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ESSAYS ON DECISION MAKING BY CHILDREN AND ADULTS ON THE AUTISTIC SPECTRUM

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Abstract

This thesis presents three essays on decision making by autistic individuals. In the first chapter we draw on the studies germane to decision making and autism to provide an extensive review focused on such crucial aspects as mentalizing, decision making under risk and uncertainty, learning in Autistic Spectrum Disorders (social learning; reinforcement learning), time (concept of time; intertemporal choice) and counterfactual emotions 1. The review is followed by two related experimental studies with patient population: 'Effects of Counterfactual Emotions on Decision Making of Individuals on the Upper End of the Autistic Spectrum' 2 and 'Insights on Counterfactual Emotions of Autistic Individuals within Social Contexts' 3.

There is a big array of feelings and counterfactual emotions which could result from assessing the outcome of social comparisons against ourselves and/or others. How do the individuals with autistic spectrum disorders process counterfactual emotions? Are they able to experience regret and relief, disappointment and joy? Are they able to account for these emotions? Do they process them the same way as the individuals with typical development? What do individuals on the autistic spectrum feel when comparing themselves to other people in a social context? And how do they process these social comparison emotions?

We inquire into the behavioral and skin conductance responses within an autistic patient group and a typical development (*TD*) control group matched demographically, educationally and *IQ*-wise. We employ a gambling task to look into the participants' choices along with their subjective reports on the labeling of the emotion felt and intensity of their feelings. We learned that while the *TD* controls experienced regret more intensely than disappointment, there was not significant difference in the intensity of these two emotions for the *ASD* patients in our first experiment.

Strikingly, in the private conditions the *ASD* patients accounted for weaker regret as compared to the *TD* controls, but increased shared regret associated with very posi-

tive feelings in the social condition. Still, in a social context appraisal, the subjective accounts in participants with *ASD* are not different from those of *TD* controls', implying preserved social feelings in the context of social comparison for the autistic individuals. Surprisingly, skin conductance responses mainly contradicted the subjective self-reports, showing more intense activity in the condition eliciting regret or relief, and less intense responses in the social context condition. Hence our results endorse the fact that individuals with *ASD* experience disruptive emotion processing and fail to fully integrate cognitive input and intrinsic information during decision making.

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To my son Christopher.

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Chapter 1

Review of Literature on Autism and Decision Making

1.1 Introduction

All the best in me is due to my son Christopher

With an ever-increasing number of consumers and potential work force of all ages diagnosed with Autism Spectrum Disorders (*ASDs*) it is imperative for Marketing, Financial Decision Making, Human Resources and other Business entities to understand how this specific population, and especially the population segment on the upper end of the autistic spectrum - with Asperger's Syndrome (*AS*) and High Functioning Autism (*HFA*) - makes decisions. We draw on the most relevant studies germane to decision making and autism to provide an extensive review focused on such crucial aspects as mentalizing, decision making under risk and uncertainty, learning in *ASD* (social learning and reinforcement learning), time (concept of time and intertemporal choice) and counterfactual emotions.

Overview

Decision making is an umbrella term that covers various cognitive processes that are collectively involved in the selection of an option among a set of alternatives that are expected to result in differing outcomes. As such decision making is a complex concept that encapsulates a broad range of behaviours across all living species and, in humans is influenced by many physiological, environmental and mental factors. In recent years, the two traditional normative and empirical approaches that have dominated studies on decision making have merged with two additional disciplines in the spheres of learning theory and neuroscience. The normative approach focuses on what is the most optimal choice when handling a decision-making problem. These studies build upon principles of utility maximization and equilibrium in economics and game theory respectively, where out of self-interest, rational thinking should influence the behaviour in the context of an individual or as part of a group.

Empirical studies relate these normative predictions to altruistically influenced human and animal behaviour to more accurately predict behaviours that tends to deviate from classical normative theories [Lakshminaryanan et al., 2008, Santos and Hughes, 2009]. Learning theories impart how decision-making strategies are tuned by our learning experience with theories such a reinforcement learning theory, where we learn to take actions in an environment so as to maximize some notion of reward [Sutton and Barto, 1998]. Being prominent in the literature, neuroscientific studies on the other hand incorporate these spheres of decision-making studies in relating them to their cognitive underpinnings [Glimcher et al., 2008]. Such studies have become integral to understanding the core mechanisms in the brain responsible for various computational steps of decision making and reinforcement learning.

Decision Making and its Neural Underpinnings

Through understanding the neural mechanisms that constitute the decision-making processes, it is clear that multiple interconnected systems and networks within the brain, have distinct functions that collectively influence the decision-making behaviour [Rangel et al., 2008, Lee, 2013, van der Meer et al., 2012]. The complex nature involved in the cognitive control of decision-making makes identifying and understanding the maladaptive systems involved in the vast array of neurological and psychiatric disorders that abhorrently affect decision making a challenging undertaking.

As multiple neurological systems are operating under differing principles and are combined in a manner optimal for the task at hand, the number of variables involved, make inclusive use of econometric and reinforcement learning models invaluable in the emerging field of computational psychiatry, with the ultimate goal of building computational models of mental disease and injury. Such combinatorial studies have the increasing potential to revolutionize the quantitative definition, diagnosis, understanding and treatment of psychiatric disease through bringing neuroscience, psychiatry and decision sciences together.

1.2 Mentalizing

The psychological concept of mentalizing describes the capacity to infer the mental state of oneself and others which underlies overt behaviour and outcome choice in decision making. As a form of imaginative mental activity it allows for the perception and interpretation of human behavior in terms of intentional mental states including beliefs, emotions, needs, desires, beliefs, goals, reasoning and intentions [Fonagy et al., 2005], be it with regards to our own internal mental states or others. The early studies on mentalizing focused on pretense play [Leslie, 1987], perception of

emotions [Ozonoff et al., 1991, Stone et al., 1998], memory tasks [Joseph and Tager-Flusberg, 2004, Singer, 2008], while later studies focused on empathy [Golan et al., 2006a, Frith and Singer, 2008, Ahl, 2012], visuo-spatial perspective taking [Hamilton et al., 2009, David et al., 2010, Schnell et al., 2011], more subtle mentalizing tasks [Buitelaar et al., 1999, Perner et al., 2002, Dapretto et al., 2006, Apperly, 2012] and the development of more appropriate developmental tests [Baron-Cohen et al., 2001], relying on an enhanced use of functional magnetic resonance imaging (*fMRI*), positron emission tomography (*PET*) [Castelli, 2002], multichannel electroencephalography (*EEG*) [Ortigue et al., 2009], magnetoencephalography (*MEG*) [Vistoli et al., 2011] and physiological measures [Lim and Reeves, 2010, Young et al., 2012].

Theory of Mind and Default Mode Network

At the core of mentalizing is a neural network called the theory of mind (*ToM*) network that governs the interpretation of observed behavior and the attribution of mental states to the individual displaying that behavior. The *ToM* network shows robust and systematic response to a variety of stimuli that invoke the attribution of mental states, including in stories and cartoons, and consists of the bilateral temporo-parietal junction (*TPJ*), right superior temporal sulcus (*rSTS*), medial precunius (*PC*), anterior cingulate cortex (*ACC*) and medial prefrontal cortex (*MPFC*) [Koster-Hale and Saxe,].

Interestingly, many of the *ToM* regions that are associated with self and inter-personal mental state attribution are the same regions that are found to be activated in studies of the larger default mode network (*DMN*) which is deactivated when an individual is engaged in a cognitively demanding, goal-oriented task and more active when internalizing attention on internal thought processes [Buckner et al., 2008]. These shared regions include the *MPFC*, *ACC*, *PC* and the *DMN* additionally includes the posterior cingulate cortex (*PCC*), angular gyrus (*AG*), and bilateral inferior pari-

etal lobules (*IPL*), among others. Specifically, the *MPFC* has been shown to play a distinct role in ascribing mental states to others [Aichhorn et al., 2009].

Indeed, the *DMN* has been hypothesized to be involved in internal mentalizations that helps individuals navigate their social environment by attributing mental states to oneself and to others, the ability to rehearse social narratives, to engage in interactions with others, and to imagine the future [Schilbach et al., 2008]. From childhood the immature *DMN* and more specifically the *ToM* network postulates observables (including mental representations) to account for observable actions which over the course of development become increasingly refined as this network matures [Caruthers, 1996]. It is reported that together with developing a robust mentalizing ability, the empathic skills are also augmented permitting an enhanced inference of the mental and emotional states of other people [Koster-Hale et al., 2013].

Decision Making Tasks in a Social Context

In a recent study, the influence of social information on decision making was investigated by using two alternative forced choice tasks - that have been used extensively in previous research to identify the neural systems that mediate this influence [Tomlin et al., 2013]. Among their key findings is that social information influencing decision making was correlated with neural responses in a set of brain regions that showed greater activity when participants were incongruent with the rest of the group.

Insula activity has been previously associated with emotional processes and in the empathic pain response [Singer et al., 2006]. These results suggest that the insula (emotion), the dorsolateral prefrontal cortex (*DLPFC*, cognition) and to a lesser extent, the portion of dorsal *ACC* (*ToM* processes) play an integral role in the detection of an individual's behavior that differs from that of other group members, and in initiating choice behavior that realigns the individual with the group. This is

in line with other experiments, including the functional magnetic resonance imaging (*fMRI*) experiments of Ultimatum Game (where two players split a sum of money; one player proposes a division and the other can accept or reject it) and other two-person economic exchange tasks [Sanfey et al., 2003, Berns et al., 2005].

Similarly, insula and *DLPFCs* activity highlighted the importance of combining emotional and cognitive processes in economic social decision making. One clear finding is that moral social decision-making entails a greater degree of internally directed processing, such as self-referential mental processing and *DMN* and *ToM* engagement in the representation of intentions and feelings, than in non-moral decision-making [Reniers et al., 2012].

Decision Making Tasks in a Social Emotional Context

Mind reading is at the core of prediction of other people's behavior, based on inference of their beliefs. When the awareness of those belief states is merged with the awareness of the emotional effects on the inferred states, then we are dealing with advanced mind reading abilities. According to the most recent research, these advanced mind reading abilities are closely interconnected with the emphasizing abilities of an individual. In a study the authors employed an advanced mentalizing task to identify neural mechanisms involved in predicting a future emotional responses based on a belief state [Hooker et al., 2008].

The participants viewed social scenes and were prompted to predict the emotion of a character that is harboring a false belief: how would they feel if they had a full understanding about the situation. They found that neural regions related to both mentalizing and emotion were involved when predicting a future emotional response, including the superior temporal sulcus (*STS*), *MPFC* (mentalizing) and somatosensory related cortices (*SRC*), inferior frontal gyrus and thalamus (emotion). When

specifically predicting an emotional response neural activity involves the generation and implementation of internal representation of emotions and that increased activity in emotion related is related to increased empathic feelings.

Theory of Mind in Autism

In comparison with typically developing individuals, individuals with *ASDs* consistently show altered functional brain activity patterns and network connectivity during a variety of cognitive tasks [Zelazo et al., 2002, Joseph and Tager-Flusberg, 2004, Singer, 2008, Schnell et al., 2011] and at rest [Schilbach et al., 2008, Fair et al., 2008, Lombardo et al., 2010]. Individuals with *ASD* characteristically display deficits in social interactions and this is represented in the differences in functional brain activity studies when comparing results with control participants.

There is an abnormal connectivity within the Default Mode Network (*DMN*) in *ASD* patients, a result supported by all the *fMRI* studies related to our topic. These studies endorse the hypothesis that the impaired social interactions in *ASDs* may be partially accounted for by this atypical recruitment and connectivity of *DMN*. During task-induced deactivation experiments the data is analyzed from resting blocks in an *fMRI* study by relating them to intermittent task blocks [Zielinski et al., 2010, Murdaugh et al., 2012, Hasenkamp and Barsalou, 2012]. Collectively these studies indicate that individuals with *ASD* have lower levels of functional deactivation of the *DMN* than those of typical control participants, especially in the *MPFC* and *ACC* regions that appear to be independent of task performance and integral to mentalizing and *ToM*.

While some tasks incorporate unusual activity in *ToM* regions, the activations are task-specific. In the tasks that require the participants to make judgments based on internal personality or external observable traits, the deficits in *DMN* may con-

tribute to dysfunctions in social tasks while other non-social *DMN* functions remain unimpaired. An emerging theory is that altered deactivation of the *DMN* in *ASD* is what imparts difficulties in performing mentalizing and *ToM* tasks.

1.3 Risk and Uncertainty

Risk, Uncertainty and Utility

Risk can be generally considered as the potential involved in a behavior resulting in the loss of something of value in relation to the potential involved in a behavior resulting in gaining something of value. However, risk may also be defined as the intentional interaction with uncertainty with regards to the expected outcome. Risk can also be defined as a state of uncertainty where some possible outcomes have an undesired effect or significant loss. Perceiving such risks is dependent on the subjective judgment an individual makes about the severity of a particular risk.

In economic decision making risk perception is closely connected with utility. Utility refers to the aggregated sum of satisfaction or benefit that an individual gains from consuming goods or services and influences a decision maker's attitude toward uncertainty or risk in the choosing between available options. Moreover, for choice outcomes presenting an elevated degree of uncertainty the utility can be estimated as the average of the utilities of different outcomes weighted by their probabilities, and is referred to as expected utility [von Neumann and Morgenstern, 1944]. Moreover, the utility functions shape is representative of the decision maker's behavior in terms of uncertainty and risk.

A concave utility function would indicate that this individual is risk-averse and would make choices in order to minimize risk. However, when discussing utility in terms of risk and uncertainty, in real life decision making an individual is still consid-

ered rational irrespective of their attitude towards risk if the choices they make are consistent with the principle of maximizing utility.

Neural Underpinnings of Risk, Uncertainty and Utility

Numerous neuropsychology studies have collectively identified that the expected value of a reward or utility is reflected in neural activity in multiple brain areas, including the ventromedial prefrontal cortex (*vmPFC*) and ventral striatum [Kuhnen and Knutson, 2005, Knutson et al., 2005, Knutson and Wimmer, 2007, Luhmann et al., 2008, Chib et al., 2009]. Additionally, the activity in the *vmPFC* and ventral striatum is influenced oppositely by expected gains and losses, with this activity being more enhanced for losses than for gains, the difference of which is related to an individual's level of aversion to losses [Tom et al., 2007]. Emotional circuitry is also implicated in estimating the value in relation to risk and losses [Wunderlich et al., 2009].

Alterations in amygdala activity can be indicative of whether a particular outcome may be viewed positively as a gain or negatively as a loss [De Martino et al., 2006], which correlates with the abolishment of loss aversion in focal lesions patients [De Martino et al., 2010]. Related studies highlight the chances of selecting one particular action from alternatives, being also dependant on the perceived cost of carrying out an action and may be processed preferentially in the anterior cingulate cortex (*ACC*) [Walton et al., 2003, Rudebeck et al., 2006, Rudebeck et al., 2008, Croxson et al., 2009, Kennerley et al., 2009, Prévost et al., 2010, Hillman and Bilkey, 2010]. How these values and costs are associated with different options remains to be significantly elucidated.

Decision Making under Risk and Uncertainty in Autism

The relationship between risk, uncertainty and utility is construed in individuals with *ASDs*. A recent experiment in adolescents indicates that individuals with *ASDs* demonstrate moderate to strong negative correlations between psychophysiological response to unpredictable threats (uncertainty) and questionnaire measures of generalized anxiety, intolerance to uncertainty, and repetitive behavior in comparison with control participants [Chamberlain et al., 2013]. This is in line with an emphasis on immediate gain in choice behaviour. This emphasis on immediate gain may be especially true in adolescence with its inherent difficulty of inhibiting impulsive reward-based choices [Smith et al., 2012].

However, in direct contrast with typically developing adolescents, *ASD* adolescents are seemingly less motivated by reward as opposed to the possibility of loss [South et al., 2011]. The latest reports in the literature extend this idea, indicating that *ASD* individuals harbor a decision-making style characterized by a drive to avoid potential loss rather than to seek possible reward. Such behavior may help decision making for *ASD* individuals in some situations, but ultimately hinder functioning in relation to prosocial engagement and other complex situations, where gain rather than punishment is the most effective motivating factor [South et al., 2013].

While some situations may benefit more from loss aversion oriented decision making, including gambling, in many everyday situations, particularly social ones, risk-avoidance likely lends itself to social anxiety and underpins aspects of restrictive, repetitive behaviors and interests [Rodgers et al., 2012]. Evidence suggests that the developmental dysfunction in the orbitofrontal-amygdala circuit presents problems with self-regulation of social-emotional behaviour in *ASDs* [Bachevalier and Loveland, 2006], however it would likely involve *ToM* and *DMN* related activations with respect to social contexts. Such developmental cognitive dysfunction may generate

differences in how one approaches risk in relation to differential processing of value and benefits associated with choice behavior.

By combining imaging techniques with tasks eliciting decision making patterns under risk and uncertainty, a big body of research managed to show significant differences between autistic individuals and healthy controls or *ADHD* participants [Geurts et al., 2008] with regard to decision consistency and responsiveness to changes in risk [Johnson et al., 2006], explaining the results by evoking selective attention in *ASD* individuals, theory of mind deficits [Klin, 2000, Allman et al., 2005], certain higher cognitive abilities [de Jonge et al., 2006], a low response rate to social rewards [Ernst et al., 2002, Dichter et al., 2012] and abnormal neural connectivity [Dawson et al., 2001, Hirstein et al., 2001, Schmitz et al., 2008].

1.4 Learning: Social Learning and Reinforcement Learning

Individual, Social and Reinforcement Learning

Theories and models of learning involve combinatorial concepts that describe how information is acknowledged, processed, and retained for later development and use. Cognitive, emotional, and environmental paradigms, as well as prior experience, are considered to collectively influence one's retention of information. Drawing from behavioral paradigms, learning can be considered as the exploitation of past experiences to increase the reward in recurring situations - a rudimentary adaptation found in higher organisms.

This is reflected in the field of machine learning when pertaining to the fundamental paradigm of reinforcement learning. In the sphere of computer science, reinforcement learning similarly illustrates how actions of software in a virtual environment

are modified in order to maximize some notion of cumulative reward. In relation to the notion of maximizing reward, individual learning, which can require multiple trial and error attempts to find a reward maximizing solution, can be costly. This is where social learning [Rendell et al., 2010, Rendell et al., 2011] may be valued as more advantageous as it employs the learning results of other individuals in the social group, diminishing the need for going through the difficulties and risks of learning oneself [Boyd and Richerson, 1985].

Social Learning

Social learning theory initially conceptualized social learning as individual learning that takes place in a social context and is thus influenced by social norms [Bandura and Walters, 1963]. The initial theory has gone through several paradigm shifts and has been integrated with behavioral and cognitive theories of learning in the creation of a more comprehensive model that could more readily account for broad variety of real world learning experiences, given that most classifications of learning take place in some form of social context, be it direct or otherwise.

In early formulations of the theory behavioural aspects were outlined in terms of imitation of the behaviour of role models [Bandura, 1977]. Through role models individuals need not have direct experiences to learn and instead considerable learning may occur by observing other people's behavior and the resultant outcome integrated in the form of a live model, verbal instruction or symbols in which modeling occurs via media, including movies, television, Internet, literature, and radio and may originate from a fictitious character. Vicarious reinforcement is another concept from the social learning theory, which involves determining whether role models are perceived as rewarded or punished for their behaviour. Interestingly, an outcome that results in a gain is not always necessary to stimulate imitation behavior, and the behaviour of a role model may be imitated even when a loss is involved for either the role model

or the learner. Similarly, observing and learning may not result in a change in behaviour.

On the other hand, cognitive considerations include the attributes of the self and the internal processing of the learner. Ultimately, cognitive principles reflect the self-regulation and control that an individual exerts through the process of acquiring information and altering behaviour. While a role model may demonstrate behaviour as an external process, four internal cognitive processes are involved in the self-regulation and control in learning. Namely they are the attentional phase, where a role model may be observed; the retention phase, where information is processed and represented as memory; the reproduction phase, where memory guides mental rehearsal of the observed behavior and the motivational phase, influenced by vicarious reinforcement.

Later theory formulations [Bandura, 2001] include the concept of reciprocal determinism, whereby the environment is also considered to influence behaviour and where these internal and external processes are in fact influenced by and influence the environment and social setting in which an individual may perform a learned behavior [Sanfey, 2007].

Reinforcement Learning

In economic decision making experiments implicate selection from a relatively small number of options with relatively well-characterized outcomes. This is in contrast with real life, where complexities often necessitate learning and changing decision-taking strategies through experience. Reinforcement learning theory posits that the knowledge of whether the previous outcome of an observed behavior was reinforcing or punishing [Thorndike, 1911] and any new information learned about the regularities choice behavior, even when it is not directly related to reward or penalties [Tolman, 1948] can modify the reward values associated with alternative actions and thus in-

fluence behaviour [Sutton and Barto, 1998].

While model-based reinforcement learning has its origins in machine learning, it is also of significant interest to researchers in cognitive sciences, as it is believed to closely correspond to the type of learning that humans routinely demonstrate. Fundamentally, reinforcement learning represents the humans' acquisition of core skills to connect states of the world to actions resulting in maximizing expected utilities [1998], implicating accurate deduction of reinforcement history directly from the surrounding environment [Cleeremans and McClelland, 1991, Lohrenz et al., 2007a].

Neural Substrates of Reinforcement Learning

In recent years, substantial progress has been made in understanding the cognitive and neural underpinnings of learning and reinforcement learning. Both animal and computational models [Brown et al., 2004], as well as human behavioral and neuro imaging studies [Waltz et al., 2007], indicate that simple associative learning involves the basal ganglia neural networks in reward processing and dopamine signalling [Graybiel, 2008, Jog et al., 1999]. A significant model in primates [Schultz, 1998] describes that bursts of dopamine in the striatum are involved in a temporal difference reinforcement learning signal [Schultz, 2000]. Choices that result in unexpected or expected rewards produce transient bursts or dips in dopamine respectively, thereby training the basal ganglia about the reward value associated with any given action.

When it comes to higher-level and goal-directed behaviour, the literature converges toward the mediation role of brain regions within the prefrontal cortex (*PFC*) [Daw et al., 2005, Doll et al., 2009, Graybiel, 2008]. The orbito-frontal cortex (*OFC*) is believed to be the brain region responsible for quite fast and flexible "updating of representations of expected value" [Rolls, 2004, Schoenbaum and Roesch, 2005] and also plays a role as part of the *ToM* circuitry [Stone et al., 1998, Shamay-Tsoory et al.,

2010]. In their systems level computational model of reinforcement learning Frank and Claus [Frank and Claus, 2006] demonstrate the role of *OFC* in capturing signals from basal ganglia and storing "short term "working memories" of the reward value of actions". In the formation of habits, the role of *OFC* diminishes and that of the basal ganglia predominates [Frank and Claus, 2006].

Reinforcement Learning in Autism

While *ASDs* are characterized by core deficits in social functions associated with impaired mentalizing processes and *ToM* network functionality, the social motivational aspect of learning and choice behavior is also suggested to have cognitive underpinnings in autism. In a recent *fMRI* experiment with *ASD* individuals, a Domino game was employed to explore both mentalizing and motivation-related brain activation where participants responded to rewards or punishments (i.e. motivation) and concurrently processed information about their opponent's potential next actions (i.e. mentalizing) [Rilling et al., 2008, Assaf et al., 2013].

Results indicated that for *ASD* individuals, understanding the game rules and playing the game was comparable to healthy controls, however they showed diminished neural activity during Domino runs in which they thought they were playing against another human - the middle temporal gyrus (*MTG*) associated with *ToM* during mentalizing and right Nucleus Accumbens (*NAcc*) during reward-related motivation.

More specifically, individuals with *ASDs* only had observable deficits when playing the game in a social context as opposed to playing a computer opponent. It has also been proposed that that such social motivation and learning impairments may be related to deficits in flexible updating of reinforcement history as mediated by the orbito-frontal cortex, with spared functioning of the basal ganglia [Solomon et al., 2011]. This is reflected in the similarity between the impaired performance

of individuals with Asperger's Syndrome and patients with bilateral damage to the orbito-frontal cortex in a series of theory of mind tasks [Stone et al., 1998].

Autism: Impairments vs Superiority in Learning Skills

Back in 1979 Prior reviewed the literature on learning, noting the scarcity of studies on autism and the methodological inconsistencies in the few ones at hand [Prior, 1979]. Later on the research focused on the learning impairments in autistic individuals, such as *ASD*-specific selective attention and generalization deficits [Cohen, 1994], procedural learning [Mostofsky et al., 2000], deficits in sensory input, anterograde memory, auditory information processing, conceptual reasoning abilities, executive function [Minshew et al., 1997], while later studies attempted to change the focus onto the specific superior learning abilities in children and adults with *ASDs*, which disprove autistic symptoms as being connected to mental retardation or general deficit syndrome, but rather as a different information processing style.

Since the late 90-ies, two most common hypotheses of information processing in autism - weak central coherence (local rather than global information processing) and reduced attention-switching - and new ones proposed by various scholars have been in the center of researchers' attention, coupled with studies on autistic savant skills [Plaisted et al., 1998, Happé, 1999, Ring et al., 1999, Motttron et al., 2006], rule-based superior learning abilities [Klinger and Dawson, 2001] and *fMRI* during cognitive and learning tasks [Schultz, 2005, Schmitz et al., 2006], proving a differently wired brain in *ASDs* [Kana et al., 2006, Shohamy et al., 2008, Jellema et al., 2009a, Izuma et al., 2011], a unique adaptive learning style [Yechiam et al., 2010, Schipul et al., 2012] and also a big heterogeneity among autistic individuals with regard to deficits and superior learning skills as compared to typical development controls and/or *ADHD* patients [Molesworth et al., 2008, Kohls et al., 2009, Nemeth et al., 2010, Pellicano, 2012].

1.5 Time: Concept of Time and Intertemporal Choice

Time and Choice Behavior

Time is a dimension that is integral to everyday behaviour and survival. Essentially, time is in events which can be perceived as past, present or future and also allows for a measure of durations of events and the intervals between them. Awareness of the passage of time and its perceived duration is interlinked with emotional and motivational states and influences decisions about how and when to act [Wittmann and Paulus, 2008, Wittmann and Paulus,].

Intertemporal choice is the study of the relative value people assign to two or more payoffs at different points in time. In real life decision making, rewards for actions become available after a varied length of time - in some instances the delays can be substantial, encompassing many years.

However, when presented a choice between a small but immediate reward or a larger reward with a longer delay, humans, and animals [Green and Myerson, 2004], tend to prefer the smaller reward where the difference in the reward magnitude is considered small or if the delay for the larger reward is considered too long. In other words, there is a propensity to choose a small reward rather than waiting to receive a large reward after a long delay, although this choice depends on the amount of reward expected from each action and the amount of delay expected [van den Bos and McClure, 2013]. Under these conditions the utility for a delayed reward decreases with the duration of its delay. This variable decrease of subjective-reward value that occurs as a function of increasing delay is referred to as temporal discounting [Critchfield and Kollins, 2001]. It is worthy of note however, that temporal discounting theories have

limitations, including circumstances in which the value of an outcome increases when it is delayed [Loewenstein, 1987, Berns et al., 2007].

Temporal Discounting and Rewards

A great body of research is dedicated to how people decide when offered consumable rewards in contrast to monetary ones, which are all discounted with time, with the temporal discounting presenting an inverse relationship to the size of the reward. But different rewards follow different rules when it comes to discounting. It is known from the evidence present in literature that the intrinsic attributes of rewards, as well as their type [Kirby and Maraković, 1996, Estle et al., 2007, Demurie et al., 2012] and magnitude [Scheres et al., 2010a] influence the level of temporal discounting. For instance, money has a lower discounting rate as compared to food, with the discounting rate for entertainment media (books, compact disks) in-between. When it comes to individual discounting degrees, they prove to be very consistent across reward types [Charlton and Fantino, 2008].

Neural Correlates of Intertemporal Choice

As mentioned previously the *DMN* is implicated in internal off-task thought processes and is therefore considered to be involved in processes for episodic future thinking and mental time travel [Buckner and Carroll, 2007]. As such, during intertemporal choice the mental simulation of the hypothetical outcomes involves components of the *DMN*. Specifically, activity in the posterior cingulate cortex (*PCC*) correlates with the subjective values of delayed reward [Kable and Glimcher, 2007]. However, this activity and associated memory implicating hippocampal activity is diminished in decision making involving uncertain outcomes with no delays as opposed to the more pronounced activity with intertemporal choice. The anterior cingulate cortex (*ACC*) has also been shown to be involved in functional coupling with the hippocampus

in relation to how much episodic future thinking affects the preference for delayed rewards [Peters and Büchel, 2010].

Intertemporal Choice in Autism

Time perception is a less well explored research direction with regards to *ASDs* which may perhaps seem surprising considering consistent evidence and observations impairments with time perception. Deficits have been reported regarding time judgment [Boucher, 2000] reflected in the alteration of various behaviours [Wing, 2000], such as desiring reassurance regarding planned events and when they will occur, with distress associated with changes to plans. Congruently, cognitive tasks that implicitly require the perception of time passing, such as the ordering of events, demonstrate altered results in comparison to healthy controls - consistent with atypical temporal processing.

It has been recorded that *ASD* individuals tend to deviate from the temporal discounting rates found in the typically developing population, with higher rates reflecting a preferred immediate monetary reward over larger delayed rewards [Sonuga-Barke et al., 1992, Barkley et al., 2001, Marco et al., 2009, Paloyelis et al., 2010, Scheres et al., 2010a, Scheres et al., 2010b, Wilson et al., 2011, Demurie et al., 2012]. This points to a tendency towards higher trait time preference where immediate rewards are preferred over delayed rewards even when the delayed reward is substantially larger [Sonuga-Barke and Fairchild, 2012]. Interestingly, there seems to be a strong emotional component in the reactions to delays with delay aversion or reduced executive control in the inhibition of resisting tempting stimuli [Barkley, 1997].

1.6 Emotions and Counterfactual Thinking

Emotions and Counterfactual Thinking

Social comparison theory explains how we evaluate our own opinions and abilities through comparing ourselves to others, which is considered to be/is arguably at the heart of human interaction. According to theories of cognitive evaluation [Deci and Ryan, 1985], appraisal theory outlines that emotions result from a cognitive evaluation or appraisal that is made regarding the internal or external event that initiated it. A cognitive evaluation is defined as a fast, automatic, unconscious, cognitive process. Such appraisals influence emotional judgments, bias motivational decision-making and guide social interactions.

Among the range of human emotions, a specific subset of complex emotions can be clearly distinguished, namely "social emotions", such as envy and gloating [Scherer, 2005]. Contrary to emotions like disappointment or joy, which are experienced when an outcome does not depend on our own decisions, related emotions like relief and regret, as well as social emotions such as envy and gloating result from a counterfactual comparison. More specifically, counterfactual comparison involves the comparison between an effective value ("what is") and a fictive value ("what could have been if I had taken another decision"). Regret and relief implicates a feeling of personal responsibility which may have an important role in learning to evaluate our actions [Camille et al., 2004].

Indeed counterfactual thinking ("I would have been better off by choosing the other option") marks the alternative choice as a better alternative for future use. Envy as a social analogue of regret ("I would have been better off by choosing the option he chose") may operate in a similar way [Bault et al., 2011]. When one experiences envy or gloating the counterfactual comparison is a social one. Envy involves a comparison

between one's negative situation and another individual's positive situation; gloating refers to a comparison between one's positive situation and another individual's less fortunate situation. Regret and relief are purely a private counterfactual comparison between two choices, while envy and gloating adds to this the information on outcome of choices of others.

Regret and Disappointment

Counterfactual thinking involves imagining alternatives to one or more features of a perceived event [Epstude and Roese, 2008] and switching between the imagined (counterfactual) and real situation in one's mind. For example, regret is a common negative emotion which arises when we think that the outcome of an experience is worse than initially expected. While disappointment stems from disconfirmed expectancies upon external events, we experience regret when realizing or imagining that our present situation would have been better, had we decided differently [Zeelenberg et al., 1998c].

Ultimately, knowing that there was a better alternative, with a more preferred outcome than the one taken, is what sets regret apart from disappointment and is known as upward counterfactual thinking. Contrastingly, downward counterfactual thinking involves comparing one's current situation with a worse alternative and is associated with the emotion of relief, whose non-counterfactual counterpart is contentment. Disappointment and its emotional opposite contentment are experienced when an outcome happens independently of our decision.

The experience of post-decisional regret or relief however is conditional on the knowledge of the outcomes of the rejected alternatives. Moreover, unlike disappointment and contentment, feelings of regret and relief implicate a sense of responsibility that inherently implies a focus on the self in creating the outcome [Frijda et al., 1989a].

Emotions and Counterfactual Thinking in Autism

Empathy dysfunction, the impaired ability to share emotional states with others, has been described as one of the most striking clinical features of individuals with *ASDs* [Kanner, 1971]. However, consistent evidence indicates that individuals with *AS* and *HFA* do not demonstrate as severely impaired emotional processing and emotion recognition as other *ASD* classifications and may exhibit some empathic abilities [Capps et al., 1993a, Kasari et al., 2001, Yirmiya et al., 1992a].

Experiments in autistic children show a manifestation of psychophysiological responsiveness to others' distress suggesting that the affective component of empathy is still preserved allowing them to respond with an appropriate emotion [Blair, 1999]. However, they lack the cognitive component of empathy with which one fully relates to another person's emotional state [Dziobek et al., 2008, Rogers et al., 2007, Yirmiya et al., 1992a].

Recent neuroscience studies have highlight that alterations in the functioning of sociocognitive brain networks- with a particular focus on the *ToM* network and emotional circuitry - underpins this preserved empathic concern yet inability to take on the mental perspective of others. As such disturbances in understanding others' affective states in people with *ASDs* arise when the appreciation of the emotion requires the representation of the others' beliefs, such as surprise or embarrassment (i.e. belief-based emotion), but not for emotions generated by factual events (i.e. reality-based emotions) [Baron-Cohen et al., 1993, Golan et al., 2006a].

A general consensus is emerging where age and gender related variability in the functioning of of both sociocognitive and socioemotional networks, reflects the variable nature in the manifestations of social and emotion related problems in individuals with *ASDs* [Schulte-Rüther et al., 2013, Schneider et al., 2013]. Differences in pro-

cessing of emotions that result from counterfactual thinking have been implicated in children with *HFA* in comparison with typically developing children [Begeer et al., 2012]. Interestingly the capacity children with *HFA*'s capacity in explaining the difference between relief (upward counterfactual reasoning) and contentment was impaired. However, their distinction between regret (downward counterfactual reasoning) and disappointment was comparable to typically developing children [Begeer et al., 2012].

Chapter 2

Effects of Counterfactual Emotions on Decision Making of Individuals on the Upper End of the Autistic Spectrum

We deal with counterfactual emotions on a daily basis. In the present experiment we mainly focus on four emotions which could result from assessing the outcome of our choices. When we take a decision and obtain a positive outcome, we experience *rejoice (contentment)* and when the outcome is negative we experience *disappointment*. When we compare our actual gain against the gain which could have been obtained had we taken a different decision or course of actions (counterfactual thinking), we experience such counterfactual emotions as either *regret* or *relief*, depending on the comparison outcome, negative or positive respectively.

But how do the individuals with autistic spectrum disorders (*ASDs*) process counterfactual emotions? Are they able to experience regret and relief, disappointment and joy? Are they able to account for these emotions? Do they process them the same way as the individuals with typical development? In the present study our goal is to answer these questions by investigating deeper the emotional processing of coun-

terfactual emotions in decision-making in patients with autistic spectrum disorders (*ASDs*) and namely adults with Apeger’s Syndrome (*AS*) and High Functioning Autism (*HFA*). We inquired into the behavioral responses within the patient group and a typical development (*TD*) control group matched demographically, educationally and *IQ*-wise. We employed a gambling task typical for eliciting the four emotions under study, and looked into the participants’ choices along with their subjective reports on the labeling of the emotion felt and intensity of their feelings.

The participants completed the task individually. The subjects had to choose between two lotteries which bared different risk levels, and saw the outcome on the screen according to the experimental private conditions: in the partial feedback condition the participants were shown their own outcome only for the specific lottery chosen (eliciting *disappointment* or its positive counterpart *rejoice*); and in the complete feedback condition the participants were shown their own outcome together with the unchosen lottery outcome (eliciting *regret* or its positive counterpart *relief*).

In line with our expectations, the control group reported the feelings of disappointment or joy in the partial feedback condition (according to the outcome of the chosen lottery) and the feelings of regret or relief in the complete feedback condition (according to the outcome of the chosen and the unchosen lotteries). Positive outcomes elicited positive emotions and negative outcomes - negative emotions, as expected. Nevertheless, the comparison of self-reports of *TD* controls and *ASD* participants brought about unexpected results. While the *TD* controls experienced regret more intensely than disappointment, there was not significant difference in the intensity of these two emotons for the *ASD* patients in our experiment: in *ASDs* regret was rated lower than in *TDs*.

Although all the participants managed to anticipate regret and focused on maximizing expected values, a more risk-averse behavior was observed in the *ASD* patients.

This result comes at odds with previous literature (i.e. Camille et al. [Camille et al., 2004]) which showed that intense emotional regret triggers risk-averse behavior (in typically developing individuals), given that in our autistic group the self-reported intensity of regret is low. Hence our results do not endorse the fact that individuals with *ASD* exhibit risk averse behavior due to a self-reported intense feeling of regret. Further investigations are required to either pinpoint or deny the causality between regret and risk averse behavior in both typical and patient populations.

2.1 Introduction

Autistic Spectrum Disorders (*ASDs*), as outlined by the Centers for Disease Control and Prevention (*CDC*), are a group of developmental disabilities that can cause significant social, communication and behavioral challenges. According to *DMS – IV* [American Psychiatric Association,] (active when the current experiment was run), at the upper, high functioning end of the autistic spectrum the typical diagnoses are "Asperger's Syndrome" (*AS*) (recently and controversially removed from the American Psychiatric Association's Diagnostic and Statistical Manual of Psychiatric Disorders (*DMS – V*) [American Psychiatric Association, 2013], "High Functioning Autism" (*HFA*) and "Pervasive Developmental Disorder - Not Otherwise Specified" (*PDD – NOS*). On the lower end of the spectrum there are "Autism", "Classic Autism" and "Kanner Autism".

Those diagnosed with any *ASD* within the spectrum suffer from qualitative impairments in cognitive faculties such as communication and social interaction and have a tendency to stim (self-stimulate) and display other stereotypical behaviors. Difficulties in the cognitive processing of emotional information at least partially accounts for many of these stereotypical behaviors—especially those related to social interactions. Diagnostic criteria for *ASDs*, such as those found in the *DSM – V* [American Psychi-

atric Association, 2013], the Autism Diagnostic Interview-Revised (*ADI – R*) [Lord et al., 1994] and the Autism Diagnostic Observation Scale (*ADOS*) [Lord et al., 2000], all include impairments in emotional competence, including the inability to process nonverbal behaviours, eye-to-eye gaze, facial expression, body postures, and communicative gestures (*American Psychiatric Association, 2000*).

AS is now considered the same diagnosis as *HFA* according to *DSM – V* [American Psychiatric Association, 2013] as both the individuals with *HFA* and *AS* present themselves in a similar manner and have average or above average intelligence, but may struggle with issues related to social interaction and communication. The until recently separate diagnoses of *AS* differentiated itself from the *HFA* label through the primary requirement that, early in development, the child did not show a significant delay in language development, while in *HFA* the child had delayed language.

Rigorous investigations among individuals with *HFA* have demonstrated the ability to recognize and express basic, core emotions [Ekman and Davidson, 1994] such as happiness, sadness, and anger [Capps et al., 1993a, McGee et al., 1991, Feldman et al., 1993, Ozonoff et al., 1990, Yirmiya et al., 1992b, Smith, 2008]. However, individuals with *ASDs* sometimes differ from typically developing individuals in both the interpersonal and intrapersonal integration of their emotions. They may similarly encounter difficulties in articulating their emotions and in differentiating between emotions and bodily sensations [Hill et al., 2004].

Such symptoms are a common denominator in the diagnosis of *ASDs* and *Alexithymia*, a sub-clinical personality construct that shares such considerable overlaps with *ASDs* [Fitzgerald and Bellgrove, 2006, Lane et al., 1996, Hill and Berthoz, 2006] that it has recently been proposed to be an idiosyncratic trait of individuals with *ASD* [Paula-Pérez et al., 2010]. Due to the large heterogeneity

within the autistic population with regards to emotional competence it has recently been argued that emotional impairments are due to the condition of alexithymia rather than a feature of autism per se [Bird and Cook, 2013].

Theories of human emotion consider appraisal, the attribution of an emotional meaning to a situation which modulates our response, a key component of emotional experiences â regardless of the theoretical assumption of whether the appraisal is seen as causing (e.g. [Frijda et al., 1989a, Roseman, 1996]) or as characterising emotional experience [Frijda, 1987, Lazarus, 1994, Ortony, 1990, Scherer et al., 2001, Smith and Kirby, 2001]. A lack of reflective appraisal in autistic children reportedly leads to complications in distinguishing between different emotional experiences and in maintaining a coherent representation of their emotions [Harris et al., 1987].

Accordingly, having impaired appraisal abilities imparts problems in managing and regulating emotionally laden situations introspectively [Rieffe et al., 2007] and in interpersonal interactions [Travis and Sigman, 1998, Hobson, 1986]. Fittingly, in *ASDs*, complex social and moral emotions, such as pride, embarrassment and shame are particularly problematic as they tend to require a significantly larger degree of introspection and self-reflection than with basic emotions [Capps et al., 1992, Capps et al., 2009, Kasari et al., 2001, Loveland et al., 1997, Heerey et al., 2003].

Empathy dysfunction, the impaired ability to share emotional states with others, has been described as one of the most striking clinical features of individuals with *ASDs* [Kanner, 1971]. However, consistent evidence indicates that individuals with *AS* and *HFA* do not demonstrate as severely impaired emotional processing and emotion recognition as other *ASD* classifications and may exhibit some empathic abilities [Capps et al., 1993b, Kasari et al., 2001, Yirmiya et al., 1992b]. Experiments in autistic children show a manifestation of psychophysiological responsiveness to othersâ distress suggesting that the affective component of empathy is still preserved

allowing them to respond with an appropriate emotion [Blair, 1999].

However, they lack the cognitive component of empathy with which one fully relates to another person's emotional state [Dziobek et al., 2008, Rogers et al., 2007, Yirmiya et al., 1992b]. Recent neuroscience studies have highlighted that alterations in the functioning of sociocognitive brain networks—with a particular focus the Theory of Mind (*ToM*) network, which endows our ability to attribute mental perspectives to others as well as ourselves—underpins this preserved empathic concern yet inability to take on the mental perspective of others.

As such disturbances in understanding others's affective states in people with *ASDs* arise when the appreciation of the emotion requires the representation of the others's beliefs, such as surprise or embarrassment (i.e. belief-based emotion), but not for emotions generated by factual events (i.e. reality-based emotions) [Tager-Flusberg, Golan et al., 2006a]. A general consensus is emerging where age and gender related variability in the functioning of these sociocognitive and socioaffective networks reflects the variable nature in the manifestations of social and emotion related problems in individuals with *ASDs* [Schulte-Rüther et al., 2013, Schneider et al., 2013].

Differences in processing of emotions that result from counterfactual thinking have been implicated in children with *HFA* in comparison with typically developing children [Begeer et al., 2012]. Counterfactual thinking involves imagining alternatives to one or more features of a perceived event [Epstude and Roese, 2008] and switching between the imagined (counterfactual) and real situation in one's mind. For example, regret is a common negative emotion which arises when we think that the outcome of an experience is worse than initially expected. While disappointment stems from disconfirmed expectancies upon external events, we experience regret when realizing or imagining that our present situation would have been better, had

we decided differently [Zeelenberg et al., 1998a].

Ultimately, knowing that there was a better alternative, with a more preferred outcome than the one taken, is what sets regret apart from disappointment and is known as upward counterfactual thinking. Contrastingly, downward counterfactual thinking involves comparing one's current situation with a worse alternative and is associated with the emotion of relief, whose non-counterfactual counterpart is contentment. Disappointment and its emotional opposite contentment are experienced when an outcome happens independently of our decision. The experience of post-decisional regret or relief however is conditional on the knowledge of the outcomes of the rejected alternatives.

Moreover, unlike disappointment and contentment, feelings of regret and relief implicate a sense of responsibility that inherently implies a focus on the self in creating the outcome [Frijda et al., 1989b]. Interestingly the capacity of children with *HFA* to explain the difference between relief (upward counterfactual reasoning) and contentment was impaired. However, their distinction between regret (downward counterfactual reasoning) and disappointment was comparable to typically developing children [Begeer et al., 2012].

A simple gambling task has been used previously to assess differences in the experience of regret, disappointment, relief and contentment in individuals with typical development [Camille et al., 2004]. When presented with a choice between two risky gambles associated with a monetary reward, the same obtained outcome (a monetary gain or loss) should lead to different experienced (regret or disappointment and relief or contentment) emotions depending on whether feedback about the outcome of the unchosen gamble is provided.

In the partial feedback condition - in which only the outcome from the chosen

gamble is provided - participants are expected to experience disappointment, when the obtained value is negative, and contentment, when the obtained value is positive. In contrast, in the complete feedback condition in which outcomes from the two gambles are available - knowledge of the unselected outcome would strongly modulate the effect of the obtained one, eliciting the experience of regret or relief.

As shown previously [Camille et al., 2004], the direct comparison between the complete and partial feedback conditions reveals different levels of emotional involvement between regret and disappointment, since the type of counterfactual thinking (either across alternative choices or alternative states of the world) determines the quality and the intensity of the emotional response. Adults with typical development reported emotional responses consistent with counterfactual thinking; they experienced regret as being more intense than disappointment and chose to minimize future regret.

In contrast, studies in patients with lesions to the orbitofrontal cortex (*OFC*) failed to report regret or anticipate the negative consequences of their choices suggesting that this region plays a crucial role in mediating the experience of regret [Camille et al., 2004]. Neuroimaging studies provide also indicate that while the *OFC* is involved in the experience of regretful outcomes, the amygdala is also associated with learning to avoid choices that may engender regret [Coricelli et al., 2005a]. Compared with when one feels disappointed there is decreased activity in the striatum thought to dampen feelings of reward and increased activity in the amygdalae thought to enhance the intensity of the emotional response.

The repetitive experience of regret, in comparison with disappointment is thought to encourage risk-aversion through an increase in activity in the medial *OFC*, the anterior cingulate cortex (*ACC*) and the hippocampus. This is indicative of regret enhancing processing of the punishment of failure (*OFC*), enhancing the emo-

tional valence (amygdalae) of the emotional memory (hippocampus), encouraging the minimizing of risk and avoidance of regret [Camille et al., 2004]. Fittingly, evidence suggests that developmental dysfunction in the orbitofrontal-amygdala circuit presents problems with self-regulation of social-emotional behaviour in *ASDs* [Bachevalier and Loveland, 2006]. Such developmental cognitive dysfunction may generate differences in how one approaches risk in relation to differential processing of the feeling of regret.

2.2 Hypotheses

The present study investigated if adults with *ASDs* (namely *HFA* or *AS*) similarly experience regret, disappointment, relief and contentment compared with healthy controls in a gambling task setting and if there are differences in the experience of emotions elicited by upward and downward counterfactual thinking.

Similarly the current study examines whether the anticipatory feelings of regret and relief affect behavioural choices in so far as to stimulate advantageous choice behaviour in order to minimize feelings of regret. To elicit feelings of regret and disappointment and their positive equivalents, relief and contentment we used a gambling task in which a group of adults with *ASDs* and a control group were presented with a choice between two risky gambles associated with a monetary reward and asked to report the quality and the intensity of their emotional responses by using a rating scale.

In light of previous behavioural and neurobiological findings, we expected individuals with *ASD* to encounter difficulties in differentiating between emotions that require counterfactual thinking, while the ability to think counterfactually remains intact. The results are discussed in relation with the cognitive processing of regret and relief and the implicated consumer affect.

2.3 Methods

2.3.1 Participants

A clinical diagnosis of Asperger Syndrome (*AS*) or High Functioning Autism (*HFA*) according to *DSM-IV-TR* (American Psychiatric Association, 2000) and *ASDI* (*Asperger Syndrome Diagnostic Interview*, [Gillberg et al., 2001a]) and the *ADOS* ([Lord et al., 2000]) was confirmed for the twelve adults recruited from *Albert Chenevier Hospital* in Créteil 2.1 for the study. Diagnoses were made by experienced clinicians based on clinical observations of the participants with inclusion and exclusion criteria for the clinical groups, being based on retrospective parental information regarding the early language development of their child.

Parent or caregiver interviews were conducted using the *Autism Diagnostic Interview* (*ADI-R*, [Lord et al., 1994]). From the interview it was determined that all individuals had scores for the three classes of assessed behaviour â for reciprocal social interaction [*B*], for communication [*C*] and for stereotyped behaviours [*D*] â that were above the lower limit cut-offs scores of 10, 8 and 3 respectively, which confirmed the original *ASD* diagnoses. As part of the assessment process, a French translation of the Autism, tics, *AD-HD* and other comorbidities questionnaire (*A-TAC*, [Hansson et al., 2005]) was completed by the parents. This screening questionnaire asks parents to report any problems with various abilities, conducts and behaviours in their childâs functioning in relation to his or her peers that were observed at any period of life, even when the specific characteristic is no longer present.

An equal number of control participants with typical development (*TDs*) were recruited to match the clinical group with respect to age, educational level and gender 2.1. Included in the selection process was a screening of *TDs* to exclude

any of them with a history of psychiatric or neurological disorders. All participants had normal/corrected to normal vision and were native French speakers. Basic neuropsychological screening included both Verbal and Performance *IQs* (*WAIS – III*) [Wechsler, 1997].

All participants, both the test and control group, had an *IQ* above 70. The two groups did not differ on gender (t-test: $t(22) = 1.1, p = .029$), chronological age (t-test: $t(22) = 0.11, p = 0.91$), education (t-test: $t(22) = -0.19, p = 0.84$) and *IQ* level (Full-scale, Verbal and Performance (t-test): $t(22) = 0.34, p = 0.73$; $t(22) = -0.42, p = .067$; $t(22) = 1.63, p = 0.11$).

| | <i>ASD patients</i> | <i>TD controls</i> |
|---|-----------------------------------|--------------------|
| Age (years) | 27.0 ± 8 | 29.3 ± 9.3 |
| Gender (<i>F/M</i>) | 1/11 | 3/9 |
| Education (years) | 14.4 ± 3.5 | 14.5 ± 3.4 |
| Full Scale <i>IQ</i> | 102.6 ± 23.5 | – |
| Verbal <i>IQ</i> | 107.6 ± 26.1 | – |
| Performance <i>IQ</i> | 95.1 ± 18.6 | – |
| Autistic Quotient (<i>AQ</i>) (pathological threshold: 30) | – | – |
| ADI [B,C,D]* | 17.5 ± 7.1; 11.4 ± 6.8; 6.4 ± 3.2 | – |

Table 2.1: Demographical and Clinical Data

((a)) * [B]= reciprocal social interaction; [C] = communication; [D] = stereotyped behaviors

The present research was approved by the local Ethical committee (*Inserm, Institut Thmatique Sant Publique; C07 – 33*), with all investigations complying with *APA* ethical standards. Informed consent agreements were signed by all participants prior to volunteering for this study.

2.3.2 Experimental Design

Individual tests were conducted in a quiet room at the *Albert Chenevier Hospital in Crteil*. Participants sat in front of a computer for stimuli presentation using presentation software by *Neurobehavioral Systems, EU*. Participants played a Gambling task by choosing between two wheels associated with different amounts of money 2.1. Having two levels of valence (gain and loss) and two feedback conditions (partial and complete) the experiment is of two by two factorial design. When each gambling trial began, two lotteries were displayed. Each wheel was divided into two differentially colored sectors (blue and red) associated with different pairs of values.

The two lottery choices were formed by any pair of the following values corresponding to cents of euros: +50, 50, +200, 200. The length of each wheel sector reflected three potential outcome probabilities (0.8, 0.5, 0.2). 2.1 depicts an example of the presentation of the two lotteries. While with one lottery there is a 50% chance of gaining 50 cents and a 50% of losing 200 cents, the second lottery has a 20% chance of winning 200 cents and an 80% chance of losing 200 cents.

Following the appearance of the two lotteries on the computer screen, participants were prompted to choose one of the two wheels by pressing one of two arrow keys of the keyboard (*CHOICE*). The selected wheel was highlighted by a rectangular green box appeared (*WAIT*) and a rotating arrow started spinning in the centre of the gamble circle (*SPINNING*). The resting position of the arrow following 6 seconds of spinning indicated the outcome of the selected gamble. Two types of trials were performed with regards to choice feedback (partial or complete).



((a)) The probability of gain is represented in blue; the probability of loss is represented in red

((b)) Here, in the left lottery, the probabilities are: 1/2 chance to gain 50 cents; 1/2 chance to lose 200 cents

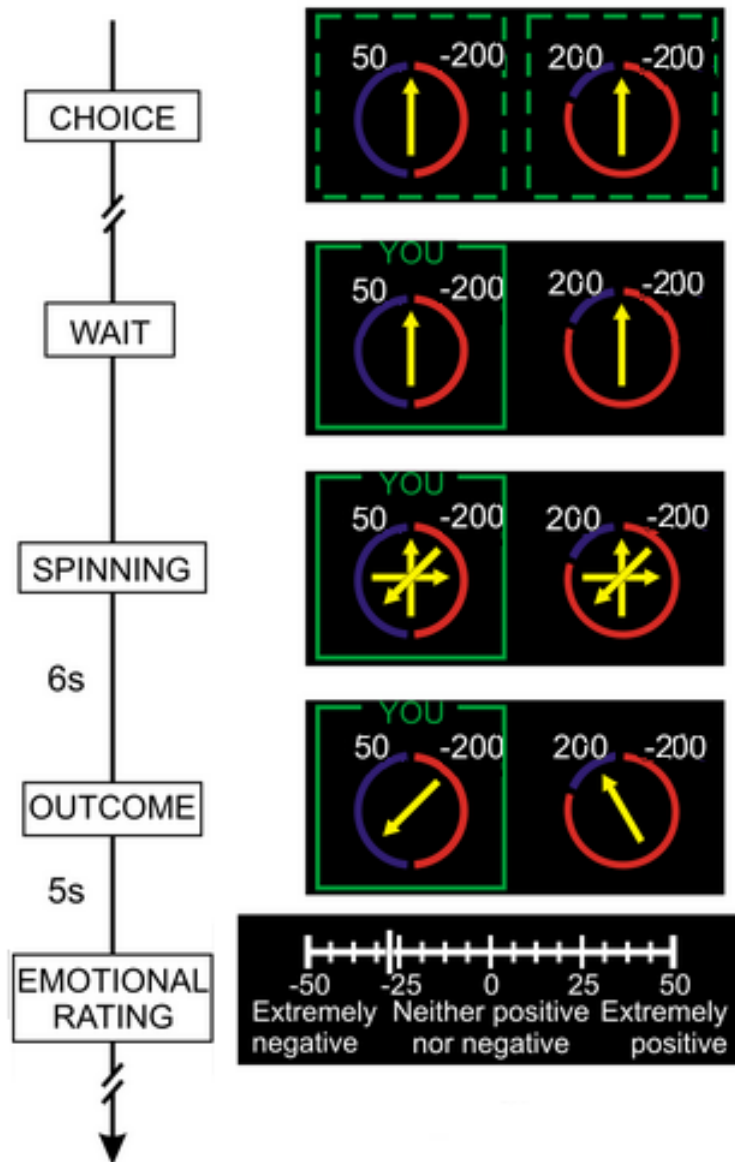
((c)) In the right lottery the probabilities are: 1/5 chance to gain 200 cents; 4/5 chance to lose 200 cents

Figure 2.1: Example of two lotteries presented at the beginning of the trial

Each participant played a total of 60 trials, split equally between receiving a partial feedback or a complete feedback. In the partial feedback condition the outcome was presented only for the gamble chosen by the participant; in the complete feedback condition the outcome of both the selected and unselected gambles (and spinning arrow) were available. Following completion of every trial participants gave a subjective rating of their emotional response associated with the outcome of their choice (emotional scale ranging from -50 , extremely sad, to $+50$, extremely happy). The inter-trial delay lasted 3 seconds. The duration of each trial depended on the choice duration taken by the subject, and the time they took to subjectively rate their associated emotional valence. On average the experiment lasted 45 minutes per participant.

It was considered that in the partial feedback condition, the participant could experience disappointment in case of loss, or contentment in case of gain 2.3. Contrastingly, in the complete feedback condition, information about the outcome of the non-chosen lottery is available and in cases of losses and wins it would elicit respective feelings of regret or relief that involve counterfactual reasoning 2.3. Subjects were informed in advance if they would receive complete or partial feedback. For the outcome period, trials were also divided according to the valence of the difference between the

outcome of the chosen lottery and the outcome of the non-chosen one. Trials were categorized as gain trials if the counterfactual comparison was advantageous and as loss trials if it was disadvantageous, regardless of the sign of the obtained outcome.







((a)) The dashed lines are representing the possible choices

((b)) The lottery chosen by the subject, in either private or social conditions is represented in green

((c)) Gains are represented in blue; losses in red. The sum associated is indicated by a positive number for gains, and a negative number for losses.

Figure 2.3: Timeline of the partial and complete conditions (adapted from Bault2008)

Events were classified as follows, according to the relative losses or gains and the gambling context 2.5: in Partial condition, the participant could experience disappointment in case of loss, or joy in case of gain; in Complete gambling, information about the outcome of the non-chosen lottery led to regret or relief feelings. For the outcome period, trials were also divided according to the valence of the difference between the outcome of the chosen lottery and the outcome of the non-chosen one. Trials were categorized as gain trials if the counterfactual comparison was advantageous and as loss trials if it was disadvantageous, regardless of the sign of the obtained outcome.

| | | Gambling Context | |
|---------|---------------|--|--|
| | | Partial Private | Complete Private |
| Valence | Relative loss | Disappointment  | Regret  |
| | Relative gain | Joy  | Relief  |

((a)) At outcome there is a 2 by 2 factorial design

((b)) The gambling context factor has two levels: partial and complete; the valence factor has two levels: gain and loss

((c)) Each cell of the design is labelled with an emotion name.

Figure 2.5: Emotions experienced in the different conditions of the lottery task

2.3.3 Data Collection and its Analysis

The statistical software package Stata (*Stata Corp, College Station, TX, Release 9/SE*) was used to perform the statistical analysis. Non-parametric tests were applied

to the data sets since they violated several parametric assumptions, particularly non-normal distribution of the data. As such the non parametric Wilcoxon signed rank test was used to identify differences in significance between behavioral variables and subjective evaluations; testing the distribution of two random variables for matched pairs. Intergroup (*ASDs* and *TDS*) differences were tested using the Mann-Whitney rank test.

We tested (by regression analysis, using a panel logit procedure with individual random effect,) a model of choice that incorporates the effects of anticipating disappointment and regret in addition to the maximization of expected values 2.3. The panel data analysis takes each subject as the unit and the trial as time. The model estimated is the random effects model, and the parameters are estimated by maximum likelihood.

Given that $Pr(g_1) = 1 - Pr(g_2)$, where $Pr(g_1)$ and $Pr(g_2)$ are the probabilities of choosing gamble 1 and gamble 2, we define the probability of choosing g_1 in terms of 4 factors affecting the choice of anticipated disappointment d , anticipated regret r , expected value e and risk d_{sd} . Let us call x_1, y_1 and x_2, y_2 the two possible outcomes of the first (g_1) and the second (g_2) gambles, respectively, with $x_1 > y_1$ and $x_2 > y_2$.

The probability of outcome x_1 is p and the probability of outcome y_1 is $1 - p$. The probability of outcome x_2 is q and the probability of outcome y_2 is $1 - q$. The model is $Pr(g_{1it}) = F[d_{it}, r_{it}, e_{it}]$, where i is individual and t is time. The function $F[\theta]$ denotes the function $exp(\theta)/[1 + exp(\theta)]$. The dependent variable, "choice of g_1 ," is 1 when the subject chooses g_1 and 0 when the subject chooses g_2 .

Independent variables are d, r, e, d_{sd} , where:

- Anticipated disappointment choosing g_1 : $d = [|y_2 - x_2|(1 - q)] - [|y_1 - x_1|(1 - p)]$. d is the probability-weight of the possibility in winning the lowest outcome of each wheel spin.
- Anticipated regret choosing g_1 : $r = [|y_2 - x_1| - |y_1 - x_2|]$. r is based on considering choosing an alternative and simultaneously rejecting other alternatives. r represents the difference between the highest outcome of the first wheel and the lowest outcome of the second; that is the comparison between the value of choice and the value of a rejected alternative [Camille et al., 2004].
- Expected value choosing g_1 : $e = EV(g_1) - EV(g_2) = [px_1 + (1 - p)y_1] - [qx_2 + (1 - q)y_2]$. Expected value is the probability-weighted sum of the possible values.
- Risk choosing g_1 : $d_{sd} = sd_1 - sd_2 = \sqrt{p(x_1 - EV_1)^2 + (1 - p)(y_1 - EV_1)^2} - \sqrt{q(x_2 - EV_2)^2 + (1 - q)(y_2 - EV_2)^2}$.

Standard deviation provides a quantified estimate of the uncertainty of future outcomes as it is a measure of variability from the mean. Hence a significant positive e or d_{sd} coefficient indicates that subjects consistently choose the lottery with highest EV or level of risk, whereas a significant negative e or d_{sd} coefficient indicates that subjects consistently choose the lottery with lowest EV or level of risk. Similarly a significant positive d or r coefficient indicates that subjects consistently anticipated disappointment or regret (respectively) [Camille et al., 2004].

To calculate the interaction between groups ($ASDs$ and TD controls) and anticipated disappointment and regret we ran four logistic regressions. d^*group indicated the interaction between groups and anticipated disappointment; r^*group indicated the interaction between groups and anticipated regret. We made two logistic regressions: one with the choice as dependent variable, and e ; d_{sd} ; e^*group ; d_{sd}^*group as

explicative variables (where 1 is attributed to *ASD* subjects and 0 to *TD* controls for the variable group); and the other one with the choice as dependent variable, and *d*; *d*group*; *r* ; *r*group* as explicative variables.

A positive coefficient indicated that anticipated disappointment (for *d*group*) or regret (for *r*group*) has a more important influence in *ASD* subjects' choices than in controls' choices, whereas a negative coefficient indicated that anticipated disappointment or regret has a more important influence in controls' choices than in *ASD* subjects' choices.

2.3.4 Counterfactual Inference Test

The counterfactual thinking test aimed to assess the subject's capacity to use counterfactual reasoning in simple social situations. We measured counterfactual thinking (comparing "what is" with "what might have been") using a four items scale, based on two variables: normality and goal proximity ([Roese and Olson, 1995], for review [Zeelenberg and van Dijk, 2004]). The test was based on the assumption that counterfactual statements are more pronounced when the relationship between previous actions and outcome is abnormal, or when there is increased physical and temporal proximity between the alternative situations.

Examples include: (i) "Ann gets sick after eating at a restaurant she often visits. Sarah gets sick after eating at a restaurant she has never visited before. Who is more upset about their choice of restaurant?" (ii) "Ed is attacked by a mugger only 10 feet from his house. James is attacked by a mugger a mile from his house. Who is more upset by the mugging?" Normally, target responses are: "Sarah" for the first example, and "Ed" for the second example. The scale ranges from 0 (no counterfactual thinking) to 4 (perfect ability in counterfactual thinking).

2.4 Results

Kruskal-Wallis equality-of-populations rank test ($K - W$) revealed no differences in educational and demographic characteristics between the control subjects and the aspergers patients (age: $chi - squared = 0.44$, $p = 0.51$; gender: $chi - squared = 0.48$, $p = 0.49$; education: $chi - squared = 0.003$, $p = 0.95$).

During the *Regret Gambling Task* we recorded the subjects' choice behaviour and the emotional response to the outcome of their choice. We first analyzed the emotional evaluation of the outcome of choice, and then to investigate whether emotional experience would be predictive of decisions made in the gambling task, we conducted a further analysis on the choice behavior.

2.4.1 Emotional Evaluation and Choice Behavior

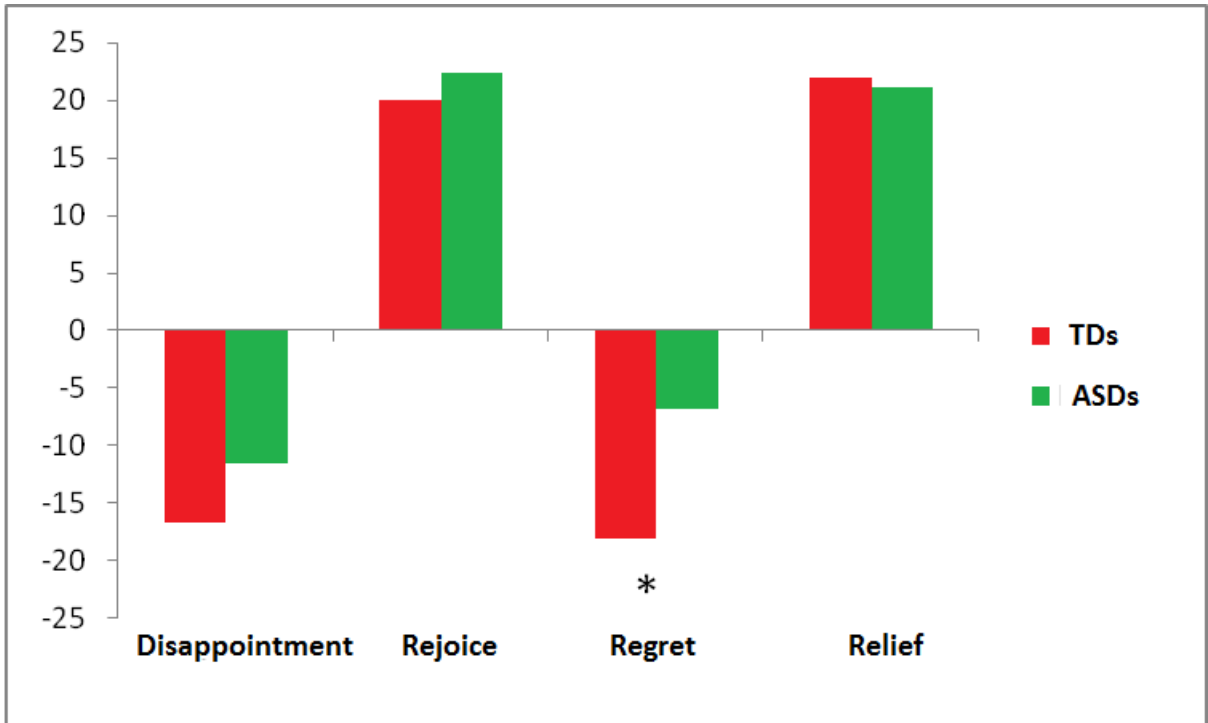
The *Wilcoxon Sign Rank Test* was used to evaluate subjective emotional responses following the choice's outcome. The test revealed that in partial feedback conditions the control group showed a pattern of emotional ratings consistent with the presence of disappointment, whereas under complete feedback conditions ratings were consistent with regret. In the complete and partial feedback trials control participants reported a more negative loss with an outcome of -50 (or a win of $+50$) when the alternative outcome of the lottery chosen was $+200$ compared with an alternative outcome of -200 ($z = -3.058$, $p = 0.002$, for both -50 and $+50$ obtained).

This negative emotional experience was intensified in the complete feedback condition when the participants experienced regret and felt responsibility for making the worse of the two choices (regret effect, 2.7), as compared with the partial feedback condition (disappointment effect) ($z = -2.35$, $p = 0.01$).

When *ASD* participants were similarly asked to evaluate their emotional responses,

they also experienced a loss of -50 (or a win of $+50$) as being a more negative emotional experience than when the alternative outcome of that spin was $+200$ as compared to those circumstance in which alternative outcome was -200 ($z = -2.787$, $p = 0.005$, for -50 obtained; and $z = -3.059$, $p = 0.002$, for $+50$) in both complete and partial feedback conditions.

However, in the complete feedback conditions, where control participants experienced a more intense negative regretful emotion, the test group participants did not report any statistically significant amplification of the negative valence experienced for disappointment (partial feedback conditions) and regret (complete feedback condition) ($z = -0.549$, $p = 0.58$).



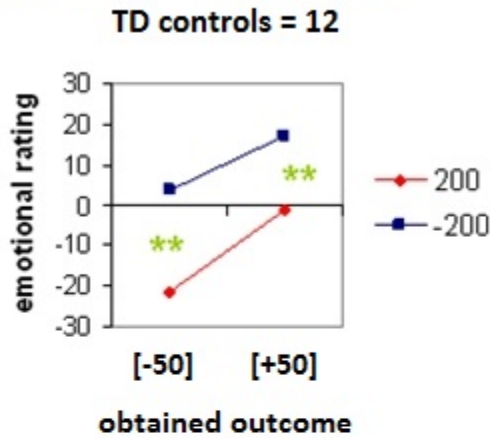
((a)) The bars represent the average value of the subjective emotional evaluation given by participants in the different events

((b)) The emotion associated to each condition is indicated on the x-axis, the emotional rate on the y-axis. * : $P < 0.05$

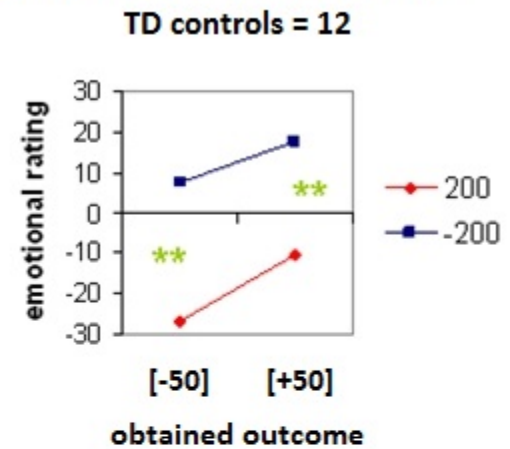
Figure 2.7: Emotional responses: average subjective emotional evaluations

Moreover we plotted the mean emotional ratings for the two obtained outcome (-50 and $+50$) as a function of the unobtained outcomes of -200 (blue) and $+200$ (red), in partial and complete feedback conditions, respectively 2.9. Controls evaluated as more negative a loss of -50 (or a win of $+50$) when the alternative outcome was $+200$ compared with an alternative outcome of -200 (Wilcoxon sign rank test, $z = -3.058$, $p = 0.002$, for both -50 and $+50$ obtained). As shown in 2.7, this effect was amplified in the complete feedback condition when the subjects might have felt responsible for the wrong choice (regret effect). *ASD* subjects showed a pattern of emotional evaluation similar to that of *TDI* controls 2.9. The *ASD* group behaved like control subjects in complete feedback condition (Wilcoxon sign rank test, $z = -2.787$, $p = 0.005$, for -50 obtained; and $z = -3.059$, $p = 0.002$, for $+50$), even though they did not report any amplification effect between disappointment and regret. In other words they colored the evaluation of the outcome of their choices with emotions, such as disappointment and regret.

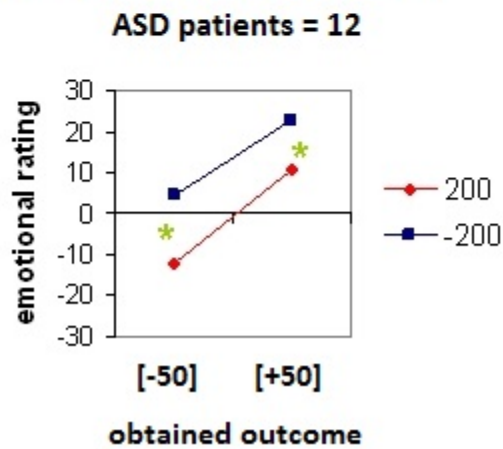
[A] Partial feedback condition



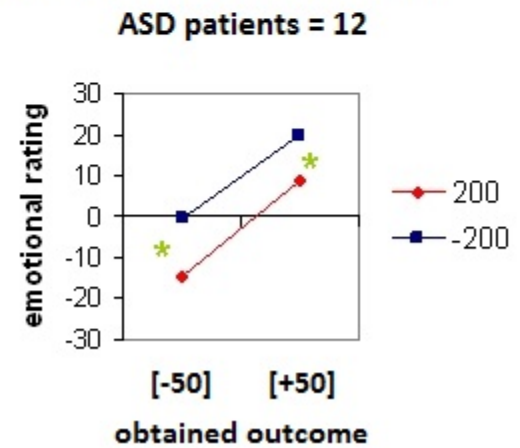
[B] Complete feedback condition



[C] Partial feedback condition



[D] Complete feedback condition



((a)) We plotted the mean emotional ratings for the two obtained outcomes (-50 and $+50$) as a function of the foregone outcomes of -200 (blue) and $+200$ (red), in partial and complete feedback conditions, respectively

((b)) Data from: *TD* control subjects (*A* and *B*), and *ASD* patients (*C* and *D*): control subjects reported disappointment and regret; *ASD* patients ($N = 21$) reported disappointment and regret – Wilcoxon sign rank test between the emotional ratings of the two unobtained outcomes (-200 vs. $+200$) for each obtained outcome (-50 or $+50$): * : $P < 0.05$, ** : $P < 0.001$

Figure 2.9: Mean emotional ratings for the two obtained outcomes (-50 and $+50$)

The Mann-Whitney test was used to compare emotional rating across the four different conditions that each elicit a distinct emotional response in control participants.

The test revealed a significant group difference for regret only ($U = 32$; $z = -2.31$; $p = 0.02$; *mean diff.* = -16.8), while the two groups of participants reported comparable emotional rating for disappointment ($U = 47$; $z = -1.44$; $p = 0.14$; *mean diff.* = -6.23), contentment ($U = 65$; $z = -0.4$; $p = 0.68$; *mean diff.* = -3.29) and relief ($U = 53$; $z = -1.1$; $p = 0.27$; *mean diff.* = 2.6). Interestingly, participants with *ASD* reported higher scores in emotional rating for contentment, as compared to relief (Wilcoxon sign rank test: $z = -2.22$; $p = 0.026$; *mean diff.* = 5.73), unlike control participants who reported an equal level of intensity ($z = -0.16$; $p = 0.87$; *mean diff.* = -0.17).

ASD participants showed a pattern of behaviour similar to that of the *TD* controls, since they chose maximizing expected values by choosing the lottery with the highest value and anticipating regret through minimizing risk (the coefficients of e and r respectively, were significant, both $p < 0.05$). However, the two groups differed in their risk propensity (as indicated by the coefficient of the variable *dsd*), that is participants with *ASD* were significantly less prone to making risky decisions than control participants. In other words, while experiencing regret was minimized in *ASD* participants through making less risky choices, this could not have been influenced by a more intense negative feeling of regret as found in *TDs* 2.3.

2.4.2 Counterfactual Inference Test

TD controls and *ASD* patients showed no difference in their ability to reason counterfactually in the counterfactual inference test. The mean counterfactual score was 1.9 ($SD = 1.3$) and ($SD = 1.13$) for *ASD* and *TD* participants respectively (Mann-Whitney test, $z = 0.137$, $p = 0.8914$).

| Variable Name | TDs, $N = 12$ | ASDs, $N = 12$ | All Participants, $N = 24$ |
|-----------------|--------------------|--------------------|----------------------------|
| Constant | 0.17 (0.16) | 0.38 (0.17)* | 0.27 (0.11)* |
| e | 0.029 (0.004)** | 0.024 (0.004)** | 0.029 (0.004)** |
| d | -0.004 (0.002)* | 0.0017 (0.0019) | -0.0041 (0.002)* |
| r | 0.003 (0.001)* | 0.0029 (0.001)* | 0.0033 (0.0014)* |
| e^*group | | | -0.0005 (0.002) |
| d^*group | | | 0.006 (0.003)* |
| r^*group | | | -0.0051 (0.006) |

Table 2.3: Regression analysis of choice behavior in the regret gambling task

((a)) Note: numbers indicate coefficients, and standard errors in parentheses. * $p < 0.05$, ** $p < 0.0001$

2.5 Discussion

As expected, all participants reported experiencing more positive emotions following a favourable, obtained outcome and more negative emotions following an unfavourable, obtained outcome, but while control participants experienced feeling of regret as being more intense than disappointment, participants with *ASD* did not exhibit any increase in the emotion intensity associated with regretful events. In addition, when we compared participants's subjective evaluation for all types of emotional experiences generated during the gambling task, the two groups only differed in the evaluation of the regret experience, that is, participants with *ASD* experienced regret as being significantly less intense than control participants. In contrast, the two groups did

not differ in the evaluation of disappointment, contentment and relief.

Favourable comparisons between the obtained and the unselected outcome are expected to determine contentment or relief, respectively, depending on the respective use of either partial or complete feedback conditions. However, relief did not generate a more intense emotion in comparison with contentment in either of the participant groups. This can be explained by the greater saliency and self-relevance of negative emotions relative to the positive ones. The asymmetric impact of negative and positive events on outcome choice is repeatedly represented in the literature [Taylor, 1991].

Mandler's theory of emotion [Mandler, 1975] assigns an important emotional role for negative events as they implicitly elicit greater physiological arousal and mobilize affective, cognitive and social resources to a greater extent than do comparable positive events. The repetitive experience of regret, in comparison with disappointment is thought to encourage risk-aversion through an increase in activity in the medial *OFC*, the anterior cingulate cortex (*ACC*) and the hippocampus. This is indicative of regret enhancing processing of the punishment of failure (*OFC*), enhancing the emotional valence (amygdalae) of the emotional memory (hippocampus), encouraging the minimizing of risk and avoidance of regret [Camille et al., 2004]. Fittingly, evidence suggests that developmental dysfunction in the orbitofrontal-amygdala circuit presents problems with self-regulation of social-emotional behaviour in *ASDs* [Bachevalier and Loveland, 2006]. Such developmental cognitive dysfunction may generate differences in how one approaches risk in relation to differential processing of the feeling of regret.

It has been established that regret and disappointment have distinct experiential and cognitive contents: they are associated with different antecedent counterfactual conditions and appraisal patterns, as well as distinctive patterns of risky decision

making [Zeelenberg and van Dijk, 2004]. While counterfactual thinking modulated the intensity of the emotional experience of regret, participants with *ASD* did not subjectively differentiate disappointment and regret.

Differences in defective counterfactual reasoning cannot explain the difficulties in distinguishing regret from disappointment in our participants with *ASD*, as the two groups performed equally in the counterfactual reasoning task, which is in accordance with previous research showing intact reasoning abilities in *ASD* patients. [Lincoln et al., 1988]. Similarly intact counterfactual reasoning abilities were found in children with *ASDs*; however they similarly explained feelings of regret and relief as *TDs* and instead had problems distinguishing between contentment and relief. This may reflect the age related differences in emotional processing identified for individuals with *ASDs* [Schulte-Rüther et al., 2013].

Importantly, compared with the control group, they maximized expected values and anticipated both regret and disappointment, as these factors appear to affect their choice. These findings suggest that negative and positive valences of events are unconsciously processed and covertly affect *ASD* subject's behaviours, but fail to be recognized by an emotional appraisal system which originates distinctive phenomenological experiences and makes this information available for conscious reasoning.

Alternatively contentment being perceived as being a more intense emotion than relief in *ASD* participants, in comparison with *TDs* who showed no such difference in emotional valence, may influence risk-averse behaviour. This line of argument would lean towards a propensity for seeking the pleasure that comes from making the best choice being a factor that promotes risk-averse behaviours as opposed to avoiding regret in individuals with *ASD*. This is in stark contrast with subjects with typical development whose development of risk-averse behaviour is thought to stem from the intensity of the negatively valenced emotion of regret in comparison with

disappointment [van Dijk et al., 1999, Saffrey et al., 2008].

When participants deployed cognitive strategies that reduce negative emotional experience or reinterpreted the meaning of affective stimuli and their emotional impact, increased activity in the ventrolateral and dorsomedial prefrontal cortices was observed [Ochsner and Gross, 2005] marking the prefrontal cortex as being important for cognitive regulation of emotions. In a previous study using a similar paradigm, patients with damage to the orbito-frontal cortex (*OFC*) were able to think counterfactually on the chosen gamble and could experience disappointment, however they did not experience regret [Camille et al., 2004].

Given that the *OFC* integrates the cognitive and the emotional components in the process of decision making, a dysfunction of this region was logically considered to affect the ability to generate and modulate, through counterfactual thinking, specific cognitive-based emotions, such as regret. As shown in a subsequent neuroimaging study [Coricelli et al., 2005b], the ability to incorporate the affective values with reasoning processes, such as counterfactual thinking, critically relies on the *OFC* and on its functional connectivity with the amygdala.

Previous research has provided consistent evidence in support of the view that psychophysiological emotional responses are not normally integrated in cognitive processes in *ASDs* because of amygdala dysfunctions or abnormal connectivities between the amygdala and the ventro-medial prefrontal cortex (*vmPFC*) [Baron-Cohen et al., 2000]. This fronto-limbic dysfunction might also underlie difficulties in processing introspective knowledge in alexithymia, a behavioral construct affecting a large proportion of individuals with *ASDs*, although it is thought to be that results of altered connectivity and activity in the fronto-insular cortex [Bernhardt et al., 2013].

Regret is a self-relevant experience which focuses on unattained goals, promotes goal

persistence and motivates active attempts for future behaviour, such as to avoid unpleasant events. In contrast, disappointment is associated with feelings of powerless and inactivity, because it is often unclear how one could have avoided the disappointing event or what one could do to avoid choices that could result in even greater disappointment in the future. It is likely that participants, that predominantly experience an undifferentiated feeling of disappointment when faced with negative events from that of regret, are less prone to engage in risky options.

Repetitively experiencing regret, in comparison with disappointment is thought to encourage risk-aversion through an increased activity in the medial *OFC*, the anterior cingulate cortex (*ACC*) and the hippocampus relating to the processing of the punishment of failure (*OFC*), enhancing the emotional valence (amygdalae) of the emotional memory (hippocampus), encouraging the minimizing of risk and avoidance of regret [Coricelli et al., 2005b]. However risk aversion was more pronounced in *ASD* in our study, despite a less intense report of the experience of regret.

It would seem that for the participants in our experiment a lack of intense emotions experienced in situations expected to elicit feelings of regret would not reflect higher activity in this fronto-limbic circuitry when experiencing regret over disappointment as expected in healthy individuals. A similar mechanism may be at work that could influence risk-aversion by altered fronto-limbic activations in response to contentment in comparison with relief which is worthy of further investigation.

Nonetheless, such differences in the functioning of these emotional networks clearly influence how individuals with *ASDs* have altered emotional responses to emotionally stimulating experiences, which when combined with differences in other socio-cognitive networks such as the ToM network, result in the spectrum of social and communication dysfunction observed in *ASDs*.

The experience of regret seems to be associated with responsibility judgments and specific cognitive and attitudinal states. Zeelenberg and collaborators [Zeelenberg et al., 1998c, Zeelenberg et al., 1998b] showed that regret typically arises in situations where one is, or feels responsible for the occurrence of the negative event. A recent neuroimaging study [Nicolle et al., 2011] has shown that regret crucially depends on subjective responsibility rather than on the sense of agency (caused by uncontrollable circumstances or casual events) of the regretful event.

Interestingly neuronal activity in the amygdala was enhanced by increased responsibility associated with this "self-blame regret". Because of this self-blame appraisal dimension, regret is an intense negative emotion. Yet it remains a useful faculty by which focusing attention on one's own role in the occurrence of the aversive event, promotes learning from one's mistakes. Since people's choices are often made to avoid highly unpleasant events, anticipation of emotional reactions (e.g., regret versus relief/self-approval) allows for the possibility to control for engagement in the more advantageous and positive actions. It may be a lack of anticipatory self-blame that prevents *ASDs* from experiencing intense regret.

Indeed such maladaptive cognitive appraisals may be associated with the connectivity differences in the *ToM* network which deals with attributing mental states to oneself as well as attributing them to others [Deshpande et al., 2013]. Recent studies have even suggested that such alterations to the connectivity in the brain in *ASD* could serve as a potential non-invasive neuroimaging signature for autism [Deshpande et al., 2013].

Giorgetta extended the evidence for neural activity in processing both regret and disappointment by showing that at the neural level both feedback and agency affected the brain responses associated with regret and disappointment, demonstrating differential localization in the brain for each: feedback regret showed greater brain activity

in the right anterior and posterior regions, with agency regret producing greater activity in the left anterior region [Giorgetta et al., 2013].

The influence that regret has on decision making can also be interpreted with respect to the "framing effect". The framing effects was originally defined by Tversky and Kahneman [Tversky and Kahneman, 1981] as a deviation from rational decision-making, assuming that presenting the same option in different contexts would alter people's decisions. De Martino [De Martino et al., 2006] used a financial decision-making task in which participants had the choice of two options presented in the context of two different frames. Using this paradigm, authors found that orbital and medial prefrontal cortex activity predicted a reduced susceptibility to the framing effect.

Subsequently, De Martino and collaborators [De Martino et al., 2008] showed that individuals with *ASDs* are insensitive to the framing manipulation. The present results are in accordance and further extend our proposal by showing that this insensitivity to bias can be characterized by a failure to integrate physiological and cognitive contextual cues into the process of decision-making. As the emotional experience of regret has been shown to drastically influences consumer affect, making consumers averse to risk taking, further studies into the neurological differences that result in a dampening of the emotional experience of regret yet an increase in aversion to take risks should better indicate how this will affect the individuals choices as consumers.

2.6 Conclusions

In conclusion, the present findings suggest that conscious appraisal of regret is disrupted in individuals with *ASDs* despite harboring intact counterfactual reasoning. The reduced experience of regret in *ASDs* likely results from neural abnormalities

affecting the amygdala or its functional connectivity with the prefrontal cortex, in particular the *OFC* and the *vmPFC*. We suggested that this fronto-limbic dysfunction extends beyond the domain of social cognition by affecting the ability to process relevant affective values related to one's own choice or self-relevant events [Sander et al., 2003].

Further research is needed to corroborate the present findings on a larger sample of individuals with *ASDs* by using psychophysiological measures of emotions, such as electrodermal activity and heart rate, in addition of explicit appreciation of the subject's emotional states.

Chapter 3

Insights on Counterfactual Emotions of Autistic Individuals within Social Contexts

As humans, in our social life we rely heavily on social comparisons. There is a big array of feelings and counterfactual emotions which could result from assessing the outcome of social comparisons against ourselves and/or others. When we compare our actual gain against the gain which could have been obtained had we taken a different decision or course of actions, we experience either *regret* or *relief*, depending on the comparison outcome. When we compare (socially) our actual gain to the gain of others, the assesment of this comparison triggers either *envy* or *gloating*. But what do individuals on the autistic spectrum feel when comparing themselves to other people in a social context? And how do they process these social comparison emotions?

In the present study our goal is to answer these questions by investigating deeper the emotional processing of private and social emotions in decision-making in patients with autistic spectrum disorders (*ASDs*) and namely adults with Aperger's Syndrome (*AS*) and High Functioning Autism (*HFA*). We inquired into the behavioral

responses and the physiological activity within the patient group and a typical development (*TD*) control group matched demographically, educationally and *IQ*-wise.

We employed a gambling task typical for eliciting counterfactual emotions, and looked into the participants' choices along with their subjective reports on the labeling of the emotion felt and intensity of their feelings. We also collected and analyzed skin conductance responses. The participants completed the task in pairs of one experiment participant and one confederate. The subjects had to choose between two lotteries which bared different risk levels, and saw the outcome on the screen according to the experimental private conditions: their own outcome only for the specific lottery chosen (eliciting *disappointment* or its positive counterpart *rejoice*) or their own outcome together with the unchosen lottery outcome (eliciting *regret* or its positive counterpart *relief*); and the social condition: their own outcome and the confederate's outcome (eliciting *envy* or *shared regret* or their positive counterparts *gloating* or *shared relief*).

Strikingly, in the private conditions the *ASD* patients accounted for weaker regret as compared to the *TD* controls, but increased shared regret associated with very positive feelings in the social condition. Still, in a social context appraisal, the subjective accounts in participants with *ASD* are not different from those of *TD* controls', implying preserved social feelings in the context of social comparison. Our results suggest that the subjective experience of emotions might be disrupted in autism, and according to our findings specifically for regret and shared regret. Surprisingly, skin conductance responses mainly contradicted the subjective self-reports, showing more intense activity in the condition eliciting regret or relief, and less intense responses in the social context condition. Hence our results endorse the fact that individuals with *ASD* experience disruptive emotion processing and fail to fully integrate cognitive input and intrinsic information during decision making.

3.1 Introduction

3.1.1 Counterfactual Comparisons

Social comparison theory explains how we evaluate our own opinions and abilities through comparing ourselves to others, which is considered to be/is arguably at the heart of human interaction. According to theories of cognitive evaluation [Deci and Ryan, 1985], appraisal theory outlines that emotions result from a cognitive evaluation or appraisal that is made regarding the internal or external event that initiated it. A cognitive evaluation is defined as a fast, automatic, unconscious, cognitive process. Such appraisals influence emotional judgments, bias motivational decision-making and guide social interactions. Among the range of human emotions, a specific subset of complex emotions can be clearly distinguished, namely “social emotions”, such as envy and gloating [Scherer, 2005].

Contrary to emotions like disappointment or joy, which are experienced when an outcome does not depend on our own decisions, related emotions like relief and regret, as well as social emotions such as envy and gloating result from a counterfactual comparison. More specifically, counterfactual comparison involves the comparison between an effective value (“what is”) and a fictive value (“what could have been if I had taken another decision”). Regret and relief implicates a feeling of personal responsibility which may have an important role in learning to evaluate our actions [Camille et al., 2004].

Indeed counterfactual thinking (“I would have been better off by choosing the other option”) marks the alternative choice as a better alternative for future use. Envy as a social analogue of regret (“I would have been better off by choosing the option he chose”) may operate in a similar way [Bault et al., 2011]. When one experiences envy or gloating the counterfactual comparison is a social one. Envy involves a comparison

between one's negative situation and another individual's positive situation; gloating refers to a comparison between one's positive situation and another individual's less fortunate situation 3.1. Regret and relief are purely a private counterfactual comparison between two choices, while envy and gloating adds to this the information on outcome of choices of others.

| Context | Negative Outcome | Positive Outcome |
|---------------------------|-----------------------|------------------|
| No Comparison | Disappointment | Joy |
| Counterfactual Comparison | Regret | Relief |
| Social Comparison | Envy | Gloating |

Table 3.1: Emotions labeling, depending on the context and either the positive or negative outcome

3.1.2 The Autistic Spectrum

Autistic Spectrum Disorders (*ASDs*)

According to the Diagnostic and Statistical Manual of Mental Disorders (*DSM – V*, [American Psychiatric Association, 2013]), autism is defined as a disorder characterized by a qualitative impairment in social interaction and communication, and restricted repetitive and stereotyped patterns of behavior, interests and activities. The symptoms of people with autism fall on a continuum, namely autism spectrum disorders (*ASDs*), with some individuals showing mild symptoms and others having much more severe symptoms.

According to *DMS – IV* [Ozonoff et al., 2000] (active when the current experiment was run), at the upper, high functioning end of the autistic spectrum the typical diagnoses are "Asperger Syndrome" (*AS*) and "High Functioning Autism" (*HFA*). *AS* is now considered the same diagnosis as *HFA* according to *DSM – V* ([American Psychiatric Association, 2013]) as both the individuals with *HFA* and *AS* present

themselves in a similar manner and have average or above average intelligence but may struggle with issues related to social interaction and communication.

High Functioning Autism (*HFA*)

Rigorous investigations among individuals with *HFA* have demonstrated the ability to recognize and express basic, core emotions [Ekman and Davidson, 1994] such as happiness, sadness, and anger [Capps et al., 1993a, McGee et al., 1991, Ozonoff et al., 1990, Yirmiya et al., 1992a]. However, their social and communication difficulties still have a strong emotional component, with deficits in social-emotional reciprocity; ranging from abnormal social approach and failure of normal back and forth conversation through to a reduced sharing of interests, emotions, and affect and response to a total lack of initiation of social interaction (*DSM – V*).

As such, individuals with *ASD* are commonly regarded as lacking in empathy. Due to the large heterogeneity within the autistic population with regards to emotional competence it has recently been argued that emotional and empathy related impairments are due to a co-morbid condition called alexithymia, more specifically the inability to describe one's emotions. Consistent evidence indicates that individuals with *AS* and *HFA* do not demonstrate as severely impaired emotional processing and emotion recognition as other *ASD* classifications and may exhibit some empathic abilities [Capps et al., 1993a, Kasari et al., 2001, Yirmiya et al., 1992a].

3.1.3 Social Cognition and Empathy

Healthy Subjects

Empathy is a process requiring the inference of the affective state of another by generating an isomorphic affective state in the self, while retaining knowledge that the cause of the affective state is the other person [de Vignemont and Singer, 2006, Singer

and Lamm, 2009]. Empathy contributes significantly to social interactions and indeed social comparisons, allowing for the prediction, perception and understanding of others's behavior and the generation of an appropriate response.

However, empathy is modulated by many different factors such as the object of empathy, the social context, our beliefs and goals, the mental and physical state of the empathizer and the appraisal of the situation, which is reflected in the interplay between neural networks underlying the generation and regulation of empathy [Engen and Singer, 2013]. The core network of empathy includes the anterior insula (*AI*) involved in the evaluation and experience of emotion [Lindquist and Barrett, 2012, Kober et al., 2008] and interoceptive awareness [Craig, 2009] and the boundary area between posterior anterior and anterior medial cingulate cortex (*pACC/aMCC*), with which the *AI* is strongly connected to, which has pivotal roles in the integration of pain, negative affect and cognitive control [Shackman et al., 2011].

This core *AI*/midcingulate empathy network acts as a central hub in many other neural networks allowing for the integration of information from other cognitive processes in the adaptive regulation of empathy. Of particular relevance in the regulation of empathy are emotion regulation networks. These networks are involved in both automatic empathy modulation that supplants the immediate emotional content of the stimulus with context appropriate appraisal as well as conscious, intentional empathy modulation to allow for a change in the affective quality of a distressing empathic experience [Engen and Singer, 2013]. The cognitive generation and regulation of empathic responses are clearly complex and dynamic processes that involve many interconnected overlapping neuronal networks.

ASD subjects

There is the potential for many different components of these interacting empathy related networks to directly or indirectly affect the generation of accurate empathic representations of others affective states through aberrant functioning in individuals with *ASD*. It has recently been proposed that variability in the functioning of both sociocognitive and socioaffective networks reflects the variable nature in the manifestations of social and emotion related problems in individuals with *ASDs* [Schulte-Rüther et al., 2013, Schneider et al., 2013].

In *ASD* individuals, impairments in empathy and related social emotions may arise from impairments to the ToM network in attributing beliefs, desires and mental states to others [Mathersul et al., 2013]; from mirror neuron system abnormalities in empathic imitation of emotions [Baird et al., 2011] and emotion regulation abnormalities in the limbic system; depending on the context and many factors that influence the experience of empathy [Bernhardt et al., 2013].

This is thought to reflect the severe difficulties *HFA* individuals have in recognizing social emotions such as envy and gloating [Shamay-Tsoory, 2008] or in understanding cognitive emotions, such as regret or embarrassment [Baron-Cohen et al., 1993, Golan et al., 2006b]. Several studies have investigated the social impairments harboured by *HFA* and *AS* subjects through observing physiological responses to social information, notably in face recognition tasks [Harms et al., 2010, Wilson et al., 2010].

3.2 Hypotheses

The current study investigates the relationship between *AS* and *HFA* individuals and the processing of both social (envy and gloating) and non-social (relief and regret) emotions that require counterfactual reasoning. The primary objective was the

evaluation of *HFA* and *AS* subjects' abilities to use counterfactual thinking and social comparison in a gambling task setting.

Concurrently, we wanted to analyze the emotional impact of decisions, in terms of disappointment, regret or envy (and their positive equivalents) and to test the patients' ability to experience these emotions. Another objective of this study was to further investigate physiological reactivity during social comparison. Although social impairments are a core feature of the autistic disorder, data on autonomic reactivity and subjective experience during a task that implicates a social component does not exist to our knowledge. Our hypotheses were as follows:

- In contrast to control subjects whose emotional response is expected to be particularly sensitive to social counterfactual comparison as well as self-reflective counterfactual comparisons, an insensitivity to differences in the social or non-social context was expected in autistic subjects. We anticipated that individuals with *ASD* would ignore social information and focus on information associated with the expected value. This hypothesis complements findings regarding context being less of an influence than expected value on emotional processing [De Martino et al., 2008] and is supported by *ASD* individuals maintaining perceptual processing despite impaired involuntary processing of social cues [Jellema et al., 2009b].
- We expected that autistic subjects will have abnormal skin conductance responses (*SCRs*) during their emotional response to counterfactual comparison, particularly when social comparison is required. In line with [Khalifa and Peretz, 2007] we were expecting abnormal *SCR* in response to emotional stimuli, in autistic subjects.

3.3 Experimental Design and Procedure

3.3.1 Participants

We recruited *thirteen* participants with *ASD* (*Asperger's Syndrome* and *High Functioning Autism*): 2 females and 11 males; 12 right-handed and 1 left-handed) and 25 control participants with typical development (*TDS*): 4 females and 21 males; 23 right-handed and 2 left-handed) for the current study. Recruitment of *ASD* subjects took place at a patient support group center in the *Chenevier Hospital* in *Crteil*, having received their diagnosis prior to recruitment. Screening of *TDS* was performed to exclude those with a history of psychiatric or neurological disorders.

The French National Ethical Committee (*Comit Consultatif de Protection des Personnes dans la Recherche Biomedicale*) approved the full consent given by the participants. The *TDS* and autistic subjects were age- and study level-matched (age: $mean = 31.7 \pm 10.0$ for *ASD* subjects; $mean = 25.4 \pm 8.4$ for controls; study level: $mean = 14 \pm 2.9$ for *ASD* subjects; $mean = 14.3 \pm 2$ for controls). All the participants performed the Autism Quotient (*AQ*) test (French version, [Braun and Kempnaers, | (Autism Research Centre, 2007) : the mean was 30.8 ± 7.2 for patients and 15.4 ± 5.2 for controls.

Prior to release of *DSM – V*, individuals with a clinical diagnosis of *HFA* or *AS* according to the *DSM – IV – TR* (*American Psychiatric Association*, 2000) and the *Asperger Syndrome Diagnostic Interview* [Gillberg et al., 2001b] were recruited from *Albert Chenevier Hospital* in *Crteil*. Retrospective parental details given regarding the early language development of their child was used as *AS* diagnosis inclusion criteria.

Clinical observations of the participants by experienced clinicians to diagnose all participants. Moreover, the Autism Diagnostic Interview [Couteur et al., 1989] was given

to participants's parents or caregivers to confirm the diagnoses. All participants scored above cut-off points for the three classes of behavior are reciprocal social interaction: 10, communication: 8, and stereotyped behaviors: 3, respectively. The French translation of *A – TAC* (Autism, tics, *AD – HD* and other comorbidities [Larson et al., 2010] was completed by the parents and used as part of the checking process.

This screening questionnaire is focused on a number of abilities, conducts and behaviors in the child's functioning as compared to his or her peers. Parents were asked to report any problem or specific characteristic observed at any period of life, even when this was no longer present. All *ASD* participants received basic neuropsychological screening, which included Verbal and Performance *IQs* (*WAIS – III*) [Wechsler, 1997]. They had an *IQ* of 107.8 (± 19.9) 3.2.

3.3.2 The Experimental Task

Subjects participated in the experiment in pairs, separated from one another by a board to avoid any disturbances caused by the physical presence of their counterpart, each sitting in front of a separate computer. Pairs consisted of either two controls or one *ASD* participant and one control. The second player was a confederate of the same gender that was introduced to the subject as another participant recruited under the same conditions as they had been. Stimuli presentation was mediated by the Presentation software (*Neurobehavioral Systems, EU*). The task was adapted for *ASD* subjects to be more visually striking, using green to associate with wins and red associated with losses [Bault et al., 2011].

An adaptation of Mellers, Schwartz, Ritov's lottery task was used [Mellers et al., 1999], with an event-related design, manipulating the magnitude and probabilities of potential gains and losses, and was based on regret theories emerging from Bernoulli's expected utility model [Schoemaker, 1982]. The Lottery task was based on regret the-

ories. These theories moved on from Bernoulli's expected utility model. According to this model, people choose between alternative courses of action by assessing the pleasure or utility of each possible outcome, and selecting the action that leads to the greatest utility. Loomes and Sugden [Loomes and Sugden, 1982] and [Bell, 1982a] postulated that anticipated feelings modify the utility function.

This process, called "second-level learning", dissents from first-level reward processing, in that it involves rewards not received, from actions not taken. This affective evaluation leads to a modification of the subject's behavior, resulting of learning the information on the outcome of the actions he did not choose, i.e. the *Q-values*. This type of learning is called "fictive learning", or counterfactual *Q-learning* [Lohrenz et al., 2007b, Montague et al., 2006]. In this model, the error signal is a "fictive error" calculated as the difference between the obtained reward and the rewards of alternative previous actions.

To provide participants with financial motivation, they were informed that the sum of the outcomes of 10 randomly chosen trials would be calculated at the end of the experiment and that they will receive this amount plus a 5 Euro show-up fee. This prevented participants from mentally summing their earnings and to allow the trials to be treated independently. It was also made clear that the payment would not be in any way influenced by the performance of the other participants. All participants received 20 Euros for ethical purposes. 3.1.

3.3.3 Procedure

In three successive sessions, a total of 100 trials were recorded for each participant. Controls and *ASD* subjects were repeatedly presented with a choice between two risky gambles, with each of the two lotteries having two possible outcomes 3.3. Using



((a)) The probability of gain is represented in green; the probability of loss is represented in red

((b)) The length of each arc is reflecting the associated probability of winning or losing respectively

((c)) Here, in the left lottery, the probabilities are: 1/2 chance to gain 5 Euros; 1/2 chance to lose 20 Euros

((d)) In the right lottery the probabilities are: 1/6 chance to gain 20 Euros; 5/6 chance to lose 20 Euros

Figure 3.1: Example of two lotteries presented at the beginning of the trial

four possible values -20 ; -5 ; $+5$; $+20$ for each trial, every outcome was associated with one of the three possible probabilities 0.2; 0.5; 0.8, whose probability values are reflected in the length of the circlesâ circumference for that particular outcome.

The expected value is defined as the outcome associated with the lottery, weighted by its probability. We ensured that the difference in expected values of the two lotteries of all pairs were relatively equivalent (did not exceed seven points). Fixing the probabilities across the experiment, controlled for instances where one of the two lotteries would be clearly more appealing than the other. All participants went through the same sequence of pairs of lotteries and associated outcomes.

At the beginning of the trial, two lotteries were displayed. The subject could choose one of the two lotteries at any time by pressing one of two arrow keys on the keyboard. Two sequences of trials were completed by the participants 3.3: one sequence with partial feedback (20 trials) and one with complete feedback (80 trials). With the partial feedback session, the *PARTIAL/PRIVATE* condition only the result of the chosen lottery was shown. With the complete feedback sessions, both chosen and

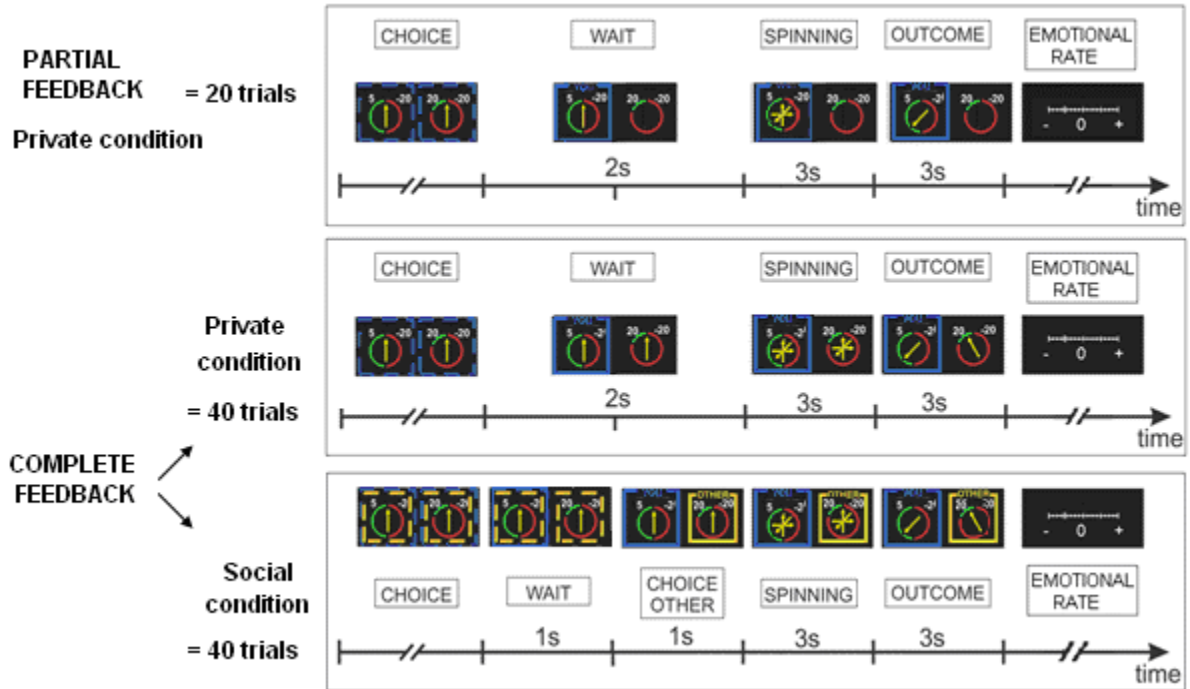
non-chosen lottery results were shown.

This complete feedback sequence was divided into two component parts, a *private* condition (40 trials) and a *social* condition (40 trials), respectively named *COMPLETE/PRIVATE* and *COMPLETE/SOCIAL* conditions. During the *Complete/Private* condition, the subject could see the outcome of both their chosen and non-chosen lottery, in the *Complete/Social* condition; participants were shown the other player's choice and outcome as well as their own. In the complete/social and complete/private conditions the outcomes of both lotteries were displayed at the same time, following a spinning period.

The participants were then in the position to compare their outcome to that of the non-chosen lottery (*complete/private* condition) or they can compare their own outcome to that of the second player (*complete/social* condition). Half participants performed the order 1 experiment: *Partial/Private*; *Complete/Private*; *Complete/Social*, half participants performed the order 2 experiment: *Partial/Private*; *Complete/Social*; *Complete/Private*.

Altering the feedback condition allowed for manipulation of the gambling effect and the related emotions elicited depending on a win or loss. Four situations could occur: *partial/private*; *complete/private*; *social same choice (SSC)*, when the participant and his counterpart had chosen the same lottery in *complete/social* condition; and *social different choice (SDC)*, when the participant and his counterpart chose different lotteries in *complete/social* condition.

According to whether the participant experiences a relative gain or relative loss respectively, emotional outcomes were classified as follows 3.5: in partial/private condition, the participant may experience joy or disappointment; in complete/private gambling, information about the outcome of the non-chosen lottery should lead to relief or re-



((a)) The dashed lines are representing the possible choices.

((b)) The lottery chosen by the subject, in either *private* or *social* conditions is represented in blue; the lottery chosen by the other participant, in social condition is represented in yellow

((c)) Gains are represented in green; losses in red. The sum associated with the outcome is indicated by a positive number for gains, and a negative number for losses.

Figure 3.3: Timeline of the *partial* and *complete* conditions

gret feelings; in *SSC* conditions participants experienced shared relief or regret; and in *SDC* conditions the feelings experienced were gloating or envy.

An advantageous or disadvantageous counterfactual comparison defined a trial as a gain or loss trial respectively irrespective of the sign of the obtained outcome. Prior to the experimental session the participants engaged in a short lottery trial training session that led them to believe that they would see the other participants's choice. However, in actuality their counterpart's choice was computer simulated allowing for independent analysis of the participants's behaviour and control of the environment created by the other player's choices and outcomes.

Similarly the experiment was normalized for those risk-averse as individuals with *ASD* have a documented avoidance of risk [Johnson et al., 2009]. The lottery was subjected to a risk-averse algorithm, so as to select the lottery pairs with lowest standard deviation (which is a measure of the level of risk) in 90% of the trials. This paradigm allowed testing the *ASD* capacity to change their strategy during for maximizing the possibility of gloating as opposed to minimizing the potential risk involved

| | | Gambling Context | | | |
|---------|---------------|--------------------|------------------|--------------------|--------------------------|
| | | Partial Private | Complete Private | Social same choice | Social different choices |
| Valence | Relative loss | Disappointment | Regret | Shared regret | Envy |
| | Relative gain | Joy | Relief | Shared Relief | Gloating |

((a)) There is a 2×4 factorial design for an outcome; each cell of the design is labelled with an emotion name

((b)) The gambling context factor has four levels: *partial*, *private*, *SSC* and *SDC*

((c)) The valence factor has two levels: gain and loss

Figure 3.5: Emotions experienced in the different conditions of the lottery tasks

At the end of each trial the subject was offered to give a subjective emotional rate on a scale from "Extremely Negative", through "Neither Positive nor Negative" up to "Extremely Positive". For the analysis this subjective report was associated to an emotion, according to the kind of trial: *Partial/Private*, *Complete/Private*, *Complete/Social* with same choices and *Complete/Social* with different choices and transposed in scores from -50 to 50 .

Participants were financially motivated. To avoid participants to mentally sum their earning and be able to treat trials independently, they were told that the sum

of the outcomes of 10 randomly drawn trials would be calculated at the end of the experiment and that they will receive this amount added to a 5 Euros show-up fee. They were clearly instructed that the payment would not depend in any way on the performance of the other participant. For ethical reasons, all participants received 20 Euros.

3.3.4 Questionnaires

Following experiment completion subjects filled in a questionnaire to assess if they truly believed through the whole experiment that gains were random and that the other participant's choices that were displayed to them were real. The last six participants had to answer an additional supplementary set of questions designed to investigate their sense of responsibility. Subsequently, all subjects filled in another two additional supplementary questionnaires, the *Counterfactual Inference Test* [Hooker et al.,] and *Comparison Orientation Measure* [Buunk and Gibbons, 2005].

The *Counterfactual Inference Test* measured counterfactual reasoning capacities of the subject's in simple social situations. One point is given or subtracted depending on whether the answer given follows principles of counterfactual reasoning, with a final score ranging from -4 to 4 . Conversely, the *Comparison Orientation Measure* uses 11 assertions to estimate the subject's tendency to compare himself to other people in daily life. The degree of veracity between the assertions and the individual's personality was assessed on a scale of one to five. The total score is from 11 to 55. All the participants filled the *Autistic Spectrum Quotient* 3.2.

3.4 Data Analysis

The normality of the distribution was tested using standardized samples that were compared with a standard normal distribution using *Kolmogorov – Smirnov* and

Shapiro – Wilk tests. Parametric tests were used in instances where data did not comply with a normal distribution. First *ANOVA* and *Kruskal – Wallis* tests (non-parametric *ANOVA*) were used to test the null hypothesis -that two or more population means are equal. T-tests, not being particularly sensitive to the deviations from the norm for moderate sample sizes were additionally used in the comparisons between groups.

Using the statistical software package *Stata* (*Stata Corp, College Station, TX*), panel data analysis was used to analyzed choice behavior. Panel logit regressions were run, allowing each participant to be considered as the unit and the trial as time, and estimation of both random and conditional fixed effects.

Given that $Pr(g_1) = 1 - Pr(g_2)$, where $Pr(g_1)$ and $Pr(g_2)$ are the probabilities of choosing gamble 1 and gamble 2, we define the probability of choosing g_1 in terms of 4 factors affecting the choice of anticipated disappointment d , anticipated regret r , expected value e and risk d_{sd} . Let us call x_1, y_1 and x_2, y_2 the two possible outcomes of the first (g_1) and the second (g_2) gambles, respectively, with $x_1 > y_1$ and $x_2 > y_2$.

The probability of outcome x_1 is p and the probability of outcome y_1 is $1 - p$. The probability of outcome x_2 is q and the probability of outcome y_2 is $1 - q$. The model is $Pr(g_{1it}) = F[d_{it}, r_{it}, e_{it}]$, where i is individual and t is time. The function $F[\theta]$ denotes the function $exp(\theta)/[1 + exp(\theta)]$.

The dependent variable, "choice of g_1 ," is 1 when the subject chooses g_1 and 0 when the subject chooses g_2 . The selection of one alternative choice while simultaneously rejecting other potential alternatives is the basis of anticipated regret. The difference between the highest outcome of the first wheel and the lowest outcome of the second

is represented by r , which is the comparison between the value of choice and the value of a rejected alternative.

Standard deviation is a measure of the variability, showing how much variation there is from the mean. It provides a quantified estimate of the uncertainty of future outcomes. Thus a significant positive e or dsd coefficient indicates that subjects consistently choose the lottery with the highest expected value or level of risk, whereas a significant negative e or dsd coefficient indicated that subjects consistently choose the lottery with lowest expected value or level of risk. Similarly a significant positive d or r coefficient indicates that subjects consistently anticipated disappointment or regret (respectively).

Independent variables are d , r , e , dsd , where:

- Anticipated disappointment choosing g_1 : $d = [|y_2 - x_2|(1 - q)] - [|y_1 - x_1|(1 - p)]$. d is the probability-weight of the possibility in winning the lowest outcome of each wheel spin.
- Anticipated regret choosing g_1 : $r = [|y_2 - x_1| - |y_1 - x_2|]$. r is based on considering choosing an alternative and simultaneously rejecting other alternatives. r represents the difference between the highest outcome of the 1st wheel and the lowest outcome of the 2nd; that is the comparison between the value of choice and the value of a rejected alternative [Camille et al., 2004].
- Expected value choosing g_1 : $e = EV(g_1) - EV(g_2) = [px_1 + (1 - p)y_1] - [qx_2 + (1 - q)y_2]$. Expected value is the probability-weighted sum of the possible values.
- Risk choosing g_1 : $dsd = sd_1 - sd_2 = \sqrt{p(x_1 - EV_1)^2 + (1 - p)(y_1 - EV_1)^2} - \sqrt{q(x_2 - EV_2)^2 + (1 - q)(y_2 - EV_2)^2}$.

Logistic regressions were used to calculate the interaction between groups (*ASD* and controls) and anticipated disappointment and regret. An interaction between the groups and anticipated disappointment or anticipated regret was indicated by d^*group and r^*group respectively. Two logistic regressions were made. The first used the choice as a dependent variable, and e ; dsd ; e^*group ; dsd^*group as explicative variables (where 1 is attributed to *ASD* subjects and 0 to *TD* controls for the variable group).

The second regression used the choice as a dependent variable, and d ; d^*group ; r ; r^*group as explicative variables. A positive coefficient indicates that anticipated disappointment (for d^*group) or regret (for r^*group) has a more important influence in *ASD* subjects' choices than in *TD* controls' choices, whereas a negative coefficient indicates that anticipated disappointment or regret has a more important influence in controls' choices than in *ASD* subjects' choices. Any session order effects were also evaluated by logistic regression.

Skin Conductance Response (*SCR*)

A *BIOPAC MP35* data acquisition unit (*BIOPAC Systems, EU*) continuously recorded and sampled skin conductance at $500Hz$. Median filtering was used to remove magnetic resonance artifacts following the taking of measurements. Ten participant's data sets were removed for analysis as they were impaired by acquisition problems or have less than 10% of the trials being detectable. For the 26 remaining subjects (12 *ASD* subjects and 14 *TD* controls), we considered only the event specific *SCRs* occurring between 1 second after stimulus onset and half a second prior to the end of the event with a amplitude threshold of $0.02 \mu S$ [Bault et al., 2011].

The mean value of amplitude computed across all trials, as well as those without

a measurable *SCR*, was taken as the *SCR* magnitude. Responses were summed to control for cases in which several responses occur in the same window of interest according to the different conditions. As the data sets violate many parametric assumptions, non-parametric tests were used.

3.5 Results

3.5.1 Questionnaire

The responsibility assessing questions answered by the last six subjects showed that *ASD* subjects felt globally less responsible for their losses than controls (without significant effect). *ASD* subjects reported a lower rating than controls (*Mann – Whitney*, $P = 0.049$) when asked if comparing their result to the un-chosen wheel (*complete/private*) amplified their responsibility feeling.

Similarly, *ASD* subjects also showed a tendency to report a lower rate than controls (*Mann-Whitney*, $P = 0.080$) for their result, in light of other participants's results, amplifying their feeling of responsibility (*complete/social*). No group differences were found for the ability to make counterfactual comparison reasoning. Non-parametric tests showed a significant difference between *ASDs* and *TD* control subjects for the *Comparison Orientation Measure* test (*Mann – Whitney*, $P = 0.023$): *ASD* subjects compared themselves to others in daily life more often than controls 3.2.

3.5.2 Affective Reports / Emotional Rates

In the control subjects the results of self evaluation of emotional state about the choice's outcome showed that disappointment, regret, shared regret and envy had a negative rating 3.7, while joy, relief, shared relief and gloating received an average positive score 3.9. Regret was stronger than disappointment (*Wilcoxon*, $Z = 2.59$,

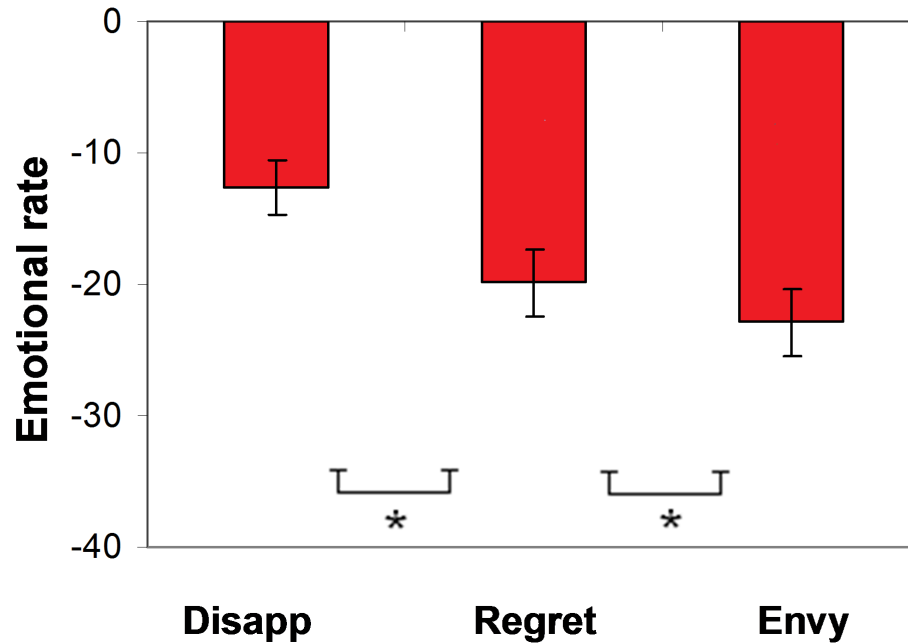
| | ASD patients | TD controls |
|--|---------------------|--------------------|
| Age (years) | 31.7 ± 10 | 25.4 ± 8.4 |
| Gender (F/M) | 2/13 | 4/25 |
| Education (years) | 14 ± 2.9 | 14.3 ± 2 |
| Full Scale IQ | 107.8 ± 19.9 | – |
| Verbal IQ | 113.1 ± 23.4 | – |
| Performance IQ | 98.8 ± 15.5 | – |
| AQ (pathological threshold: 30) | 30.78 ± 7.25 | 15.19 ± 5.55 |
| Comparison Test (scale from 0 to 55) | 37.80 ± 6.46 | 34.18 ± 7.32 |
| Counterfactual Reasoning Test (scale from –4 to 4) | 1.5 ± 1.9 | 1.43 ± 1.43 |

Table 3.2: Participants Data

$P = 0.009$) whereas there was no significant difference between emotional rate associated to joy and relief.

Under social conditions, the associated emotions received a stronger rating, than their emotional counterpart in the private player trial. Specifically, gloating was stronger than relief (*Wilcoxon*, $Z = 3.88$, $P = 0.000$), and envy was stronger than regret (*Wilcoxon*, $Z = 2.11$, $P = 0.034$). This shows that for typically developing individuals counterfactual comparison amplifies the intensity of negative emotions, and that social comparison enhances the intensity of both negative and positive emotions. Contrastingly, the shared emotions in the social trials had a weaker rating than their single player correspondent did: relief was stronger than shared relief (*Wilcoxon*, $Z = 3.94$, $P = 0.000$), and regret was stronger than shared regret (*Wilcoxon*, $Z = 3.85$, $P = 0.000$).

TD CONTROLS: NEGATIVE EMOTIONS



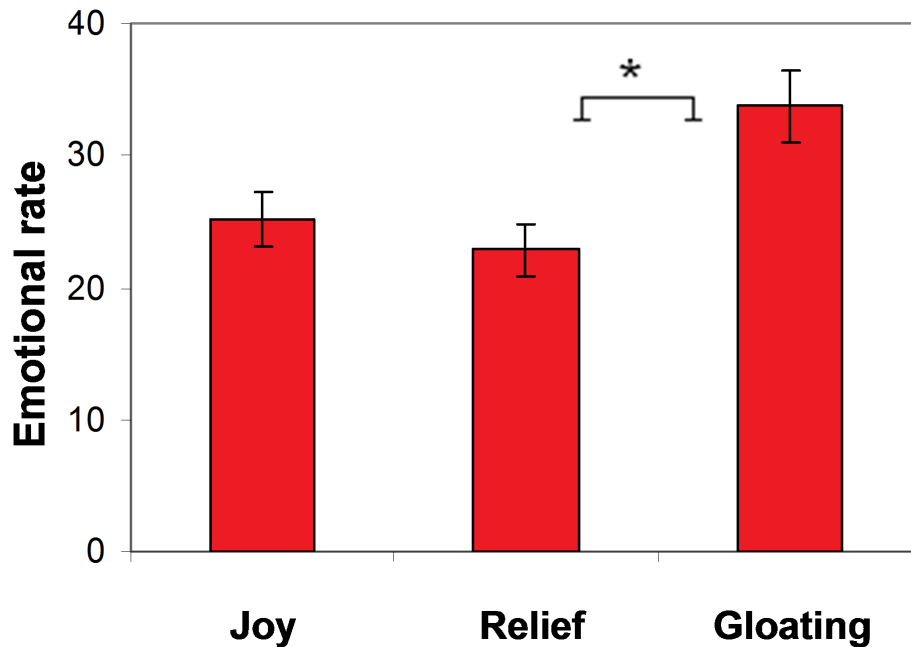
((a)) Disappointment was observed in *Partial/Private* conditions, regret in *Complete/Private* conditions, and envy in *Complete/Social* conditions

((b)) The bars represent the average value ($\pm SEM$) of the subjective emotional evaluation given by participants in the different events

((c)) The emotion associated to each condition is indicated on the x-axis, the emotional rate is indicated on the y-axis. * : $P < 0.05$

Figure 3.7: Negative emotions scored by *TD* Controls

TD CONTROLS: POSITIVE EMOTIONS



((a)) Joy was observed in Partial/Private conditions, relief in Complete/Private conditions, and gloating in Complete/Social conditions

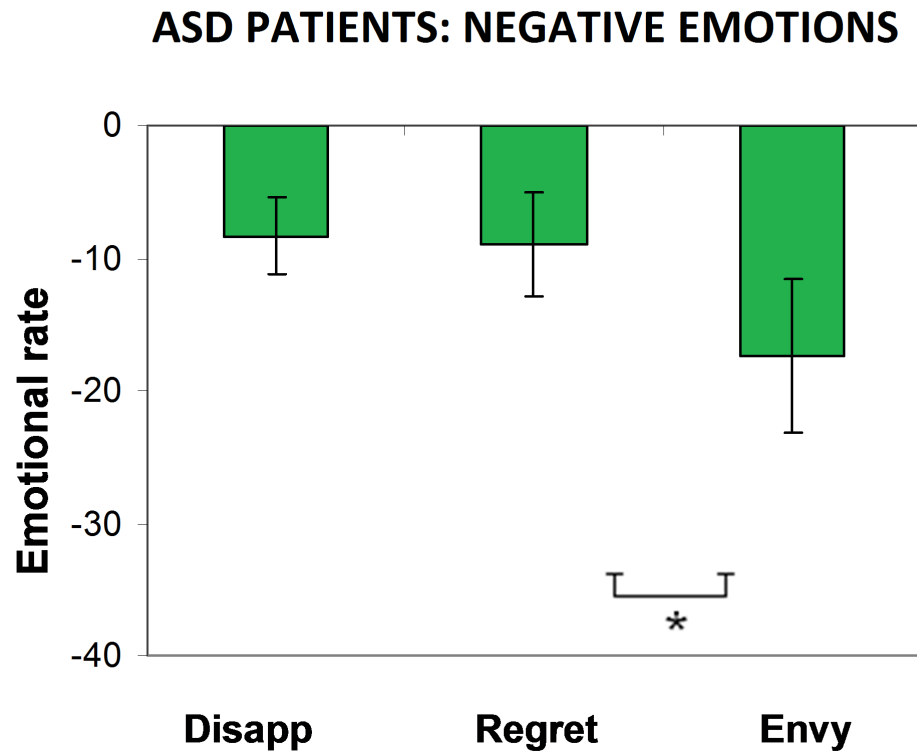
((b)) The bars represent the average value ($\pm SEM$) of the subjective emotional evaluation given by participants in the different events

((c)) The emotion associated to each condition is indicated on the x-axis, the emotional rate is indicated on the y-axis. * : $P < 0.05$

Figure 3.9: Positive emotions scored by *TD* Controls

In the group with *ASD* (3.11, 3.13) the results of self evaluation of emotional state showed that contrary to what was observed in the control group regret was no stronger than disappointment and also no significant difference between emotional rate associated to joy and relief was observed. In the two players condition gloating was stronger than relief (*Wilcoxon*, $Z = 2.69$, $P = 0.007$), and envy was stronger than regret (*Wilcoxon*, $Z = 2.20$, $P = 0.027$). Furthermore, the shared regret in the two player trials had a significantly higher rate than their single player correspondent

-i.e. the regret- did (*Wilcoxon*, $Z = 3.05$, $P = 0.002$). Indeed, shared regret received an average positive score, whereas it received an average negative score by controls. Any significant difference was observed between relief and shared relief.



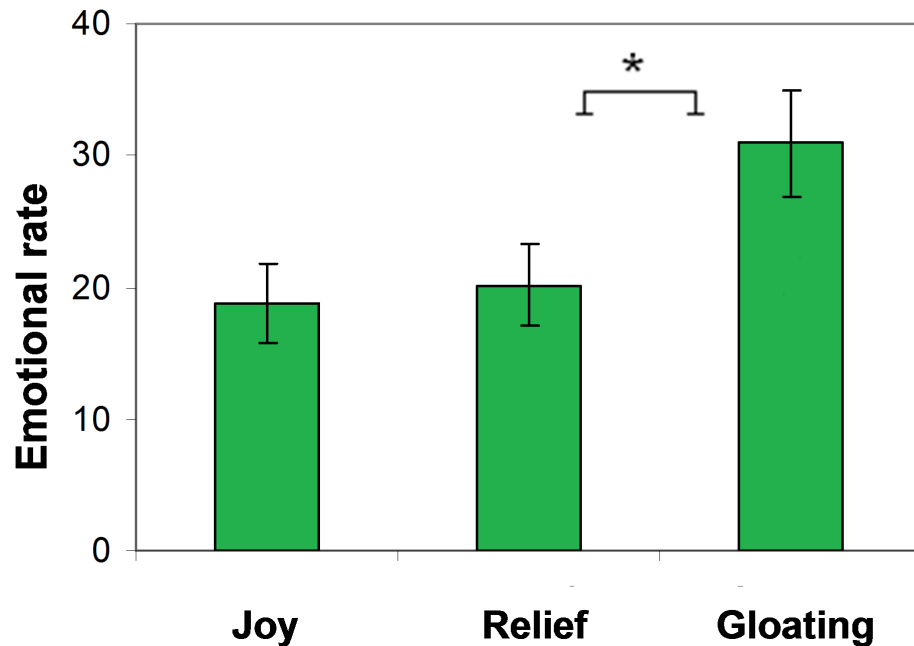
((a)) Disappointment was observed in *Partial/Private* conditions, regret in *Complete/Private* conditions, and envy in *Complete/Social* conditions

((b)) The bars represent the average value ($\pm SEM$) of the subjective emotional evaluation given by participants in the different events

((c)) The emotion associated to each condition is indicated on the x-axis, the emotional rate is indicated on the y-axis. * : $P < 0.05$

Figure 3.11: Negative emotions scored by *ASD* patients

ASD PATIENTS: POSITIVE EMOTIONS



((a)) Joy was observed in *Partial/Private* conditions, relief in *Complete/Private* conditions, and gloating in *Complete/Social* conditions

((b)) The bars represent the average value ($\pm SEM$) of the subjective emotional evaluation given by participants in the different events

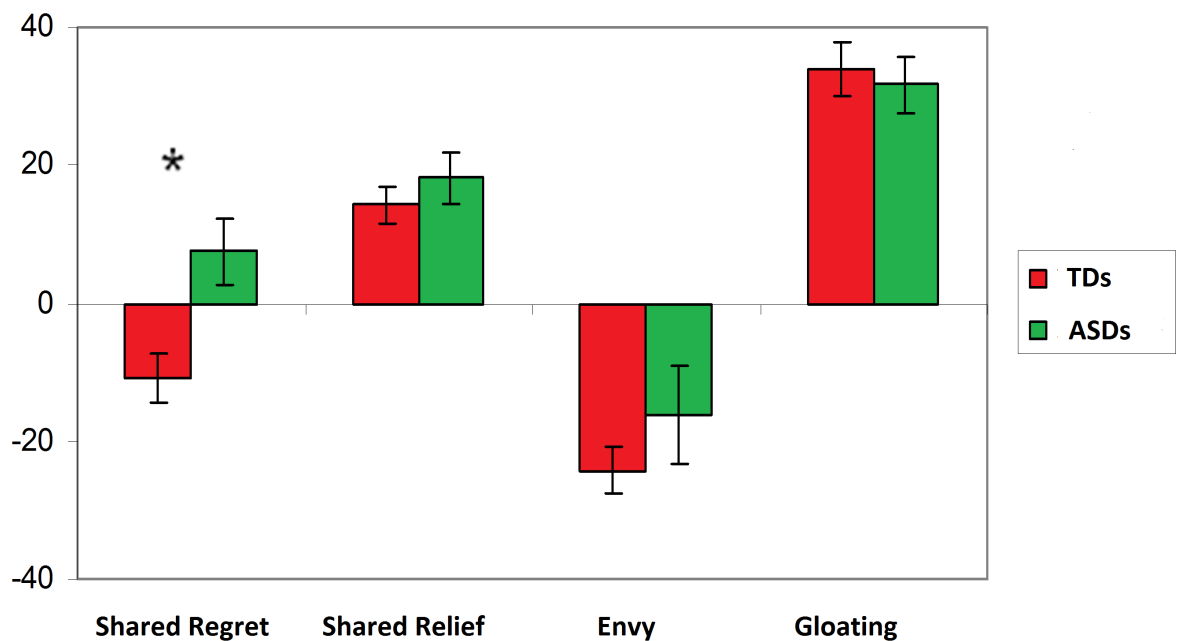
((c)) The emotion associated to each condition is indicated on the x-axis, the emotional rate is indicated on the y-axis. * : $P < 0.05$

Figure 3.13: Positive emotions scored by *ASD* patients

Comparing emotional rates of *ASD* subjects and *TD* controls: A T -test showed that the valence reported for regret was less emotionally intense for *ASD* subjects than by controls ($T = -2.39$, $P = 0.022$) in private, non-social conditions. However, no significant difference was found for the other non-shared emotions. Thus autistic individuals and *TDs* have a mutually intense and positive or negative valence for disappointment envy, gloating, relief and joy. Non-parametric and parametric tests yielded a significant difference between the two groups ($Z = -2.44$, $P = 0.007917$

for the *Mann and Whitney* test, $T = -2.82$, $P = 0.014297$ for the $T - test$) for shared regret, while no such difference was identified for the degree of valence for the other social emotions. In fact, strikingly, the autistic group actually reported a positive emotional response to shared regret, while controls reported an approximately equal negative emotional response. This suggests that *ASD* subjects have a modified perception of shared regret. Notably this difference is not due to the presence of outsider subjects, as the difference is not observed with other social emotions.

EMOTIONAL RATING IN THE SOCIAL CONDITION



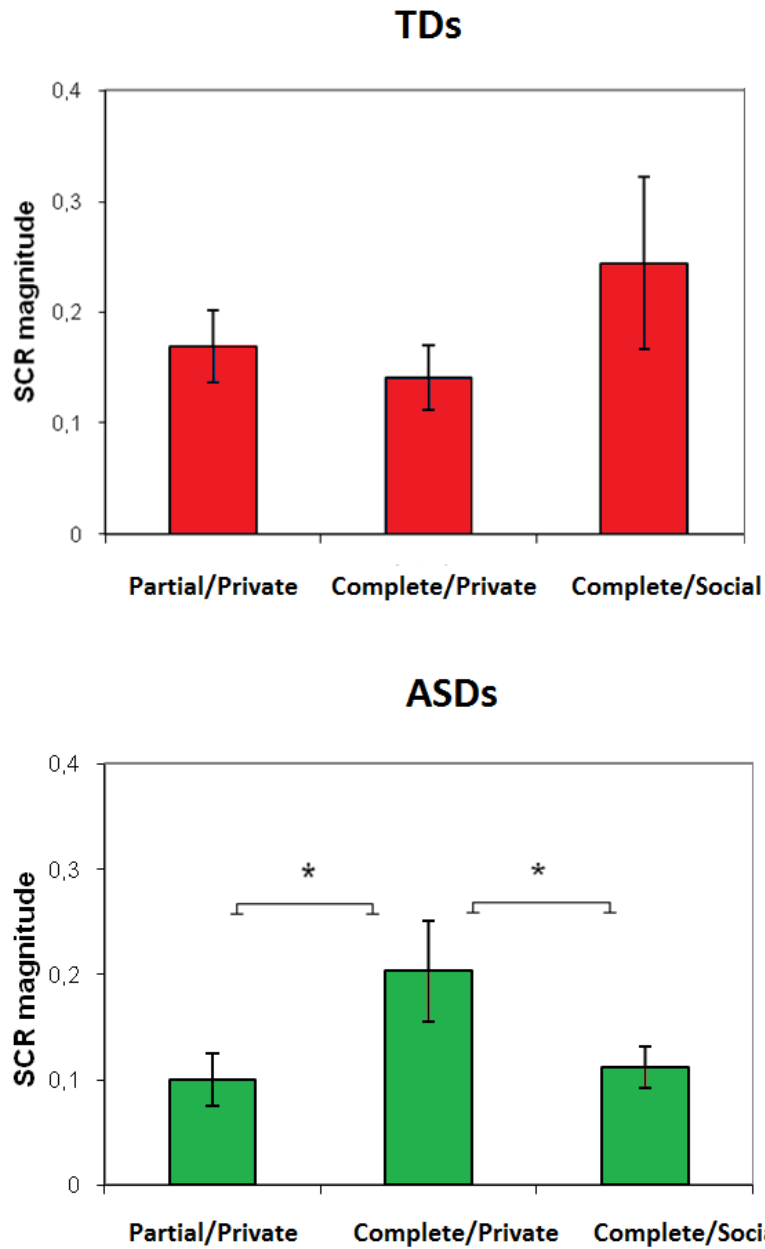
((a)) The bars represent the average value ($\pm SEM$) of the subjective emotional evaluation given by participants in the different events

((b)) The emotion associated to each condition is indicated on the x-axis, the emotional rate is indicated on the y-axis. * : $P < 0.05$

Figure 3.15: Emotional responses: Average subjective emotional evaluations in *socialconditions*

3.5.3 Skin Conductance Response (*SCR*)

Through measuring participants' skin conductance responses (*SCRs*) throughout the experiment we were able to assess the physiological arousal associated with the outcome evaluation for the various event conditions. At the moment of outcome presentation, no difference was detected across the conditions by control subjects 3.17). Although the absence of significant difference a greater *SCR* was noted in social condition. With *ASD* subjects a greater *SCR* was observed in *Complete/Partial* condition 3.17 than in *Partial/Private* (*Wilcoxon*, $P = 0.000$), and *Complete/Social* conditions. (*Wilcoxon*, $P = 0.001$).



((a)) The bars represent the *SCR* magnitude in microsiemens after the outcomes of the lotteries were displayed

((b)) Data are classified by condition: *Partial/Private*; *Complete/Private*; *SSC*, and *SDC*

Figure 3.17: Magnitude of *SCR* at the moment of the outcome presentation: *TD* controls and *ASD* patients

3.6 Discussion

Counterfactual Emotions

Another important result is that when asked to evaluate their emotional reactions on the scale, people with *ASD* did not seem to differentiate disappointment and regret whereas regret was judged as being more negative than disappointment by controls. While in the control group counterfactual comparison amplified the intensity of negative emotions, in the group with *ASD* this comparison do not seem to generate any amplification of the valence of emotion reported on the scale. This finding suggests that experience of regret in subjects with *ASD* differ from that of the control group.

Importantly, our results indicate that counterfactual reasoning is not impaired in *ASD* subjects but it is not associated with an emotional amplification, as observed in the control group. Thus, the weaker effect of the affective response following the counterfactual reasoning usually inducing the experience of regret could be associated with a diminished sense of responsibility. To test this hypothesis, we administered a supplementary questionnaire to our six last subjects.

The results showed that *ASD* subjects felt globally less responsible for their losses than controls. Moreover the feeling of responsibility was intensified in controls when comparing their gain to the gain of the other wheel or to the other participant's gain; in contrast *ASD* subjects's experience of this emotion was not as intense as the control participants's. On the basis of our results further studies are needed to investigate the hypothesis of a diminished sense of responsibility in subjects with *ASD*.

Shared Counterfactual Emotions

In the present study we found that it is more rewarding to win when one's counterpart is losing than to win when one's counterpart is also winning in both the *ASD* and

TD groups. Dvash [Dvash et al., 2010] compared the activations between an actual gain and a relative gain (in comparison with a counterpart's gain). Their results suggest that the ventral striatum plays a role in mediating the emotional consequences of social comparison. Reward circuitry has been implicated in autism [Langen et al., 2009, Schmitz et al., 2008, Scott-Van Zeeland et al., 2010, Dichter et al., 2012] but our results, in line with Dvash et al. [Dvash et al., 2010], indicate an intact function of the ventral striatum in autism.

Moreover shared regret induced a stronger positive emotion in *ASD* persons, suggesting that they have an abnormal perception of shared regret. For *ASD* persons making the same choice than another person is more positive than the fact of losing is negative. This finding is not in accordance with previous literature showing a lack of empathic behaviors and a diminished social motivation. Hence, alternatively, one could argue that a diminished self-confidence along with a strong social motivation might explain the fact that people with *ASD* experience shared regret as more positive than control subjects.

This hypothesis is consistent with the results of the comparison questionnaire, showing that *ASD* subjects are more prone to compare themselves to others in daily-life situations than individuals in the control group. These results are in part in contrast with some current theories of autism. Thus the motivation theory suggests that autistic subjects suffer from a motivation deficiency [Johnson et al., 2006] but other studies showed that both social and non-social reward significantly improved task performance [Geurts et al., 2008, Kohls et al., 2009]. Moreover Yirmiya [Yirmiya et al., 1992a] found that children with autism did surprisingly well on the empathy-related measures.

Social Counterfactual Emotions in *ASDs*

Interestingly and contrary to our expectations, people with *ASD* exhibited similar responses to controls in rating social emotions, such as envy and gloating, suggesting a similar evaluation of social emotions in people with *ASD*. A previous study indicated that people with *ASD* have difficulties in understanding envy and gloating when they have to read facial expressions. In a previous study [Shamay-Tsoory, 2008] difficulties were reported in a facial expression recognition task for envy, gloating and identification in individuals with *ASD*.

Difficulties in understanding the relationship between the emotional state depicted in an image and the displayed character's affective mental state is also found in patients with frontal lobe lesions, especial medial *PFC* lesions. The *mPFC* is involved in both social comparison and recognition of envy and gloating; the former function seems to be preserved whereas the latter appears to be impaired in people with *ASD* [Gilbert et al., 2009]. In comparison with our data, this highlights that recognizing an emotion in others is clearly a distinct cognitive process from experiencing and reporting one's own experience of the same emotion.

Since recognizing emotions require the empathic use of the Theory of Mind (*ToM*) network - *ToM* being the capacity to attribute mental states to the others and to implicitly take account of the fact that different people have different thoughts - which includes the *mPFC*, it is logical to assume typical that *ToM* functioning is impaired in attributing envy and gloating to others in *ASD* individuals. However, in our experiment we may assume that *ToM* functioning is not required for the social comparison that results in the personal experience of envy or gloating in *ASDs*.

SCRs

Another objective of this study was to investigate physiological reactivity during social comparison. In the present study we did not observe an increase of the *SCR* in *ASD* persons in social context, despite their preserved capacity to report social feelings. These inconsistencies make the present results inconclusive with respect to their ability to experience regret and social emotions. The question remaining is: does the *SCR* reflect the actual feelings of an individual? In autistic people reports have been made of normal physiological emotion processing, along with an altered affective report, in line with Ben Shalom et al. [Ben Shalom et al., 2006].

On the other hand, they can also present a preserved ability to report their feeling with an altered autonomic processing [Bölte et al., 2008, Hubert et al., 2009, Khalifa and Peretz, 2007]. *ASD* persons may rely on different cognitive strategies in appraisal of emotional and social situations because of an altered autonomic processing or of a disconnection syndrome affecting the cognitive and emotional interactions. Yechiam [Yechiam et al., 2010] showed that individuals with *ASD* have a particular adaptive learning style, which may be beneficial in some learning environments but maladaptive in others, particularly in social contexts.

Indeed, in the present study we showed a preserved ability to use counterfactual and social comparison in *ASD* persons, whereas their skin conductance responses did not corroborate their feelings report. Thus *ASD* subjects' choices could be based on more rational cognitive strategies and less on affective (visceral) components. Control subjects had a more important arousal when confronted to a more complex situation, which is not the case for autistic persons. We can postulate that *AS* individuals use rational cognitive strategies in decision-making, instead of using their experienced feelings.

Decision Making and Risk Aversion

Importantly, we found a risk-averse behavior in *ASD* subjects, which is in accordance with Johnson [Johnson et al., 2009], suggesting that children and adolescents with *ASD* demonstrate a risk-averse decision-making pattern across tasks. We also observed that *ASD* subjects' decision making was sensitive to the lotteries' expected value, but to a lesser extent compared to controls. This view is not consistent with de Martino et al.'s study [De Martino et al., 2008], which found a more important influence of expected value in autistic subjects than in controls.

This could be explained by the fact that our task involved several factors: emotions and especially subjective feeling, social cognition and the notion of attribution (i.e. the cognitive part of the theory of mind) and decision making associated to the gain motivation. These three domains are in a dynamic interaction, making the analysis more difficult. We can postulate that the involvement of these several factors may explain that we did not replicate de Martino et al.'s results concerning the influence of the expected value. Thus the influence of the framing bias by *ASD* subjects remains to be investigated.

3.7 Conclusions

The present results suggest a dissociation between physiological responses and subjective experience in *ASD* subjects. The subjective experience of emotions might be disrupted in autism, especially for regret and shared regret. Interestingly and contrary to our expectations, when appraisal arose in a social context, subjective reports in subjects with *ASD* did not differ from controls'.

Our results also indicate that counterfactual reasoning is not impaired in *ASD* subjects but it is not associated with an emotional amplification, as observed in the

control group. Control subjects had a more important arousal when confronted to a more complex situation, which is not the case for autistic persons. We can postulate that AS individuals use rational cognitive strategies in decision-making, instead of using their experienced feelings.

The present study suggests that individuals with *ASD* have a major difficulty to integrate cognitive and visceral information during decision making but does not allow to conclude about their ability to use counterfactual reasoning and social comparison in their decision-making, and to experience regret and social emotions, because of the difficulty to define which feeling they are actually experiencing. Meanwhile, the present study can be regarded as an opening on this interesting line of research.

3.7.1 Fitting our Study within Related Literature

The research focusing primarily on the link between counterfactuals and decision making [Roese, 1999, Tsiros and Mittal, 2000] and the studies incorporating counterfactual emotions in decision models (the case of regret in particular) [Bell, 1982b, Grant et al., 2004] along with the *fMRI* studies proposing models of regret and other counterfactuals based on neural underpinnings of such emotions during decision making [Bechara, 2000], fails to account for the real characteristics of counterfactual emotions as to how they are perceived, acknowledged and processed [Camille et al., 2004]. Some studies, although showing that counterfactual reasoning is intact in both children [Scott et al., 1999, Perner et al., 2004] and adults with *ASDs*, fail to account properly for the under-reported counterfactual emotions in this population.

Along with our experiment, some other studies did attempt to challenge the typical assumptions made on counterfactual emotions in general and regret in particular, but have not been taken into account for a reviewed regret model as of yet. Shalom shows in an experiment with typical and autistic children that "impairments in socio-

emotional expression in autism may be related to deficits in perception and/or expression of conscious feelings; physiological emotions may be relatively preserved" - given that skin conductance responses differed from self-reports in the autistic participants, a discrepancy present also in our experiment [Ben Shalom et al., 2006]. Another study proved "altered physiological reactivity and affective report in autism, which may be related to more general impairments in socio-emotional functioning" [Bölte et al., 2008].

In a similar line of thought, Shamay-Tsoory et al. show that the mentalizing network plays an important role in mediating the understanding of such emotions as envy and gloating [Shamay-Tsoory et al., 2007], but failed to prove the intact ability of *ASD* individuals to identify envy and gloating by using eye-gaze measures and mentalizing tasks [Shamay-Tsoory, 2008].

It has been shown that the autistic population develops different strategies for their counterfactual reasoning as compared to healthy controls [Begeer et al., 2009, Begeer et al., 2012], but these studies may have overlooked the real reason behind a lower self-report of downward counterfactual emotions, such as contentment and relief (the upward counterfactual reasoning - disappointment, regret - being considered intact as they were similar to typical development children's measures). The studies reporting alexithymia in the autistic population are also of great importance in redefining the assumptions made on regret and other counterfactuals, and on emotion labeling and regulation in general [Samson et al., 2012].

Our experiments take a step ahead in the attempt to disentangle the perception (input) of counterfactual emotions, their processing and their conscious acknowledgment (reporting) within typical development individuals and *ASD* patients and to determine the disruption points at any level they commonly occur.

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Estratto per riassunto della tesi di dottorato

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Thesis Title: Essays on Decision Making by Children and Adults on the Autistic Spectrum

Abstract: This thesis presents three essays on decision making by autistic individuals. In the first chapter we draw on the studies germane to decision making and autism to provide an extensive review focused on such crucial aspects as mentalizing, decision making under risk and uncertainty, learning in Autistic Spectrum Disorders (social learning; reinforcement learning), time (concept of time; intertemporal choice) and counterfactual emotions 1. The review is followed by two related experimental studies with patient population: 'Effects of Counterfactual Emotions on Decision Making of Individuals on the Upper End of the Autistic Spectrum' 2 and 'Insights on Counterfactual Emotions of Autistic Individuals within Social Contexts' 3.

There is a big array of feelings and counterfactual emotions which could result from assessing the outcome of social comparisons against ourselves and/or others. How do the individuals with autistic spectrum disorders process counterfactual emotions? Are they able to experience regret and relief, disappointment and joy? Are they able to account for these emotions? Do they process them the same way as the individuals with typical development? What do individuals on the autistic spectrum feel when comparing themselves to other people in a social context? And how do they process these social comparison emotions?

We inquire into the behavioral and skin conductance responses within an autistic patient group and a typical development (*TD*) control group matched demographically, educationally and *IQ*-wise. We employ a gambling task to look into the participants' choices along with their subjective reports on the labeling of the emotion felt and intensity of their feelings. We learned that while the *TD* controls experienced regret more intensely than disappointment, there was not significant difference in the intensity of these two emotions for the *ASD* patients in our first experiment.

Strikingly, in the private conditions the *ASD* patients accounted for weaker regret as compared to the *TD* controls, but increased shared regret associated with very positive feelings in the social condition. Still, in a social context appraisal, the subjective accounts in participants with *ASD* are not different from those of *TD* controls', implying preserved social feelings in the context of social comparison for the autistic individuals. Surprisingly, skin conductance responses mainly contradicted the subjective self-reports, showing more intense activity in the condition eliciting regret or relief, and less intense responses in the social context condition. Hence our results endorse the fact that individuals with *ASD* experience disruptive emotion processing and fail to fully integrate cognitive input and intrinsic information during decision making.

Titolo della tesi: Saggi sulla Presa di Decisione in Bambini ed Adulti sullo Spettro Autistico

Estratto: Questo saggio presenta tre saggi sulla presa di decisione in individui sullo spettro autistico (*SA*). Nel primo capitolo compiliamo un'estesa rassegna degli studi pertinenti alla presa di decisione e l'autismo, focalizzandoci su aspetti cruciali quali la "mentalizzazione", la presa di decisione quando vi sono rischi o incertezza, l'apprendimento (sociale e per rinforzo), la percezione del tempo (i.e. il concetto di tempo, decisioni intertemporali) e le emozioni controfattuali 1. La rassegna è seguita da due esperimenti su popolazioni affette da autismo: 'Effetti delle emozioni controfattuali sulla presa di decisione in individui nell'estremo superiore dello spettro autistico' 2 e 'Emozioni controfattuali in individui con autismo in contesti sociali' 3. V'è una vasta gamma di sensazioni ed emozioni controfattuali che possono risultare dall'esito di confronti sociali su noi stessi ed altri. Come sono processate tali emozioni in individui con autismo? Sono capaci di esperire rimpianto o il sollievo, il disappunto e la gioia? Sono consapevoli di queste emozioni? Le processano allo stesso modo degli individui con sviluppo tipico? Cosa provano gli individui sullo spettro autistico quando si confrontano con gli altri in contesti sociali? E come processano tali confronti sociali? Per rispondere a tali domande, confrontiamo il comportamento e le risposte fisiologiche (i.e. conduttanza galvanica) in soggetti con autismo e soggetti con sviluppo tipico (*ST*), accoppiandoli per età, *QI*, educazione ed altre variabili demografiche. Utilizziamo un gioco d'azzardo per esaminare il tipo di scelte compiute, come i soggetti classificano le emozioni provate, e quanto le ritengono intense.

Nel nostro primo esperimento scopriamo che, mentre i controlli *ST* provano rimpianto più intensamente del disappunto, ciò non vale per i soggetti *AS*. Inoltre, sorprendentemente, mentre in condizioni private gli individui *AS* provano meno rimpianto dei controlli *ST*, in contesti sociali, provano più rimpianto condiviso, e lo associano a sensazioni positive. Ciononostante, quando esplicitamente interrogati, individui *AS* ed *ST* non differiscono nella loro esperienza soggettiva di tali eventi. Ne segue che le loro sensazioni in contesti sociali sono preservate. Tuttavia, e sorprendentemente, le risposte galvaniche contraddicono le autovalutazioni, esibendo un'elevata attività nelle condizioni di rimpianto e sollievo, e attività ridotta nelle condizioni sociali. In sintesi, i nostri risultati suggeriscono che individui sullo spettro autistico processano emozioni in modo frammentario e non riescono ad integrare informazioni ausiliarie intrinseche al contesto nella loro presa di decisione.