caractéristiques mélancoliques	Actuelle (2 dernières semaines)	Optionnel
B. DYSTHYMIE	Actuelle (2 dernières années)	
C. RISQUE SUICIDAIRE	Actuelle (mois écoulé)	
D. EPISODE (HYPO-)MANIAQUE	Actuelle + Vie entière	
E. TROUBLE PANIQUE	Actuelle (mois écoulé) + Vie entière	
F. AGORAPHOBIE	Actuelle	
G. PHOBIE SOCIALE	Actuelle (mois écoulé)	
H. TROUBLE OBSESSIONNEL COMPULSIF	Actuelle (mois écoulé)	
I. ETAT DE STRESS POST-TRAUMATIQUE	Actuelle (mois écoulé)	Optionnel
J. ALCOOL (DEPENDANCE /ABUS)	Actuelle (12 derniers mois)	
K. DROGUES (DEPENDANCE /ABUS)	Actuelle (12 derniers mois)	
L. TROUBLES PSYCHOTIQUES	Actuelle + Vie entière	
M. ANOREXIE MENTALE	Actuelle (3 derniers mois)	
N. BOULIMIE	Actuelle (3 derniers mois)	
O. ANXIETE GENERALISEE	Actuelle (6 derniers mois)	
P. TROUBLE DE LA PERSONNALITE ANTISOCIALE	Vie entière	Optionnel

INSTRUCTIONS GENERALES

Le M.I.N.I. (DSM-IV) est un entretien diagnostique structuré, d'une durée de passation brève (moyenne 18,7 min. ± 11,6 min.; médiane 15 minutes), explorant de façon standardisée, les principaux Troubles psychiatriques de l'Axe I du DSM-IV (American Psychiatric Association, 1994). Le M.I.N.I. peut être utilisé par des cliniciens, après une courte formation. Les enquêteurs non-cliniciens, doivent recevoir une formation plus intensive.

• Entretien :

Afin de réduire le plus possible la durée de l'entretien, préparez le patient à ce cadre clinique inhabituel en lui indiquant que vous allez lui poser des questions précises sur ses problèmes psychologiques et que vous attendez de lui / d'elle des réponses en oui ou non.

• Présentation :

Le M.I.N.I. est divisé en **modules** identifiées par des lettres, chacune correspondant à une catégorie diagnostique.

- Au début de chacun des modules (à l'exception du module « Syndromes psychotiques »), une ou plusieurs **question(s) / filtre(s)** correspondant aux critères principaux du trouble sont présentées dans un cadre grisé.
- A la fin de chaque module, une ou plusieurs **boîtes diagnostiques** permet(tent) au clinicien d'indiquer si les critères diagnostiques sont atteints.

• Conventions :

Les phrases écrites en « lettres minuscules » doivent être lues "mot-à-mot" au patient de façon à standardiser l'exploration de chacun des critères diagnostiques.

Les phrases écrites en « MAJUSCULES » ne doivent pas être lues au patient. Ce sont des instructions auxquelles le clinicien doit se référer de façon à intégrer tout au long de l'entretien les algorithmes diagnostiques.

Les phrases écrites en **« gras »** indiquent la période de temps à explorer. Le clinicien est invité à les lire autant de fois que nécessaire au cours de l'exploration symptomatique et à ne prendre en compte que les symptômes ayant été présentés au cours de cette période.

Les phrases entre (parenthèses) sont des exemples cliniques décrivant le symptôme évalué. Elles peuvent être lues de manière à clarifier la question.

Lorsque des termes sont séparés par un *slash (/),* le clinicien est invité à ne reprendre que celui correspondant au symptôme présenté par le patient et qui a été exploré précédemment (par ex. question A3).

Les réponses surmontées d'une flèche **(➔)** indiquent que l'un des critères nécessaires à l'établissement du diagnostic exploré n'est pas atteint. Dans ce cas, le clinicien doit aller directement à la fin du module, entourer « NON » dans la ou les boîtes diagnostiques correspondantes et passer au module suivant.

• Instructions de cotation :

Toutes les questions posées doivent être cotées. La cotation se fait à droite de chacune des questions en entourant, soit OUI, soit NON en fonction de la réponse du patient.

Le clinicien doit s'être assuré que chacun des termes formulés dans la question ont bien été pris en compte par le sujet dans sa réponse (en particulier, les critères de durée, de fréquence, et les alternatives "et / ou").

Les symptômes imputables à une maladie physique, ou à la prise de médicaments, de drogue ou d'alcool ne doivent pas être côtés OUI. Le M.I.N.I. Plus qui est une version plus détaillée du M.I.N.I. explore ces différents aspects.

Si vous avez des questions ou des suggestions, si vous désirez être formé à l'utilisation du M.I.N.I. ou si vous voulez être informés des mises à jour, vous pouvez contacter :

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➔: **ALLEZ DIRECTEMENT** A LA (AUX) CASE(S) DIAGNOSTIQUE(S), **ENTOUREZ NON** DANS CHACUNE ET **PASSEZ** AU MODULE SUIVANT

A. EPISODE DEPRESSIF MAJEUR

A1	Au cours des deux dernières semaines, vous êtes-vous senti(e) particulièrement triste, cafardeux(se), déprimé(e), la plupart du temps au cours de la journée, et ce, presque tous les jours ?	NON	OUI	1
A2	Au cours des deux dernières semaines, aviez-vous presque tout le temps le sentiment de n'avoir plus goût à rien, d'avoir perdu l'intérêt ou le plaisir pour les choses qui vous plaisent habituellement ?	NON	OUI	2
	A1 OU **A2** SONT-ELLES COTEES **OUI** ?	➔ NON	OUI	
A3	**Au cours de ces deux dernières semaines, lorsque vous vous sentiez déprimé(e) et/ou sans intérêt pour la plupart des choses :**			
a	Votre appétit a-t-il notablement changé, ou avez-vous pris ou perdu du poids sans en avoir l'intention ? (variation au cours du mois de ± 5 %, c. à d. ± 3,5 kg / ± 8 lbs., pour une personne de 65 kg / 120 lbs.) COTER **OUI,** SI **OUI** A L'UN OU L'AUTRE	NON	OUI	3
b	Aviez-vous des problèmes de sommeil presque toutes les nuits (endormissement, réveils nocturnes ou précoces, dormir trop)?	NON	OUI	4
c	Parliez-vous ou vous déplaciez-vous plus lentement que d'habitude, ou au contraire vous sentiez-vous agité(e), et aviez-vous du mal à rester en place, presque tous les jours ?	NON	OUI	5
d	Vous sentiez-vous presque tout le temps fatigué(e), sans énergie, et ce presque tous les jours ?	NON	OUI	6
e	Vous sentiez-vous sans valeur ou coupable, et ce presque tous les jours ?	NON	OUI	7
f	Aviez-vous du mal à vous concentrer ou à prendre des décisions, et ce presque tous les jours ?	NON	OUI	8
g	Avez-vous eu à plusieurs reprises des idées noires comme penser qu'il vaudrait mieux que vous soyez mort(e), ou avez-vous pensé à vous faire du mal ?	NON	OUI	9
A4	Y A-T-IL AU MOINS **3 OUI** EN **A3** ? (ou 4 si A1 OU A2 EST COTEE NON)	**NON**	**OUI** ***EPISODE DEPRESSIF MAJEUR ACTUEL***	
	SI LE PATIENT PRESENTE UN EPISODE DEPRESSIF MAJEUR ACTUEL :			
A5a	Au cours de votre vie, avez-vous eu d'autres périodes de deux semaines ou plus durant lesquelles vous vous sentiez déprimé(e) ou sans intérêt pour la plupart des choses et où vous aviez les problèmes dont nous venons de parler ?	➔ NON	OUI	10
b	Cette fois ci, avant de vous sentir déprimé(e) et/ou sans intérêt pour la plupart des choses, vous sentiez-vous bien depuis au moins deux mois ?	NON	OUI	11
	A5b EST-ELLE COTEE **OUI** ?	**NON**	**OUI** ***EPISODE DEPRESSIF MAJEUR PASSE***	

A'. EPISODE DEPRESSIF MAJEUR AVEC CARACTERISTIQUES MELANCOLIQUES (option)

SI LE PATIENT PRESENTE UN EPISODE DEPRESSIF MAJEUR ACTUEL (**A4 = OUI**), EXPLORER CI-DESSOUS :

A6	a	**A2** EST-ELLE COTEE **OUI ?**	NON	OUI	12
	b	Au cours de cette dernière période, lorsque vous vous sentiez le plus mal, aviez-vous perdu la capacité à réagir aux choses qui vous plaisaient ou qui vous rendaient joyeux(se) auparavant ?	NON	OUI	13
		SI NON : Lorsque quelque chose d'agréable survenait, étiez vous incapable de vous en réjouir, même temporairement ?			
		A6a <u>OU</u> **A6b** SONT-ELLES COTEES **OUI**	➔ NON	OUI	
		Au cours des deux dernières semaines, lorsque vous vous sentiez déprimé(e) et sans intérêt pour la plupart des choses :			
A7	a	Les sentiments dépressifs que vous ressentiez étaient-ils différents de ceux que l'on peut ressentir lorsque l'on perd un être cher ?	NON	OUI	14
	b	Vous sentiez-vous, en général, plus mal le matin que plus tard dans la journée ?	NON	OUI	15
	c	Vous réveilliez-vous au moins deux heures trop tôt, en ayant des difficultés à vous rendormir, presque tous les jours?	NON	OUI	16
	d	**A3c** EST ELLE COTEE **OUI** ?	NON	OUI	17
	e	**A3a** EST-ELLE COTEE **OUI** (ANOREXIE OU PERTE DE POIDS) ?	NON	OUI	18
	f	Vous sentiez-vous excessivement coupable ou ressentiez-vous une culpabilité qui était hors de proportion avec ce que vous viviez ?	NON	OUI	19
		Y A-T-IL **AU MOINS 3 OUI** EN **A7** ?	**NON**	**OUI**	

NON **OUI**

EPISODE DEPRESSIF
MAJEUR
avec Caractéristiques
Mélancoliques
ACTUEL

B. DYSTHYMIE

NE PAS EXPLORER CE MODULE SI LE PATIENT PRESENTE UN EPISODE DEPRESSIF MAJEUR ACTUEL

B1	Au cours des deux dernières années, vous êtes-vous senti(e) triste, cafardeux(se), déprimé(e), la plupart du temps ?	➔ NON	OUI	20
B2	Durant cette période, vous est-il arrivé de vous sentir bien pendant plus de deux mois ?	NON	➔ OUI	21
B3	**Depuis que vous vous sentez déprimé(e) la plupart du temps :**			
a	Votre appétit a-t-il notablement changé ?	NON	OUI	22
b	Avez-vous des problèmes de sommeil ou dormez-vous trop ?	NON	OUI	23
c	Vous sentez-vous fatigué(e) ou manquez-vous d'énergie ?	NON	OUI	24
d	Avez-vous perdu confiance en vous-même ?	NON	OUI	25
e	Avez-vous du mal à vous concentrer, ou des difficultés à prendre des décisions ?	NON	OUI	26
f	Vous arrive-t-il de perdre espoir ?	NON	OUI	27
	Y A-T-IL AU MOINS **2 OUI** EN **B3** ?	➔ NON	OUI	
B4	Ces problèmes entraînent-ils chez vous une souffrance importante ou bien vous gênent-ils de manière significative dans votre travail, dans vos relations avec les autres ou dans d'autres domaines importants pour vous?	➔ NON	OUI	28

B4 EST-ELLE COTEE **OUI ?**

NON **OUI**

DYSTHYMIE
ACTUEL

C. RISQUE SUICIDAIRE

Au cours du mois écoulé, avez-vous :

C1	Pensé qu'il vaudrait mieux que vous soyez mort(e), ou souhaité être mort(e) ?	NON	OUI	1
C2	Voulu vous faire du mal ?	NON	OUI	2
C3	Pensé à vous suicider ?	NON	OUI	3
C4	Etabli la façon dont vous pourriez vous suicider ?	NON	OUI	4
C5	Fait une tentative de suicide ?	NON	OUI	5
	Au cours de votre vie,			
C6	Avez-vous déjà fait une tentative de suicide ?	NON	OUI	6

Y A-T-IL AU MOINS **UN** OUI CI-DESSUS

SI OUI, SPECIFIER LE NIVEAU DU RISQUE SUICIDAIRE COMME SI DESSOUS :

C1 ou C2 ou C6 = OUI : LEGER
C3 ou (C2 + C6) = OUI : MOYEN
C4 ou C5 ou (C3 + C6) = OUI : ELEVE

NON **OUI**

RISQUE SUICIDAIRE ACTUEL

LEGER ☐
MOYEN ☐
ELEVE ☐

D. EPISODE (HYPO-)MANIAQUE

D1	a	Avez-vous déjà eu une période où vous vous sentiez tellement exalté(e) ou plein(e) d'énergie que cela vous a posé des problèmes, ou que des personnes de votre entourage ont pensé que vous n'étiez pas dans votre état habituel ? NE PAS PRENDRE EN COMPTE LES PERIODES SURVENANT UNIQUEMENT SOUS L'EFFET DE DROGUES OU D'ALCOOL. SI LE PATIENT NE COMPREND PAS LE SENS D'EXALTE OU PLEIN D'ENERGIE, EXPLIQUER COMME SUIT : Par exalté ou plein d'énergie, je veux dire être excessivement actif, excité, extrêmement motivé ou créatif ou extrêmement impulsif.	NON	OUI	1
		SI OUI			
	b	Vous sentez-vous, en ce moment, exalté(e) ou plein(e) d'énergie ?	NON	OUI	2
D2	a	Avez-vous déjà eu une période où vous étiez tellement irritable que vous en arriviez à insulter les gens, à hurler, voire même à vous battre avec des personnes extérieures à votre famille ? NE PAS PRENDRE EN COMPTE LES PERIODES SURVENANT UNIQUEMENT SOUS L'EFFET DE DROGUES OU D'ALCOOL.	NON	OUI	3
		SI OUI			
	b	Vous sentez-vous excessivement irritable, en ce moment ?	NON	OUI	4
		D1a OU **D2a** SONT-ELLES COTEES **OUI** ?	➔ NON	OUI	
D3		SI D1b OU D2b = OUI : EXPLORER SEULEMENT L'EPISODE **ACTUEL** SI D1b ET D2b = NON : EXPLORER L'EPISODE **LE PLUS GRAVE**			
		Lorsque vous vous sentiez exalté(e), plein d'énergie / irritable :			
	a	Aviez-vous le sentiment que vous auriez pu faire des choses dont les autres seraient incapables, ou que vous étiez quelqu'un de particulièrement important ?	NON	OUI	5
	b	Aviez-vous moins besoin de sommeil que d'habitude (vous sentiez-vous reposé(e) après seulement quelques heures de sommeil ?)	NON	OUI	6
	c	Parliez-vous sans arrêt ou si vite que les gens avaient du mal à vous comprendre ?	NON	OUI	7
	d	Vos pensées défilaient-elles si vite dans votre tête que vous ne pouviez pas bien les suivre ?	NON	OUI	8
	e	Etiez-vous si facilement distrait(e) que la moindre interruption vous faisait perdre le fil de ce que vous faisiez ou pensiez ?	NON	OUI	9
	f	Etiez-vous tellement actif(ve), ou aviez-vous une telle activité physique, que les autres s'inquiétaient pour vous ?	NON	OUI	10

g	Aviez-vous tellement envie de faire des choses qui vous paraissaient agréables ou tentantes que vous aviez tendance à en oublier les risques ou les difficultés qu'elles auraient pu entraîner (faire des achats inconsidérés, conduire imprudemment, avoir une activité sexuelle inhabituelle) ?	NON	OUI	11
	Y A-T-IL AU MOINS **3 OUI** EN **D3** OU **4** SI **D1a** = **NON** (EPISODE PASSE) OU **D1b** = **NON** (EPISODE ACTUEL) ?	➔ NON	OUI	
D4	Les problèmes dont nous venons de parler ont-ils déjà persisté pendant au moins une semaine **et** ont-ils entraîné des difficultés à la maison, au travail/à l'école ou dans vos relations avec les autres **ou** avez-vous été hospitalisé(e) à cause de ces problèmes ? COTER OUI, SI OUI A L'UN OU L'AUTRE	NON	OUI	12

D4 EST-ELLE COTEE **NON** ?

SI OUI, SPECIFIER SI L'EPISODE EXPLORE EST ACTUEL OU PASSE

NON **OUI**

EPISODE HYPOMANIAQUE

ACTUEL ☐
PASSE ☐

D4 EST-ELLE COTEE **OUI** ?

SI OUI, SPECIFIER SI L'EPISODE EXPLORE EST ACTUEL OU PASSE

NON **OUI**

EPISODE MANIAQUE

ACTUEL ☐
PASSE ☐

E. TROUBLE PANIQUE

E1		Avez-vous déjà eu à plusieurs reprises des crises ou des attaques durant lesquelles vous vous êtes senti(e) **subitement** très anxieux(se), très mal à l'aise ou effrayé(e) même dans des situations où la plupart des gens ne le seraient pas ? Ces crises atteignaient-elles leur paroxysme en moins de 10 minutes ? NE COTER OUI QUE SI LES ATTAQUES ATTEIGNENT LEUR PAROXYSME EN MOINS DE 10 MINUTES	NON	OUI	1
		SI **E1** = **NON,** ENTOURER NON EN E5, ET PASSER DIRECTEMENT A F1			
E2		Certaines de ces crises, même il y a longtemps, ont-elles été imprévisibles, ou sont-elles survenues sans que rien ne les provoque ?	NON	OUI	2
		SI **E2** = **NON,** ENTOURER NON EN E5, ET PASSER DIRECTEMENT A F1			
E3		A la suite de l'une ou plusieurs de ces crises, avez-vous déjà eu une période d'au moins un mois durant laquelle vous redoutiez d'avoir d'autres crises ou étiez préoccupé(e) par leurs conséquences possibles ?	NON	OUI	3
		SI **E3** = **NON,** ENTOURER NON EN E5, ET PASSER DIRECTEMENT A F1			
E4		**Au cours de la crise où vous vous êtes senti(e) le plus mal :**			
	a	Aviez vous des palpitations ou votre cœur battait-il très fort ?	NON	OUI	4
	b	Transpiriez-vous ou aviez-vous les mains moites ?	NON	OUI	5
	c	Aviez-vous des tremblements ou des secousses musculaires ?	NON	OUI	6
	d	Aviez-vous du mal à respirer ou l'impression d'étouffer ?	NON	OUI	7
	e	Aviez-vous l'impression de suffoquer ou d'avoir une boule dans la gorge ?	NON	OUI	8
	f	Ressentiez-vous une douleur ou une gêne au niveau du thorax?	NON	OUI	9
	g	Aviez-vous la nausée, une gêne au niveau de l'estomac ou une diarrhée soudaine ?	NON	OUI	10
	h	Vous sentiez-vous étourdi(e), pris(e) de vertiges, ou sur le point de vous évanouir ?	NON	OUI	11
	i	Aviez-vous l'impression que les choses qui vous entouraient étaient étranges ou irréelles ou vous sentiez-vous comme détaché(e) de tout ou d'une partie de votre corps ?	NON	OUI	12
	j	Aviez-vous peur de perdre le contrôle ou de devenir fou (folle)?	NON	OUI	13
	k	Aviez-vous peur de mourir ?	NON	OUI	14
	l	Aviez-vous des engourdissements ou des picotements ?	NON	OUI	15
	m	Aviez-vous des bouffées de chaleur ou des frissons ?	NON	OUI	16
E5		Y A-T-IL AU MOINS **4** OUI EN **E4** ? SI **E5** = **NON**, PASSER A E7	NON	OUI ***Trouble Panique Vie entière***	
E6		Au cours du mois écoulé, avez-vous eu de telles crises à plusieurs reprises (au moins 2 fois) en ayant constamment peur d'en avoir une autre ? SI **E6** = **OUI**, PASSER A F1	NON	OUI ***Trouble Panique Actuel***	17
E7		Y A-T-IL **1**, **2** OU **3 OUI** EN **E4** ?	NON	OUI ***Attaques Paucisymptomatiques vie entière***	18

F. AGORAPHOBIE

F1 Etes-vous anxieux(se) ou particulièrement mal à l'aise dans des endroits ou dans des situations dont il est difficile ou gênant de s'échapper ou bien où il serait difficile d'avoir une aide si vous paniquiez, comme être dans une foule, dans une file d'attente (une queue), être loin de votre domicile ou seul à la maison, être sur un pont, dans les transports en commun ou en voiture ? NON OUI 19

SI **F1** = **NON**, ENTOURER NON EN F2

F2 Redoutez-vous tellement ces situations qu'en pratique vous les évitez ou bien êtes-vous extrêmement mal à l'aise lorsque vous les affrontez seul(e) ou bien encore essayez-vous d'être accompagné(e) lorsque vous devez les affronter ? NON OUI 20

Agoraphobie
Actuel

F2 (AGORAPHOBIE *ACTUEL*) EST-ELLE COTEE **NON**
et
E6 (TROUBLE PANIQUE *ACTUEL*) EST-ELLE COTEE **OUI** ?

NON **OUI**

TROUBLE PANIQUE
sans Agoraphobie
ACTUEL

F2 (AGORAPHOBIE *ACTUEL*) EST-ELLE COTEE **OUI**
et
E6 (TROUBLE PANIQUE *ACTUEL*) EST-ELLE COTEE **OUI** ?

NON **OUI**

TROUBLE PANIQUE
avec Agoraphobie
ACTUEL

F2 (AGORAPHOBIE *ACTUEL*) EST-ELLE COTEE **OUI**
et
E5 (TROUBLE PANIQUE *VIE ENTIERE*) EST-ELLE COTEE **NON** ?

NON **OUI**

AGORAPHOBIE
sans antécédents de
Trouble Panique
ACTUEL

➔: **ALLEZ DIRECTEMENT** A LA (AUX) CASE(S) DIAGNOSTIQUE(S), **ENTOUREZ NON** DANS CHACUNE ET **PASSEZ** AU MODULE SUIVANT

G. PHOBIE SOCIALE

G1	Au cours du mois écoulé, avez-vous redouté ou avez-vous été gêné d'être le centre de l'attention ou avez-vous eu peur d'être humilié(e) dans certaines situations sociales comme par exemple lorsque vous deviez prendre la parole devant un groupe de gens, manger avec des gens ou manger en public, ou bien encore écrire lorsque l'on vous regardait ?	➔ NON	OUI	1
G2	Pensez-vous que cette peur est excessive ou déraisonnable ?	➔ NON	OUI	2
G3	Redoutez-vous tellement ces situations qu'en pratique vous les évitez ou êtes-vous extrêmement mal à l'aise lorsque vous devez les affronter ?	➔ NON	OUI	3
G4	Cette peur entraîne-t-elle chez vous une souffrance importante ou vous gêne-t-elle vraiment dans votre travail ou dans vos relations avec les autres ?	NON	OUI	4

G4 EST-ELLE COTEE **OUI** ?

NON **OUI**

PHOBIE SOCIALE
ACTUEL

H. TROUBLE OBSESSIONNEL COMPULSIF

H1	Au cours du mois écoulé, avez-vous souvent eu des pensées ou des pulsions déplaisantes, inappropriées ou angoissantes qui revenaient sans cesse alors que vous ne le souhaitiez pas, comme par exemple penser que vous étiez sale **ou** que vous aviez des microbes, **ou** que vous alliez frapper quelqu'un malgré vous, **ou** agir impulsivement **ou** bien encore étiez-vous envahi(e) par des obsessions à caractère sexuel, des doutes irrépressibles **ou** un besoin de mettre les choses dans un certain ordre ? NE PAS PRENDRE EN COMPTE DES PREOCCUPATIONS EXCESSIVES CONCERNANT LES PROBLEMES DE LA VIE QUOTIDIENNE NI LES OBSESSIONS LIEES A UN TROUBLE DU COMPORTEMENT ALIMENTAIRE, A DES DEVIATIONS SEXUELLES, AU JEU PATHOLOGIQUE, OU A UN ABUS DE DROGUE OU D'ALCOOL PARCE QUE LE PATIENT PEUT EN TIRER UN CERTAIN PLAISIR ET VOULOIR Y RESISTER SEULEMENT A CAUSE DE LEURS CONSEQUENCES NEGATIVES	NON	OUI	1
	SI **H1** = **NON**, PASSER A **H4**			
H2	Avez-vous essayé, mais sans succès, de résister à certaines de ces idées, de les ignorer ou de vous en débarrasser ?	NON	OUI	2
	SI **H2** = **NON**, PASSER A **H4**			
H3	Pensez-vous que ces idées qui reviennent sans cesse sont le produit de vos propres pensées et qu'elles ne vous sont pas imposées de l'extérieur ?	NON	OUI	3
H4	Au cours du mois écoulé, avez-vous souvent éprouvé le besoin de faire certaines choses sans cesse, sans pouvoir vous en empêcher, comme vous laver les mains, compter, vérifier des choses, ranger, collectionner, ou accomplir des rituels religieux ?	NON	OUI	4
	H3 OU H4 SONT-ELLES COTEES **OUI** ?	➔ NON	OUI	
H5	Pensez-vous que ces idées envahissantes et/ou ces comportements répétitifs sont déraisonnables, absurdes, ou hors de proportion ?	➔ NON	OUI	5
H6	Ces pensées ou ces pulsions envahissantes et/ou ces comportements répétitifs vous gênent-ils(elles) vraiment dans vos activités quotidiennes, votre travail, ou dans vos relations avec les autres, ou vous prennent-ils (elles) plus d'une heure par jour ?	NON	OUI	6
	H6 EST-ELLE COTEE **OUI** ?	**NON**	**OUI** ***TROUBLE OBSESSIONNEL-COMPULSIF ACTUEL***	

I. ETAT DE STRESS POST-TRAUMATIQUE (option)

I1		Avez-vous déjà vécu, ou été le témoin ou eu à faire face à un événement extrêmement traumatique, au cours duquel des personnes sont mortes ou vous-même et/ou d'autres personnes ont été menacées de mort ou ont été grièvement blessées ou ont été atteintes dans leur intégrité physique ? EX DE CONTEXTES TRAUMATIQUES : ACCIDENT GRAVE, AGRESSION, VIOL, ATTENTAT, PRISE D'OTAGES, KIDNAPPING, INCENDIE, DECOUVERTE DE CADAVRE, MORT SUBITE DANS L'ENTOURAGE, GUERRE, CATASTROPHE NATURELLE...	→ NON	OUI	1
I2		Au cours du mois écoulé, avez-vous souvent pensé de façon pénible à cet événement, en avez-vous rêvé, ou avez-vous eu fréquemment l'impression de le revivre ?	→ NON	OUI	2
I3		**Au cours du mois écoulé :**			
	a	Avez-vous essayé de ne plus penser à cet événement ou avez-vous évité tout ce qui pouvait vous le rappeler ?	NON	OUI	3
	b	Aviez-vous du mal à vous souvenir exactement de ce qu'il s'est passé ?	NON	OUI	4
	c	Aviez-vous perdu l'intérêt pour les choses qui vous plaisaient auparavant ?	NON	OUI	5
	d	Vous sentiez-vous détaché(e) de tout ou aviez-vous l'impression d'être devenu(e) un (une) étranger(ère) vis à vis des autres ?	NON	OUI	6
	e	Aviez-vous des difficultés à ressentir les choses, comme si vous n'étiez plus capable d'aimer ?	NON	OUI	7
	f	Aviez-vous l'impression que votre vie ne serait plus jamais la même, que vous n'envisageriez plus l'avenir de la même manière ?	NON	OUI	8
		Y A-T-IL AU MOINS **3 OUI** EN **I3** ?	→ NON	OUI	
I4		**Au cours du mois écoulé :**			
	a	Aviez-vous des difficultés à dormir ?	NON	OUI	9
	b	Etiez-vous particulièrement irritable, vous mettiez-vous facilement en colère ?	NON	OUI	10
	c	Aviez-vous des difficultés à vous concentrer ?	NON	OUI	11
	d	Etiez-vous nerveux(se), constamment sur vos gardes ?	NON	OUI	12
	e	Un rien vous faisait-il sursauter ?	NON	OUI	13
		Y A-T-IL AU MOINS **2 OUI** EN **I4** ?	→ NON	OUI	
I5		Au cours du mois écoulé, ces problèmes vous ont-ils vraiment gêné dans votre travail, vos activités quotidiennes ou dans vos relations avec les autres ?	NON	OUI	14

I5 EST-ELLE COTEE **OUI** ?

NON **OUI**

ETAT DE STRESS POST-TRAUMATIQUE ACTUEL

J. DEPENDANCE ALCOOLIQUE / ABUS D'ALCOOL

J1		Au cours des 12 derniers mois, vous est-il arrivé à plus de trois reprises de boire, en moins de trois heures, plus que l'équivalent d'une bouteille de vin (ou de 3 verres d'alcool fort) ?	➔ NON	OUI	1
J2		**Au cours des 12 derniers mois :**			
	a	Aviez-vous besoin de plus grandes quantités d'alcool pour obtenir le même effet qu'auparavant ?	NON	OUI	2
	b	Lorsque vous buviez moins, vos mains tremblaient-elles, transpiriez-vous ou vous sentiez-vous agité(e) ? Ou, vous arrivait-il de prendre un verre pour éviter d'avoir ces problèmes ou pour éviter d'avoir la « gueule de bois » ? COTER **OUI,** SI **OUI** A L'UN OU L'AUTRE	NON	OUI	3
	c	Lorsque vous buviez, vous arrivait-il souvent de boire plus que vous n'en aviez l'intention au départ ?	NON	OUI	4
	d	Avez-vous essayé, sans pouvoir y arriver, de réduire votre consommation ou de ne plus boire ?	NON	OUI	5
	e	Les jours où vous buviez, passiez-vous beaucoup de temps à vous procurer de l'alcool, à boire ou à vous remettre des effets de l'alcool ?	NON	OUI	6
	f	Avez-vous réduit vos activités (loisirs, travail, quotidiennes) ou avez-vous passé moins de temps avec les autres parce que vous buviez ?	NON	OUI	7
	g	Avez-vous continué à boire tout en sachant que cela entraînait chez vous des problèmes de santé ou des problèmes psychologiques ?	NON	OUI	8
		Y A-T-IL AU MOINS **3 OUI** EN **J2** ?	**NON**	**OUI** ***DEPENDANCE ALCOOLIQUE ACTUEL***	
		LE PATIENT PRESENTE-T-IL UNE DEPENDANCE ALCOOLIQUE ?	NON	➔ OUI	
J3		**Au cours des 12 derniers mois :**			
	a	Avez-vous été à plusieurs reprises ivre ou avec la « gueule de bois » alors que vous aviez des choses à faire au travail (/à l'école) ou à la maison ? Cela a-t-il posé des problèmes ? NE COTER OUI QUE SI CELA A CAUSE DES PROBLEMES	NON	OUI	9

b	Vous est-il arrivé d'être sous l'effet de l'alcool dans une situation où cela était physiquement risqué comme conduire, utiliser une machine ou un instrument dangereux, faire du bateau, etc. ?	NON	OUI	10
c	Avez-vous eu des problèmes légaux parce que vous aviez bu comme une interpellation ou une condamnation ?	NON	OUI	11
d	Avez-vous continué à boire tout en sachant que cela entraînait des problèmes avec votre famille ou votre entourage ?	NON	OUI	12

Y A-T-IL AU MOINS **1 OUI** EN **J3** ?

NON **OUI**

ABUS D'ALCOOL
ACTUEL

CARTE DES SUBSTANCES

AMPHETAMINE
CANNABIS
CAPTAGON
CATOVIT
COCAÏNE
CODEINE
COLLE
CRACK
ECSTASY
ESSENCE
ETHER
FEUILLE DE COCA
HASCHICH
HEROÏNE
L.S.D.
MARIJUANA
MESCALINE
METHADONE
MORPHINE
NEIGE
OPIUM
PALFIUM
RITALINE
SHIT
TEMGESIC
TOLUENE
TRICHLORETHYLENE

M.I.N.I.

K. TROUBLES LIES A UNE SUBSTANCE (NON ALCOOLIQUE)

K1 Maintenant je vais vous montrer / vous lire (MONTRER LA CARTE DES SUBSTANCES / LIRE LA LISTE CI-DESSOUS), une liste de drogues et de médicaments et vous allez me dire si au cours des 12 derniers mois, il vous est arrivé à plusieurs reprises de prendre l'un de ces produits dans le but de planer, de changer votre humeur ou de vous « défoncer » ? ➔ NON OUI

ENTOURER CHAQUE PRODUIT CONSOMME :

Stimulants : amphétamines, « speed », Ritaline, pilules coupe-faim.
Cocaïne : cocaïne, « coke », crack, « speedball ».
Opiacés : héroïne, morphine, opium, méthadone, codéine, mépéridine, fentanyl.
Hallucinogènes : L.S.D., « acide », mescaline, PCP, « angel dust », « champignons », ecstasy.
Solvants volatiles : « colle », éther.
Cannabinoïdes : haschisch, « hasch », THC, cannabis, « herbe », « shit ».
Sédatifs : Valium, Xanax, Témesta, Halcion, Lexomil, secobarbital, « barbis ».
Divers : Anabolisants, Stéroïdes, « poppers ». Prenez-vous d'autres substances ?

SPECIFIER LA (OU LES) SUBSTANCE(S) LES PLUS CONSOMMEE(S) : ________________________

____

SPECIFIER CE QUI SERA EXPLORE CI DESSOUS :

- SI CONSOMMATION DE PLUSIEURS SUBSTANCES (EN MEME TEMPS OU SEQUENTIELLEMENT) :
  - CHAQUE SUBSTANCE OU CLASSE DE SUBSTANCES SEPAREMENT ☐
  - UNIQUEMENT LA SUBSTANCE (OU CLASSE DE SUBSTANCES) LA PLUS CONSOMMEE ☐
- SI SEULEMENT UNE SUBSTANCE (OU CLASSE DE SUBSTANCES) CONSOMMEE :
  - UNIQUEMENT UNE SUBSTANCE (OU CLASSE DE SUBSTANCES) ☐

K2 **En considérant votre consommation de [NOMMER LA SUBSTANCE OU LA CLASSE DE SUBSTANCES SELECTIONNEE], au cours des 12 derniers mois :**

a Avez-vous constaté que vous deviez en prendre de plus grandes quantités pour obtenir le même effet qu'auparavant ? NON OUI 1

b Lorsque vous en preniez moins, ou arrêtiez d'en prendre, aviez-vous des symptômes de sevrage (douleurs, tremblements, fièvre, faiblesse, diarrhée, nausée, transpiration, accélération du cœur, difficultés à dormir, ou se sentir agité(e), anxieux(se), irritable ou déprimé(e)) ?
Ou vous arrivait-il de prendre autre chose pour éviter d'être malade (SYMPTOMES DE SEVRAGE) ou pour vous sentir mieux ? NON OUI 2
COTER **OUI,** SI **OUI** A L'UN OU L'AUTRE

c Vous arrivait-il souvent lorsque vous commenciez à en prendre, d'en prendre plus que vous n'en aviez l'intention ? NON OUI 3

d	Avez-vous essayé, sans y arriver de réduire votre consommation ou d'arrêter d'en prendre ?	NON	OUI	4
e	Les jours où vous en preniez, passiez-vous beaucoup de temps (> 2 heures) à essayer de vous en procurer, à en consommer, à vous remettre de ses (leurs) effets, ou à y penser ?	NON	OUI	5
f	Avez-vous réduit vos activités (loisirs, travail, quotidiennes) ou avez-vous passé moins de temps avec les autres parce que vous vous droguiez ?	NON	OUI	6
g	Avez-vous continué à prendre [NOMMER LA SUBSTANCE OU LA CLASSE DE SUBSTANCES SELECTIONNEE] tout en sachant que cela entraînait chez vous des problèmes de santé ou des problèmes psychologiques ?	NON	OUI	7

Y A-T-IL AU MOINS **3 OUI** EN K**2** ?

SPECIFIER LA (LES) SUBSTANCE(S) : ____________________________

NON **OUI**

DEPENDANCE à une (des) SUBSTANCES(S) ACTUEL

LE PATIENT PRESENTE-T-IL UNE DEPENDANCE POUR LA(LES) SUBSTANCES(S) CONSOMMEE(S) ? NON ➔ OUI

K3 **Au cours des 12 derniers mois :**

a	Avez-vous été à plusieurs reprises intoxiqué(e) par [NOMMER LA SUBSTANCE OU LA CLASSE DE SUBSTANCES SELECTIONNEE] ou « défoncé(e) » alors que vous aviez des choses à faire au travail (/à l'école) ou à la maison ? Cela a-t-il posé des problèmes ? NE COTER OUI QUE SI CELA A CAUSE DES PROBLEMES	NON	OUI	8
b	Vous est-il arrivé d'être sous l'effet [NOMMER LA SUBSTANCE OU LA CLASSE DE SUBSTANCES SELECTIONNEE] dans une situation où cela était physiquement risqué comme conduire, utiliser une machine ou un instrument dangereux, faire du bateau, etc. ?	NON	OUI	9
c	Avez-vous eu des problèmes légaux parce que vous aviez pris [NOMMER LA SUBSTANCE OU LA CLASSE DE SUBSTANCES SELECTIONNEE] comme une interpellation ou une condamnation ?	NON	OUI	10
d	Avez-vous continué à prendre [NOMMER LA SUBSTANCE OU LA CLASSE DE SUBSTANCES SELECTIONNEE] tout en sachant que cela entraînait des problèmes avec votre famille ou votre entourage ?	NON	OUI	11

Y A-T-IL AU MOINS **1 OUI** EN **K3** ?

SPECIFIER LA (LES) SUBSTANCE(S) : ____________________________

NON **OUI**

ABUS DE SUBSTANCE(S) ACTUEL

L. TROUBLES PSYCHOTIQUES

POUR TOUTES LES QUESTIONS DE CE MODULE, EN CAS DE REPONSE POSITIVE DEMANDER UN EXEMPLE.
NE COTER OUI QUE SI LES EXEMPLES MONTRENT CLAIREMENT UNE DISTORSION DE LA PENSEE ET / OU DE LA PERCEPTION OU S'ILS SONT CULTURELLEMENT INNAPROPRIES.
AVANT DE COTER, EVALUER LE CARACTERE « BIZARRE » DES REPONSES.

IDEES DELIRANTES BIZARRES : LE CONTENU EST MANIFESTEMENT ABSURDE, INVRAISEMBLABLE, ET NE PEUT ETRE BASE SUR DES EXPERIENCES HABITUELLES DE LA VIE.

HALLUCINATIONS BIZARRES : VOIX QUI FONT DES COMMENTAIRES SUR LES PENSEES OU LES ACTES DU PATIENT OU PLUSIEURS VOIX QUI PARLENT ENTRE ELLES.

A présent, je vais vous poser des questions sur des expériences un peu inhabituelles ou bizarres qui peuvent survenir chez certaines personnes.

				BIZARRE	
L1 a	Avez-vous déjà eu l'impression que quelqu'un vous espionnait, ou complotait contre vous, ou bien encore que l'on essayait de vous faire du mal ?	NON	OUI	OUI	1
b	**SI OUI** : Actuellement, avez-vous cette impression ?	NON	OUI	OUI ➔ **L6a**	2
L2 a	Avez-vous déjà eu l'impression que l'on pouvait lire ou entendre vos pensées ou que vous pouviez lire ou entendre les pensées des autres ?	NON		OUI	3
b	**SI OUI** : Actuellement, avez-vous cette impression ?	NON		OUI ➔ **L6a**	4
L3 a	Avez-vous déjà cru que quelqu'un ou que quelque chose d'extérieur à vous introduisait dans votre tête des pensées étranges qui n'étaient pas les vôtres ou vous faisait agir d'une façon inhabituelle pour vous ? Avez-vous déjà eu l'impression d'être possédé ?	NON		OUI	5
b	**SI OUI** : Actuellement, croyez-vous cela ?	NON		OUI ➔ **L6a**	6
L4 a	Avez-vous déjà eu l'impression que l'on s'adressait directement à vous à travers la télévision ou la radio ou que certaines personnes que vous ne connaissiez pas personnellement s'intéressaient particulièrement à vous ?	NON	OUI	OUI	7
b	**SI OUI** : Actuellement, avez-vous cette impression ?	NON	OUI	OUI ➔ **L6a**	8
L5 a	Avez-vous déjà eu des idées que vos proches considéraient comme étranges ou hors de la réalité, et qu'ils ne partageaient pas avec vous ? NE COTER OUI QUE SI LE PATIENT PRESENTE CLAIREMENT DES IDEES DELIRANTES HYPOCHONDRIAQUES OU DE POSSESSION, DE CULPABILITE, DE RUINE, DE GRANDEUR OU D'AUTRES NON EXPLOREES PAR LES QUESTIONS L1 A L4	NON	OUI	OUI	9
b	**SI OUI** : Actuellement, considèrent-ils vos idées comme étranges ?	NON	OUI	OUI	10
L6 a	Vous est-il déjà arrivé d'entendre des choses que d'autres personnes ne pouvaient pas entendre, comme des voix ? COTER OUI « BIZARRE » UNIQUEMENT SI LE PATIENT REPOND OUI A LA QUESTION : Ces voix commentaient-elles vos pensées ou vos actes ou entendiez-vous deux ou plusieurs voix parler entre elles ?	NON	OUI	OUI	11
b	**SI OUI** : Cela vous est-il arrivé au cours du mois écoulé ?	NON	OUI	OUI ➔ **L8b**	12

L7 a Vous est-il déjà arrivé alors que vous étiez éveillé(e), d'avoir des visions ou de voir des choses que d'autres personnes ne pouvaient pas voir ? COTER OUI SI CES VISIONS SONT CULTURELLEMENT INAPPROPRIEES. NON OUI 13

b **SI OUI** : Cela vous est-il arrivé au cours du mois écoulé ? NON OUI 14

OBSERVATION DE L'INTERVIEWER :

L8 b ACTUELLEMENT, LE PATIENT PRESENTE-T-IL UN DISCOURS CLAIREMENT INCOHERENT OU DESORGANISE, OU UNE PERTE NETTE DES ASSOCIATIONS ? NON OUI 15

L9 b ACTUELLEMENT, LE PATIENT PRESENTE-T-IL UN COMPORTEMENT NETTEMENT DESORGANISE OU CATATONIQUE ? NON OUI 16

L10b DES SYMPTOMES NEGATIFS TYPIQUEMENT SCHIZOPHRENIQUES (AFFECT ABRASE, PAUVRETE DU DISCOURS / ALOGIE, MANQUE D'ENERGIE OU D'INTERET POUR DEBUTER OU MENER A BIEN DES ACTIVITES / AVOLITION) SONT-ILS AU PREMIER PLAN AU COURS DE L'ENTRETIEN ? NON OUI 17

L11 DE **L1** A **L10**, Y A-T-IL AU MOINS

UNE QUESTION « **b** » COTEE **OUI BIZARRE**

OU

DEUX QUESTIONS « **b** » COTEES **OUI** (NON BIZARRE) ?

NON **OUI**

SYNDROME PSYCHOTIQUE ACTUEL

L12 DE **L1** A **L7**, Y A-T-IL AU MOINS

UNE QUESTION « **a** » COTEE **OUI BIZARRE**

OU

DEUX QUESTIONS « **a** » COTEES **OUI** (NON BIZARRE) ?
(VERIFIER QUE LES 2 SYMPTOMES SONT SURVENUS EN MÊME TEMPS)

OU

L11 EST-ELLE COTEE **OUI** ?

NON **OUI**

SYNDROME PSYCHOTIQUE VIE ENTIERE

L13a SI **L11** EST COTEE **OUI** OU S'IL Y A AU MOINS **UN OUI** DE **L1** A **L7** :

LE PATIENT PRESENTE-T-IL
UN EPISODE DEPRESSIF MAJEUR (ACTUEL OU PASSE)
OU UN EPISODE MANIAQUE (ACTUEL OU PASSE) ?

➔
NON OUI

b SI **L13a** EST COTEE **OUI** :
Vous m'avez dit tout à l'heure avoir présenté une (des) période(s) où vous vous sentiez déprimé(e) / exalté(e) / particulièrement irritable. Les idées ou impressions dont nous venons de parler telles que (CITER LES SYMPTOMES COTES OUI DE L1 A L7) sont-elles survenues uniquement pendant cette (ces) période(s) où vous étiez déprimé(e) / exalté(e) / irritable ? NON OUI 18

L13b EST-ELLE COTEE **OUI** ?

NON **OUI**

TROUBLE DE L'HUMEUR AVEC CARACTERISTIQUES PSYCHOTIQUES ACTUEL

M. ANOREXIE MENTALE

M1 a	Combien mesurez-vous ?	|__|__|__| cm		
b	Au cours des 3 derniers mois, quel est a été votre poids le plus faible ?	|__|__|__| kg		
c	LE POIDS DU PATIENT EST-IL INFERIEUR AU SEUIL CRITIQUE INDIQUE POUR SA TAILLE ? VOIR TABLEAU DE CORRESPONDANCE EN BAS DE PAGE	➔ NON	OUI	1
	Au cours des trois derniers mois :			
M2	Avez-vous refusé de prendre du poids, malgré le fait que vous pesiez peu ?	➔ NON	OUI	2
M3	Aviez-vous peur de prendre du poids ou redoutiez-vous de devenir trop gros(se) ?	➔ NON	OUI	3
M4 a	Vous trouviez-vous encore trop gros(se), ou pensiez-vous qu'une partie de votre corps était trop grosse ?	NON	OUI	4
b	L'opinion ou l'estime que vous aviez de vous-même étaient-elles largement influencées par votre poids ou vos formes corporelles ?	NON	OUI	5
c	Pensiez-vous que ce poids était normal, voire excessif ?	NON	OUI	6
M5	Y A-T-IL AU MOINS **1** OUI EN **M4** ?	➔ NON	OUI	
M6	POUR LES FEMMES SEULEMENT : Ces trois derniers mois, avez-vous eu un arrêt de vos règles alors que vous auriez dû les avoir (en l'absence d'une éventuelle grossesse) ?	➔ NON	OUI	7

POUR LES FEMMES : **M5** ET M**6** SONT-ELLES COTEES **OUI** ?
POUR LES HOMMES : **M5** EST-ELLE COTEE **OUI** ?

NON **OUI**

ANOREXIE MENTALE ACTUEL

TABLEAU DE CORRESPONDANCE TAILLE - SEUIL DE POIDS CRITIQUE (SANS CHAUSSURE, SANS VETEMENT)

TAILLE (cm)		140	145	150	155	160	165	170	175	180	185	190
POIDS (kg)	Femmes	37	38	39	41	43	45	47	50	52	54	57
	Hommes	41	43	45	47	49	51	52	54	56	58	61

(15% DE REDUCTION PAR RAPPORT AU POIDS NORMAL)

➔: **ALLEZ DIRECTEMENT** A LA (AUX) CASE(S) DIAGNOSTIQUES, **ENTOUREZ NON** DANS CHACUNE ET **PASSEZ** AU MODULE SUIVANT

N. BOULIMIE

N1	Au cours de ces trois derniers mois, vous est-il arrivé d'avoir des crises de boulimie durant lesquelles vous mangiez de très grandes quantités de nourriture dans une période de temps limitée, c'est à dire en moins de 2 heures ?	➔ NON	OUI	8
N2	Avez-vous eu de telles crises de boulimie au moins deux fois par semaine au cours de ces 3 derniers mois ?	➔ NON	OUI	9
N3	Durant ces crises de boulimie, avez-vous l'impression de ne pas pouvoir vous arrêter de manger ou de ne pas pouvoir contrôler la quantité de nourriture que vous prenez ?	➔ NON	OUI	10
N4	De façon à éviter une prise de poids après ces crises de boulimie, faites-vous certaines choses comme vous faire vomir, vous astreindre à des régimes draconiens, pratiquer des exercices physiques importants, ou prendre des laxatifs, des diurétiques, ou des coupe-faim ?	➔ NON	OUI	11
N5	L'opinion ou l'estime que vous avez de vous-même sont-elles largement influencées par votre poids ou vos formes corporelles ?	➔ NON	OUI	12
N6	LE PATIENT PRESENTE-T-IL UNE ANOREXIE MENTALE ?	NON	OUI	13
	SI **N6** = **NON**, PASSER A **N8**			
N7	Ces crises de boulimie surviennent-elles **toujours** lorsque votre poids est en dessous de ____ kg* ? * REPRENDRE LE POIDS CRITIQUE DU PATIENT DANS LA TABLE DU MODULE ANOREXIE MENTALE EN FONCTION DE SA TAILLE ET DE SON POIDS.	NON	OUI	14
N8	**N5** EST-ELLE COTEE **OUI** ET **N7** COTEE **NON** (OU NON-COTEE) ?	**NON**	**OUI**	
		BOULIMIE ACTUEL		
	N7 EST-ELLE COTEE **OUI** ?	**NON**	**OUI**	
		ANOREXIE MENTALE Binge-eating / Purging type ACTUEL		

O. ANXIETE GENERALISEE

O1	a	Au cours des six derniers mois, vous êtes-vous senti(e), excessivement préoccupé(e), inquiet(e), anxieux(se), pour des problèmes de la vie de tous les jours, au travail/à l'école, à la maison, ou à propos de votre entourage, ou avez-vous eu l'impression de vous faire trop de souci à propos de tout et de rien ?	➔ NON	OUI	1
		NE PAS COTER OUI SI L'ANXIETE SE RESUME A UN TYPE D'ANXIETE DEJA EXPLORE PRECEDEMMENT COMME LA PEUR D'AVOIR UNE ATTAQUE DE PANIQUE (TROUBLE PANIQUE), D'ETRE GENE EN PUBLIC (PHOBIE SOCIALE), D'ETRE CONTAMINE (TOC), DE PRENDRE DU POIDS (ANOREXIE MENTALE) ETC...			
	b	Avez-vous ce type de préoccupations presque tous les jours ?	➔ NON	OUI	2
O2		Vous est-il difficile de contrôler ces préoccupations ou vous empêchent-elles de vous concentrer sur ce que vous avez à faire ?	➔ NON	OUI	3
		DE O3a A O3f, COTER NON LES SYMPTOMES SURVENANT UNIQUEMENT DANS LE CADRE DES TROUBLES EXPLORES PRECEDEMMENT			
O3		**Au cours des six derniers mois lorsque vous vous sentiez particulièrement préoccupé(e), inquiet(e), anxieux(se), vous arrivait-il souvent:**			
	a	De vous sentir agité(e), tendu(e), les nerfs à fleur de peau ?	NON	OUI	4
	b	D'avoir les muscles tendus ?	NON	OUI	5
	c	De vous sentir fatigué(e), faible, ou facilement épuisé(e) ?	NON	OUI	6
	d	D'avoir des difficultés à vous concentrer ou des passages à vide ?	NON	OUI	7
	e	D'être particulièrement irritable ?	NON	OUI	8
	f	D'avoir des problèmes de sommeil (difficultés d'endormissement, réveils au milieu de la nuit, réveils précoces ou dormir trop) ?	NON	OUI	9

Y A-T-IL AU MOINS **3 OUI** EN **O3** ?

NON **OUI**

ANXIETE GENERALISEE ACTUEL

P. TROUBLE DE LA PERSONNALITE ANTISOCIALE (option)

P1 **Avant l'âge de 15 ans, avez-vous :**

a	Fréquemment fait l'école buissonnière ou passé la nuit en dehors de chez vous ?	NON	OUI	1
b	Fréquemment menti, triché, arnaqué les gens ou volé ?	NON	OUI	2
c	Brutalisé, menacé ou intimidé les autres ?	NON	OUI	3
d	Volontairement détruit ou mis le feu ?	NON	OUI	4
e	Volontairement fait souffrir des animaux ou des gens ?	NON	OUI	5
f	Contraint quelqu'un à avoir des relations sexuelles avec vous ?	NON	OUI	6
	Y A-T-IL AU MOINS **2 OUI** EN **P1** ?	➔ NON	OUI	

NE PAS COTER OUI LES REPONSES CI-DESSOUS, SI LES COMPORTEMENTS SONT UNIQUEMENT PRESENTES DANS DES CONTEXTES POLITIQUES OU RELIGIEUX.

P2 **Depuis l'âge de 15 ans, avez-vous :**

a	Eu souvent des comportements que les autres trouvaient irresponsables comme ne pas rembourser des sommes dues, agir impulsivement ou volontairement ne pas travailler pour assurer le minimum vital ?	NON	OUI	7
b	Fait des choses illégales (même si vous n'avez pas été pris) comme détruire le bien d'autrui, voler, vendre de la drogue ou commettre un crime ?	NON	OUI	8
c	Souvent été violent physiquement, y compris avec votre conjoint ou vos enfants ?	NON	OUI	9
d	Souvent menti ou arnaqué les autres dans le but d'obtenir de l'argent ou du plaisir, ou menti juste pour vous amuser ?	NON	OUI	10
e	Exposé des gens à des dangers sans vous préoccuper d'eux ?	NON	OUI	11
f	Ressenti aucune culpabilité après avoir menti, ou blessé, maltraité ou volé quelqu'un ou détruit le bien d'autrui ?	NON	OUI	12
	Y A-T-IL AU MOINS **3 OUI** EN **P2** ?	**NON**	**OUI**	

TROUBLE DE LA
PERSONNALITE
ANTISOCIALE
VIE ENTIERE

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Les versions originales française et anglaise du M.I.N.I. / DSM-IV ont été traduites et peuvent être demandées aux auteurs (voir page 3). Une version CIM-10 du M.I.N.I. est aussi disponible en français, en anglais et en danois.

Traductions	**M.I.N.I. 4.4 et versions antérieures**	**M.I.N.I. 5.0, M.I.N.I. PLUS, M.I.N.I. screen**
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Islandais		J. Stefanson
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