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Research report

Feelings of regret and disappointment in adults with high-functioning autism

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ABSTRACT

Impairments in emotional processing in Autism Spectrum Disorders (ASDs) can be characterised by failure to generate and recognize self-reflective, cognitive-based emotions, such as pride, embarrassment and shame. Among this type of emotions, regret and disappointment, as well as their positive counterparts, result from a counterfactual comparison, that is the comparison between an actual value ("*what is*") and a fictive value ("*what* might have been"). However, while disappointment is experienced when the obtained outcome is worse than the expected outcome that might have occurred from the same choice, regret occurs when one experiences an outcome that is worse than the outcome of foregone choices. By manipulating a simple gambling task, we examined subjective reports on the intensity of negative and positive emotions in a group of adults with High-Functioning Autism or Asperger syndrome (HFA/AS), and a control group matched for age, gender and educational level. Participants were asked to choose between two lotteries with different levels of risk under two conditions of outcome feedback: (i) *Partial*, in which only the outcome of the chosen lottery was visible, (ii) *Complete*, in which the outcomes of the two lotteries were simultaneously visible. By comparing partial and complete conditions, we aimed to investigate the differential effect between disappointment and regret, as well as between their positive counterparts. Relative to the control participants (CP), the group with HFA/AS reported reduced regret and no difference between regret and disappointment, along with a preserved ability to use counterfactual thinking and similar choice behaviour. Difficulties to distinguish the feeling of regret in

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participants with HFA/AS can be explained by diminished emotional awareness, likely associated with an abnormal fronto-limbic connectivity.

1. Introduction

Individuals with Autism Spectrum Disorders (ASDs) are characterized by qualitative impairments in the domains of social interaction, communication, and stereotyped behaviour. Diagnostic criteria for ASDs, as defined by the DSM 5 (American Psychiatric Association, 2013), the Revised Autism Diagnostic Interview (ADI-R) (Lord, Rutter, & Le Couteur, 1994) and the Autism Diagnostic Observation Scale (ADOS, Lord et al., 2000), all include difficulties in emotional processing. Recently, there has been a considerable progress in the understanding of the socio-emotional nature of impairments in ASDs and an increasing number of studies has acknowledged the idea that individuals with ASDs exhibit both difficulties in mindreading and in processing self-related knowledge (Lombardo et al., 2009; Millward, Powell, Messer, & Jordan, 2000; Willians, 2010). Indeed, difficulties both in reporting own past thoughts and in keeping track of prior intentions have also been reported in individuals with High-Functioning ASDs (Hurlburt, Happe & Frith, 1994; Phillips, Baron-Cohen, & Rutter, 1998). Noteworthy, disturbances in understanding others' affective states in ASDs often arise when the appreciation of the emotion requires the representation of others' beliefs, such as surprise or embarrassment (Zalla, Stopin, Ahade, Sav, & Leboyer, 2009), but not when emotions are generated by factual events (i.e., reality-based emotions) (Baron-Cohen, 1991; Baron-Cohen, Spitz, & Cross, 1993).

Concerning self-related knowledge, children with autism possess a less coherent representation of their own emotional experiences, and they may also be less able to generate and regulate emotionally laden situations introspectively or in interaction with others (Rieffe, Meerum Terwogt, & Kotronopoulou, 2007). Previous studies also revealed that children with autism have difficulties with emotions related to introspection and self-reflection, such as pride, guilt, or shame (Capps, Sigman, & Yirmiya, 1995; Kasari, Chamberlain, & Bauminger, 2001) and suggested that failure to distinguish emotional experiences would stem from a lack of reflective appraisal of those experiences (Harris, Olthof, Meerum Terwogt, & Hardman, 1987). Overall, these findings support the view that emotional responses are not normally integrated with cognitive processes in ASDs and that this might result from a diminished introspective awareness about one's own intentional and affective states, leading to serious consequences in the development of self-other relations.

Recent reports have underlined that there is a considerable overlap in the clinical presentation of persons with a diagnosis of Asperger's Syndrome and alexithymia, a condition characterized by difficulties in identifying ones' own emotions, feelings and bodily sensations, and to use them in communication and to regulate interpersonal exchanges (Fitzgerald & Bellgrove, 2006; Hill, Berthoz, & Frith, 2004; Hill & Berthoz, 2006). Precisely, it has been estimated that somewhere between 40% and 50% of the ASD population is affected by alexithymia, (Fitzgerald & Bellgrove, 2006; Hill et al., 2004). Remarkably, while high level of Alexithymia is associated with diminished mentalizing abilities in non-autistic individuals (Moriguchi et al., 2006), in ASD individuals, it may be associated with abnormal empathic brain responses, poorer facial emotion recognition and atypical gaze fixations, suggesting that difficulties in introspecting on own emotions and aspects of the reciprocal social impairments in ASDs share a common neuro-cognitive basis (Bird et al., 2010, Bird, Press, & Richardson, 2011). Silani et al. (2008) reported that, differently from controls, individuals with HFA/AS showed reduced activation of the anterior insula, when they were asked to introspect on their feelings. Interestingly, in this study, behavioural measures of self-reported alexithymia and lack of empathy were correlated, indicating a link between understanding one's own and others' emotions.

These findings are mainly based on social emotions, but little is known about emotional impairments of ASD individuals in private settings. Our study aimed to fill this gap. In the present study, we investigated whether the observed impairments of ASD individuals in self-reflective emotional responses are present also in private contexts, where self-reflection should be independent from any social interaction. To do so, we measured self-reported affective responses to (private) events that differ in terms of the level of subjective responsibility for the outcome of one's own choice. These events can be associated with the emotions of disappointment and regret and their positive counterparts.

Disappointment and regret are common self conscious, cognitive-based, unpleasant experiences arising when the current state of affairs is worse than initially expected. Both emotions originate from a comparison processes in which the outcome obtained is compared to the outcomes that might have occurred. However, despite these commonalities, these *counterfactual* emotions differ on the basis of several characteristics. While disappointment (and its positive counterpart, joy) is experienced when the obtained outcome is worse than un-obtained outcomes from the chosen option, in a *within-option* comparison; regret (and its positive counterpart, relief) results from a *between-choice* comparison, thus a comparison between the outcome of a choice (*"what is"*) and *"what could have been if I had chosen another option"*. The experience of regret is focused on the alternative *choice* rather than on the alternative *outcome*: we experience regret when realizing or imagining that our present situation would have been better, had we decided differently (Zeelenberg, van Dijk, & Manstead, 1998). The difference between these two emotions is normally reflected in the amplification of the self-reported affective responses (e.g., regret is reported as

more negative than disappointment) in individuals with typical development (Camille et al., 2004; Coricelli et al., 2005; Zeelenberg, van Dijk, & Manstead, 1998; Zeelenberg, van Dijk, Manstead, & van der Pligt, 1998; Zeelenberg & van Dijk, 2004). The lack of the ability to grasp the differences between regret and disappointment in individuals with ASD would reflect difficulties in self-reflecting emotional processing in private settings.

Neuropsychological and neuroimaging studies highlighted the role of the orbito-frontal cortex (OFC) (Camille et al., 2004; Coricelli et al., 2005) and the amygdala in the affective responses associated with regret – inducing events (Nicolle, Bach, Frith, & Dolan, 2011) and the experience of winning and losing (Zalla et al., 2000). In a previous study, Camille and collaborators (2004) showed that while patients with damage to the OFC were able to think counterfactually on the chosen gamble and could experience disappointment, they did not experience regret. The authors concluded that since OFC integrates the cognitive and the emotional components for the process of decision making, a dysfunction of this region would affect the ability to generate and modulate specific cognitive-based emotions, such as regret. Furthermore, Nicolle et al. (2011) showed that the subjective evaluation of regretful events is not just a function of being the agent of a choice, but specifically depends upon level of subjective responsibility for the outcomes of one's own actions. The authors reported that regret-related neuronal activity in the amygdala was enhanced by increased responsibility: the effect was magnified in participants who displayed a greater enhancement of their subjective ratings of regret by responsibility, suggesting a critical role of this structure in self-blame regret.

The amygdala is supposed to play a central role in the etiopathology of ASDs and several theoretical explanations compatible with the amygdala dysfunction have been proposed to account for socio-emotional impairments, including abnormal eye contact, poor recognition of fear and other negative emotions, face processing, mental state understanding and empathy (Amaral, Bauman, & Schumann, 2003; Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Baron-Cohen et al., 2000; Kim et al., 2010; Kliemann, Dziobek, Hatri, Baudewig, & Heekeren, 2012; Zalla & Sperduti, 2013). As posit by the "Relevance Detection Theory" (Sander, Grafman, & Zalla, 2003), the human amygdala is a component of this extended neural cortico-limbic system involved in detecting stimuli by focussing attentional and physiological resources on cues that have special relevance for the safety or success of an organism within the broader context of its social life. Zalla and Sperduti (2013) suggested that several behavioural and social–emotional features of ASDs could be explained in terms of a disruption of a "Relevance Detector Network" affecting the processing of stimuli that are relevant for the organism's self-regulating functions.

The present study investigated whether individuals with HFA or AS may lack the ability to distinguish between the experience of regret and disappointment. Because of the severe difficulties in emotional competences and, in particular, in recognizing self-relevant emotions in individuals with HFA/AS, we expected them to encounter difficulties differentiating between the feelings of *regret and disappointment*, and to use anticipatory emotions to regulate choice behaviour.

To elicit feelings of regret and disappointment – and their positive equivalents, relief and joy – we used a gambling task in which a group of adults with HFA/AS and a control group were presented with a choice between two risky gambles associated with a monetary reward, and asked to report the valence and the intensity of their emotional responses to the outcome of their choice by using a rating scale.

As previously shown (Camille et al., 2004), the same obtained outcome will lead to different experienced 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 supposed to experience disappointment, when the obtained value is lower than expected, and joy, when the obtained value is greater than expected. In contrast, in the complete condition in which outcomes from the two gambles are available, knowledge of the unselected outcome would strongly modulate the effect of the selected gamble, eliciting the experiences of regret or relief. Because of the different types of counterfactual thinking involved under complete and partial feedback conditions (i.e., either across alternative choices or alternative states of the world), we expected different emotional responses, which vary in valence and intensity. Because the ability to engage in counterfactual reasoning is a cognitive requirement for the experience of regret, we evaluate counterfactual thinking using the *counterfactual inference test* proposed by Roese and Olson (1995) to discount the hypothesis that difficulties to introspect and self-report on their feelings would be due to an impairment in inferential reasoning.

2. Material and methods

2.1. Participants

Twelve adults with a clinical diagnosis of Asperger Syndrome or High-Functioning Autism (HFA/AS) according to DSM-IV-TR (American Psychiatric Association, 2000) and Asperger Syndrome Diagnostic Interview (ASDI, Gillberg, Gillberg, Råstam, & Wentz, 2001) and the ADOS (Lord et al., 2000) were recruited from Albert Chenevier Hospital in Créteil (Table 1). The inclusion and exclusion criteria for the clinical group were based on retrospective parental information about the early language development of their child. All diagnoses were made by experienced clinicians and were based on clinical observations of the participants. Semistructured interview with parents or caregivers using the (ADI-R, Lord et al., 1994) yielded scores in three content areas: [B] social interaction, [C] communication, and [D] repetitive and stereotyped behaviours, allowing the separate quantification of severity of the symptomatology. The cut-off points for these domains are 10, 8, and 3, respectively. All participants scored above the cut-off points.

Twelve control participants (CP) with typical development volunteered to match the clinical group with respect to age, educational level and gender (Table 1). Prior to their recruitment, the CP were screened to exclude any with a history of psychiatric or neurological disorders. All participants were

Table 1 – Means (and standard deviations) of demographic and clinical data for participants with HFA/AS and the CP.

	HFA/AS	Controls
N (male:female ratio)	11:1	9:3
Age in years (mean, SD, range)	28.9 ± 9.5	29.3 ± 9.3
Education in years (mean, SD)	14.4 ± 3.5	14.5 ± 3.4
ADI [B,C,D][a]	18.6 (6.8); 11.6 (6.6); 6.9 (3.2)	–
Full-scale IQ	103.3 (±23.2)	105.9 (±12.2)
Verbal IQ	108.3 (±25.7)	104.6 (±15.6)
Performance IQ	96.3 (±17.8)	106.3 (±11.6)

[a] [B] = reciprocal social interaction, [C] = communication, [D] = stereotyped behaviours.

native French speakers, and had normal/corrected to normal vision.

They received basic neuropsychological screening, which included Verbal and Performance IQs (WAIS-III) (Wechsler, 1997). All participants had an IQ above 70. The two groups did not differ on gender (t-test: $t(22) = 1.1$, $p = .29$), chronological age (t-test: $t(22) = .11$, $p = .91$) and education (t-test: $t(22) = -.19$, $p = .84$) and IQ level (Full-scale, Verbal and Performance: t-test: $t(22) = .34$, $p = .73$; $t(22) = -.42$, $p = .67$; $t(22) = 1.63$, $p = .11$).

The present research has been approved by the local Ethical committee (Inserm, Institut Thématique Santé Publique; C07-33). All participants signed informed consent agreements before volunteering for this study, and all investigation complied with APA ethical standards.

2.2. *Procedure*

2.2.1. *The Gambling task*

All participants were individually tested in a quiet room at the Albert Chenevier Hospital in Créteil. Participants were sitting in front of a computer and were told that they had to play a Gambling task by choosing between two wheels associated with different amount of money (Fig. 1). We explained to the participants that earnings were hypothetical.

The experiment is 2 × 2 factorial design, with two levels of valence – relative gains and relative losses – and two feedback conditions – partial and complete. At the beginning of each trial, two lotteries were displayed. Each wheel had two sectors (green and red) associated with different values or outcome pairs. The two possible outcomes are formed by any pair of the following values: +50, −50, +200, −200 (units correspond to cents of Euros), associated with different outcome probabilities (.8, .5, .2). The length of each sector is reflecting the associated probability. As shown in Fig. 1, in the left lottery, the probabilities are: 1/2 of chance to gain 50 cents; 1/2 of chance to lose 200 cents. In the right lottery the probabilities are: 1/5 of chance to gain 200 cents; 4/5 of chance to lose 200 cents. After the two lotteries appeared on the computer screen, participants were required to choose one of the two wheels by pressing one of two *arrow* keys of the keyboard (CHOICE). A rectangular green box appeared around the selected wheel (WAIT) and a rotating arrow appeared in the centre of the gamble circle (SPINNING), always stopping after

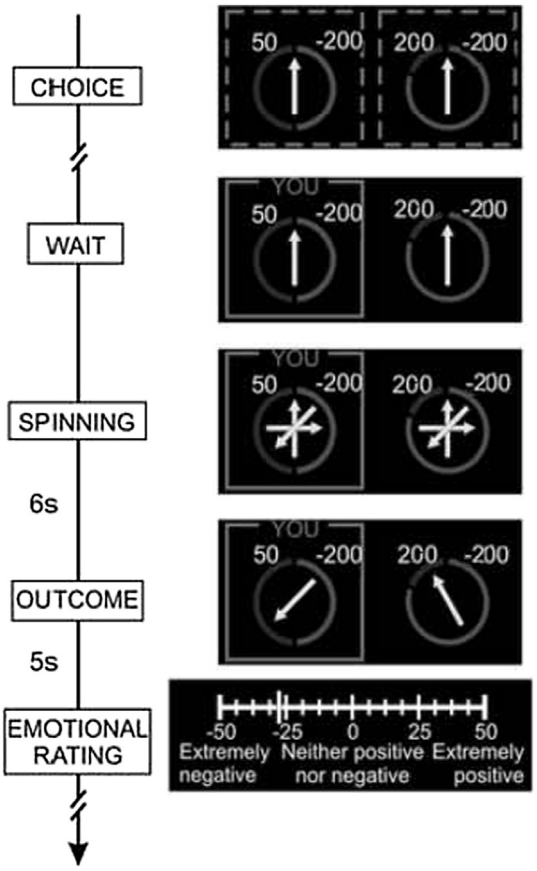

Fig. 1 – Timeline of a single trial (in complete feedback condition). At the beginning of each trial, two lotteries were displayed. Participants were required to choose one of the two wheels (CHOICE). A rectangular green box appeared around the selected wheel (WAIT) and a rotating arrow appeared in the centre of the gamble circle (SPINNING), always stopping after 6 sec (simultaneously stopping for both the selected and the unselected wheel). The arrows indicated the outcomes of the selected and the unselected gambles (OUTCOME). Participants were then asked to evaluate (EMOTIONAL RATING) the outcome of their choice on a scale ranging from −50 (extremely negative) to +50 (extremely positive). Timeline of Partial feedback condition was identical to the one depicted here. In partial feedback trials the spinning and feedback was restricted to the chosen gamble only.

6 sec. The outcome of the selected gamble was indicated by the resting position of the arrow (OUTCOME). Two types of trials were performed. In the "partial feedback" condition (30 trials), the outcome was presented only for the chosen gamble; in the "complete feedback" condition (30 trials), outcome of both the selected and unselected gambles (and spinning arrow) were available. In complete feedback condition the arrows of the chosen and the unselected gamble stopped simultaneously, indicating respectively the obtained outcome and the outcome of the foregone choice. At the end of each trial, participants were asked to give a subjective rating of their emotional response associated with the outcome of their choice (emotional scale ranging from −50, extremely

negative, to +50, extremely positive). The inter-trial delay was lasting 3 sec. Subjects played in total 60 trials. Each trial duration depended on the choice time (self-paced) of the subject, and the time he took to give a subjective emotional rate on a scale (self-paced). The whole experiment lasted around 45 min.

Events were classified according to the relative losses or gains and the gambling context (see Fig. 2). Trials were categorized as relative gain trials if the counterfactual comparison was advantageous and as loss trials if it was disadvantageous, regardless of the sign of the obtained outcome. In partial feedback condition, the participant could experience disappointment in case of relative loss, that is when the obtained outcome is worse than the un-obtained outcome of the selected gamble; or joy in case of relative gain, when the obtained outcome is better than the un-obtained outcome of the selected gamble (i.e., within-option comparison). In the "complete feedback" condition, information about the outcome of the non-chosen lottery is available, and the participant could experience regret when the obtained outcome is worse than the outcome of the unselected gamble; or relief when the obtained outcome is better than the outcome of the unselected gamble (i.e., between-choice comparison). In addition, in complete feedback condition the comparison between the obtained outcome and the un-obtained outcome from the chosen gamble is still possible (within-option comparison in complete feedback). The latter event will be considered in the analysis. The two feedback conditions were presented in a block design. Participants were informed in advance if they would have received a complete or partial feedback. Stimuli were delivered using Presentation software (Neurobehavioral Systems, EU).

2.2.2. *The counterfactual inference test*

We measured counterfactual thinking using the four item *Counterfactual Inference Test* developed by Roese and Olson (1995). This test assumes that some aspects of the perceived reality that are negative or unusual (e.g., a car accident or physical aggression) trigger the process of counterfactual thinking. Specifically, counterfactuals are more pronounced when the relationship between previous actions and outcome is abnormal (normality), or when there is increased physical and temporal proximity (goal proximity) between the alternative situations. Participants were presented with pairs of alternative scenarios that always described the experiences of two characters who are in similar situations and experienced identical outcomes. The stories always included one element in the antecedent that was different for the two characters either for normality or goal proximity this event always related to a factor known to be relevant to judgements of regret and relief. In all cases, the participants were asked to judge whether one character would feel worse than the other character or whether the two characters would feel the same. The pictures did not depict the characters' emotional responses following the stories' outcomes. The ordering of the stories was counterbalanced across participants. Examples of scenarios are: (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 item (normality), and "Ed" for the second item (goal proximity). Participants were scored 1 for each target response achieved. The test also included the "I do not know" or "both characters" answers. The scale ranges from 0 (no counterfactual thinking) to 4 (perfect ability in counterfactual thinking).

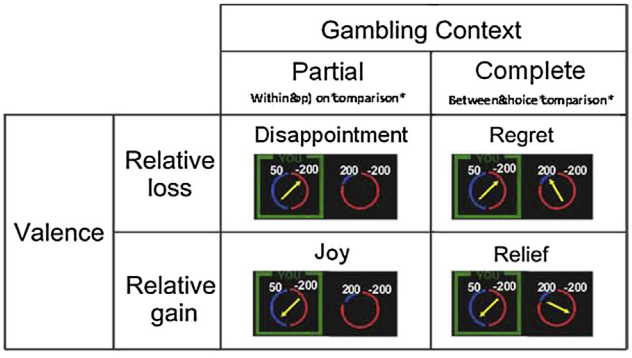

Fig. 2 – Events of interest for the comparison of partial (within-option comparison) and complete (between-choice comparison) feedback conditions. Relative loss and relative gain refer to counterfactual comparisons (e.g., loosing 50 when they could have lost 200 was classified as relative gain, and winning 50 when they could have won 200 was classified as relative loss). Note that in complete feedback condition the comparison between the obtained outcome and the un-obtained outcome from the chosen gamble is still possible (within-option in complete feedback).

2.3. *Data collection and analyses*

The statistical analyses were conducted with the statistical software package Stata (Stata Corp, College Station, TX, Release 9/SE). Non-parametric tests were applied on the data sets since the data violated several parametric assumptions, particularly non-normal distribution. The significance of the difference between behavioural variables, such as subjective evaluations is estimated with the Wilcoxon signed rank test (non-parametric test); the hypothesis tested is that the distribution of two random variables for matched pairs is the same. Between groups (HFA/AS and CP) differences were tested with Mann–Whitney rank test.

2.3.1. *Regression analyses*

Testing anticipated disappointment and regret. We tested a model of choice that incorporates the effects of anticipated disappointment and regret in addition to the maximization of expected values (Table 2). 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, respectively, we defined the probability of choosing g_1 in terms of three factors affecting the choice anticipated disappointment (d), anticipated regret (r), and expected value (e).

Table 2 – Regression analysis of choice behaviour for the two groups of participants in complete feedback condition. Numbers indicate coefficients, and standard errors in parentheses. $^{*}p < .05$, $^{**}p < .0001$.

	Controls	HFA/AS	All participants
Constant	.17 (.16)	.38 (.17)*	.27 (.11)*
e	.029 (.004)**	.024 (.004)**	.029 (.004)**
d	−.004 (.002)*	.0017 (.0019)	−.0041 (.002)*
r	.003 (.001)*	.0029 (.001)*	.0033 (.0013)*
*e**group			−.0005 (.002)
*d**group			.006 (.003)*
*r**group			−.0051 (.006)

Let us call outcomes 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*, where:

► Anticipated disappointment choosing g_1,

$$d = [|y_2 - x_2|(1 - q)] - [|y_1 - x_1|(1 - p)]$$

Anticipated disappointment is equal to the differences between the two outcomes of each gamble weighted by the probability of the worst outcome, thus indicating an avoidance of possible sources of disappointment (Camille et al., 2004).

► Anticipated regret choosing g_1,

$$r = [|y_2 - x_1| - |y_1 - x_2|]$$

Anticipated regret 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 (Camille et al., 2004). A significant positive *e* coefficient indicates that subjects consistently choose the gamble with highest expected value. Similarly significant positive *d* or *r* coefficients indicate that subjects anticipated (minimized) disappointment or regret, respectively (Camille et al., 2004).

To analyse the interaction between groups (HFA/AS and CP) and choice behaviour we run three logistic regressions (reported in Table 2): (1) with data of the CP only; (2) HFA/AS only; (3) all participants with three interaction terms: *d x group* indicated the interaction between groups and anticipated disappointment; *r x group* indicated the interaction between groups and anticipated regret; *e x group* indicated the interaction between groups and expected value. A positive coefficient indicated that the variable of interest has a more important influence in HFA/AS subjects' choices than in healthy controls' choices, whereas a negative coefficient indicated that the variable of interest has a more important influence in CPs' choices than in HFA/AS subjects' choices.

Additional regressions (one for CPs and one for HFA/AS) were run to test the effect of anticipated disappointment in partial feedback condition.

The effect of experienced emotion on subsequent choice behaviour. We finally tested the effect of experienced regret and disappointment on subsequent choice behaviour. We tested the effect of experienced emotions to the choice of anticipating regret. The dependent variable "choice of anticipated regret" took value 1 if the participant chose the gamble that minimizes regret (at time t), and 0 otherwise. Anticipated regret is computed with the variable r. The independent variables: "experienced disappointment" = (un-obtained outcome of the chosen gamble − obtained outcome) at time $t - 1$; "experienced regret" = (outcome of the unchosen gamble − obtained outcome) at time $t - 1$.

3. Results

3.1. *Emotional evaluation*

When asked to evaluate subjective emotional response following the choice's outcome, Wilcoxon Sign Rank Test revealed that the control group showed a pattern of emotional ratings consistent with the presence of disappointment (in partial feedback condition) and regret (in complete feedback condition). CP evaluated as more negative a loss of −50 (or a win of +50) when the un-obtained outcome of the chosen gamble was +200 compared with an un-obtained outcome of −200 ($z = -3.058$, $p = .002$, for both −50 and +50 obtained) in the partial feedback condition (i.e., disappointment effect, within-option comparison). As shown in Fig. 3, this effect was greater in the complete feedback condition when the comparison is made between the obtained outcome and the outcome of the unselected gamble (i.e., regret effect, between-choice comparison), thus the between-choice comparison induced greater responses than the within-option comparison ($z = -2.35$, $p = .01$). Like the control group, when asked to evaluate their emotional responses, participants with HFA/AS experienced a loss of −50 (or a win of +50) as more negative when the un-obtained outcome was +200 as compared to those circumstance in which un-obtained outcome was −200 ($z = -2.787$, $p = .005$, for −50 obtained; and $z = -3.059$, $p = .002$, for +50) in the partial feedback condition. However, emotional ratings associated with the complete feedback condition (regret effect, between-choice comparison) and the partial feedback condition (disappointment effect, within-option comparison) were similar in kind and intensity in participants with HFA/AS ($z = -.549$, $p = .58$) (Fig. 3).

When we compared emotional rating across the four different conditions, each eliciting a distinct emotional

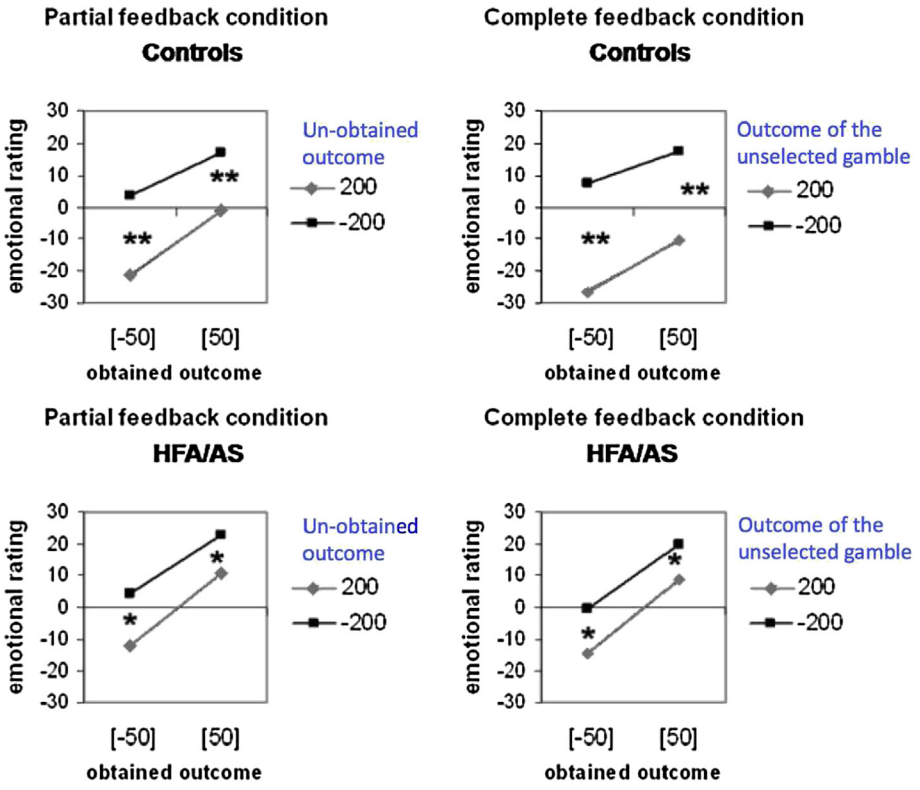

Fig. 3 – Mean emotional ratings for the two obtained outcome (−50 and +50) as a function of the foregone outcomes of −200 (blue) and +200 (red), for the control group, in partial (upper-left panel) and complete (upper-right panel) feedback conditions, and for the group with HFA/AS in partial (lower-left panel) and complete (lower-right panel) feedback conditions, respectively. The foregone outcome in partial feedback condition refers to the un-obtained outcome of the chosen wheel (within-option comparison), while the foregone outcome for the complete feedback condition is the outcome of the unchosen wheel (between-choice comparison). Wilcoxon sign rank test between the emotional ratings of the two unselected outcomes (−200 *vs* +200) for each obtained outcome (−50 or +50): $^{*}p < .05$, $^{**}p < .001$.

response, Mann–Whitney test yielded significant group difference only for emotional ratings associated with the complete feedback condition (regret effect, between-choice comparison) ($U = 32$; $z = -2.31$; $p = .02$; mean diff. $= -16.8$), while the two groups of participants reported comparable emotional rating for the partial feedback condition (disappointment effect, within-option comparison) ($U = 47$; $z = -1.44$; $p = .14$; mean diff. $= -6.23$), joy ($U = 65$; $z = -.4$; $p = .68$; mean diff. $= -3.29$) and emotional ratings associated with the complete feedback condition (relief effect, between-choice comparison) ($U = 53$; $z = -1.1$; $p = .27$; mean diff. $= 2.6$) (Fig. 4). Participants with HFA/AS reported higher score in emotional rating for the partial feedback condition (joy effect, within-option comparison), as compared to the complete feedback condition (relief effect, between-choice comparison) (Wilcoxon sign rank test: $z = -2.22$; $p = .026$; mean diff. $= 5.73$), unlike CP who reported equal level of intensity for these two events ($z = -.16$; $p = .87$; mean diff. $= -.17$).

Notably, the analysis of the effect of the un-obtained outcome of the selected gamble (within-option) in the complete feedback condition shows that for CP the between-choice comparison (i.e., regret effect) was more negative ($z = 2.74$, $p = .006$, mean diff. $= -4.46$) than the within-option comparisons (i.e., the comparison between the obtained

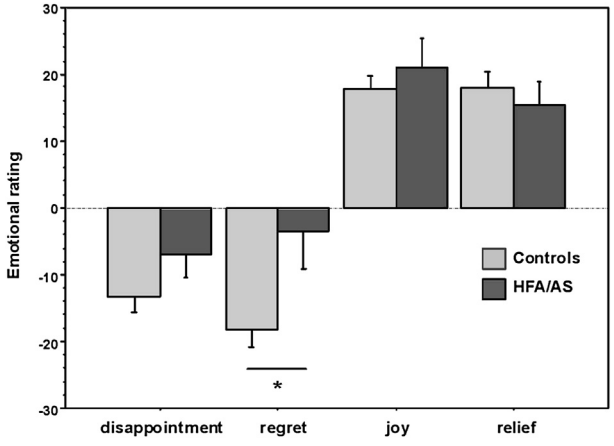

Fig. 4 – Mean subjective emotional rating for the four different events (note: disappointment and joy refer to the within-option comparison in the partial feedback condition, while regret and relief refer to the between-choice comparison in the complete feedback condition) for the two groups of participants. $^{*}p = .03$. The emotional scale ranged from −50, extremely negative, to +50, extremely positive.

outcome and the un-obtained outcome of the chosen gamble in feedback condition, mean = −13.34, SD = 9.79). Moreover, there were no differences between the within-option comparisons in the partial or complete condition ($z = .078$, $p = .93$). While patients reported identical effects for the between-choice comparison and the within-option comparison (mean = −3.51, SD = 16.08) in the complete feedback condition ($z = .31$, $p = .75$, mean diff = −.13) and also an identical effect of the within-option comparison in the two conditions ($z = 1.41$, $p = .15$).

3.2. *Choice behaviour*

Results based on regression analysis with data from the complete feedback condition revealed that CPs chose anticipating regret and maximizing the expected values. Results from the panel logit procedure with individual random effects are shown in Table 2. Participants with HFA/AS showed a pattern of behaviour similar to that of the CPs, since they chose maximizing expected values and anticipating regret (the coefficients of r and e were significant, both $p < .05$). The coefficient of the variable d is not significant for the HFA/AS group ($p = .13$) and negative for the CPs ($p = .002$) in the complete feedback condition (Table 2). We observe similar results with data from the partial feedback condition (HFA/AS group coefficient of $d = -.002$, $p = .14$; CPs group, $d = -2.99$, $p = .003$). As shown in the regression analysis with all the participant with data from complete feedback (Table 2), only d^*group is significant; thus there were no differences in choice behaviour between the two groups in terms of anticipated regret and maximization of expected values.

Additionally, both CPs and HFA/AS choices of anticipated regret were influenced by experienced regret. We regressed the choice of anticipating regret (at trial t) as a function of experienced regret at trial t − 1. Both CPs and HFA/AS increased the probabilities of anticipating regret after the experience of regret. The coefficient of experienced regret in the complete feedback condition is positive and significant for the HFA/AS group (coefficient of experienced regret = .0009, SE = .0008, $p = .03$) and marginally significant for the CP (experienced regret = .002, SE = .0009, $p = .063$).

3.3. *Counterfactual inference test*

No difference was observed between participants with HFA/AS (mean counterfactual score = 1.9, SD = 1.3) and CP (mean counterfactual score = 2, SD = 1.13; Mann–Whitney test, $z = .137$, $p = .8914$).

4. Discussion

In the present study, we used a gambling task to investigate the ability of a group of adults with HFA/AS to experience regret and disappointment. Participants were asked to make a choice between two risky gambles associated with a monetary reward, and to report the quality and the intensity of their emotional responses following winning or losing. The task consisted of two conditions in which the information about the outcome of the non-chosen lottery was either omitted (partial feedback) or available (complete feedback). Crucially, the type and the intensity of the self-reported affective responses depend both on the values of the obtained outcome and the foregone outcome. 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 a relative loss, and joy, when the obtained value is a relative gain. In contrast, since complete feedback trials enabled the participants to judge not only the financial consequence of the chosen gamble, but also the outcome that would occur if they had selected the other option, unfavourable comparison between the obtained outcome and a more favourable outcome of the unselected gamble could generate the regret experience, or the experience of relief if the obtained outcome is more favourable than the unselected one (Camille et al., 2004).

As expected, all participants reported experiencing more positive emotions following a favourable obtained outcome and more negative emotions following an unfavourable obtained one. However, whereas CP experienced the affective response to a regret-inducing event as more intense than the affective response to a disappointment-inducing event, participants with HFA/AS did not exhibit any increase in the emotion intensity associated with regretful events. In addition, when we compared participants' 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 HFA/AS experienced the affective response to a regret-inducing outcome as being significantly less intense than CP. In contrast, the two groups did not differ in the evaluation of the affective responses associated with disappointment, joy and relief outcomes. The analysis of the effect of the un-obtained outcome (within-option comparison) in complete feedback condition corroborates the fact that only CP differentiated the between-choice comparison (regret) from the within-option comparison. Thus, HFS/AS evaluation of the obtained outcome is not affected by the outcome of the unselected gamble (i.e., they do not show an *amplification* effect).

We suggest that the reduced experience of regret observed in our sample of participants with HFA/AS would reflect a diminished self-report emotional awareness that might compromise their ability to distinguish self-relevant emotional states, such as the experience of regret, from other similar internal bodily states. As pointed out by Zeelenberg and collaborators (Zeelenberg & van Dijk, 2004; Zeelenberg & Pieters, 2007), regret is a self-relevant negative emotion, differing from other general negative emotions such as disappointment, anger, sadness, envy, guilt and shame on the basis of its specific antecedent counterfactual conditions, appraisal patterns, experiential content and behavioural consequences. Different from disappointment, regret arises in situations where one is, or feels responsible for the occurrence of the negative event and its experience is associated with a tendency to blame oneself for having made the wrong decision. The emphasis on between-option counterfactuals invokes the notion that regret depends upon the personal sense of blame or feeling *responsible* for bad decisions, and that the sense of responsibility, induced from such specific counterfactual thinking, amplifies the feelings associated with a regretful event (Frijda, Kuipers, & ter Schure,

1989; Zeelenberg, van Dijk, & Manstead, 1998; Zeelenberg, van Dijk, Manstead, & van der Pligt, 1998, Zeelenberg, van Dijk, Manstead, & van der Pligt, 2000).

In the present study, the two groups showed similar performance on counterfactual reasoning task, in accordance with previous research showing intact reasoning abilities in individuals with HFA (Begeer, Terwogt, Lunenburg, & Stegge, 2009; Leevers & Harris, 2000; Scott, Baron-Cohen, & Leslie, 1999). This finding is of particular importance because it allows us to discount the hypothesis that impaired inferential reasoning would account for group difference in emotional awareness. Hence, the lack of the *amplification* effect for the experience of regret in participants with HFA/AS might reflect the failure to overtly integrate self-relevant emotional information with inferential reasoning processes.

It is noteworthy that the two participant groups reported similar emotional evaluation for disappointment, joy and relief inducing events. Although, like regret, relief depends upon between-choice counterfactual inference, that is the favourable comparison between the obtained and the unselected outcome on complete feedback conditions, different from regret-inducing events, relief and joy-inducing events were experienced as equally intense by CP. In contrast, participants with HFA/AS reported higher emotional rating for joy-inducing events, as compared to relief inducing-events. This finding suggests that while individuals with HFA/AS are sensitive to positive feedback, they exhibit some atypicalities in the subjective experience of emotions and possibly differ from typically developed individuals with respect to the conscious representation of physiological arousal states. Unfortunately, as we adopted an operational notion of 'regret', the present study does not provide a more direct measure of the experiential and evaluative contents of those emotions, which might help explaining group and potentially individual differences in subjective self-reports.

In addition, although the experience of regret elicited a less intense emotional response in participants with HFA/AS, they showed a choice behaviour similar to the one of the CP. Both groups maximized expected values, anticipated regret, and also avoided regret more after a regret event, suggesting that the HFA/AS are able to anticipate and avoid regrettable outcomes. We also found that CP reported a negative coefficient of anticipated disappointment. This might be due to the overwhelming effect of experience of anticipated regret in their choice behaviour.

Overall, the present results seem to suggest that, despite group differences in the subjective self-reports, emotional information, associated with a specific neurophysiological arousal, elicited by regretful events, is unconsciously processed and affect choice behaviour covertly. Feeling of regret plays an important role in the evaluation of behavioural alternatives and promotes learning from one's mistakes by providing critical feedback in the form of anticipatory self-blame feelings. Since behavioural choices are often made to avoid highly unpleasant events, people anticipate emotional reactions (e.g., regret *vs* relief/self-approval) and engage in the more advantageous and reparative actions (Zeelenberg, van Dijk, Manstead, & van der Pligt, 2000). As such, regret is a self-relevant emotion, which is characterized by a higher level of physiological arousal and a strong behavioural impact. It is possible that whereas the level of physiological arousal, associate with regretful events, is sufficient to orient subsequent behavioural choices, a much higher threshold is needed for generating emotional awareness and a specific emotional content. This could explain why in participants with HFA/AS who did not exhibit the amplified regret effect, they nevertheless manifest regret avoidance behaviour.

This explanation is in accordance with research in social cognition showing the existence of unconscious guidance systems, composed by a variety of automatic process detecting relevant stimuli and information in the social and physical environments. The automatic effects of environmental stimuli are directly connected to behavioural tendencies, in the absence of any involvement by conscious or intentional processes (Bargh & Morsella, 2009). Emotional states can thus trigger goals and motivational states of which the individual is not aware and does not consciously intend. Unconscious processing was found to drive a large variety of cognitive processing, including stereotyping judgements, social behaviour and motivated goal pursuit (Bargh & Morsella, 2008; Bargh, Schwader, Hailey, Dyer, & Boothby, 2012). Hence, it is likely that these unconscious guidance systems are partly preserved in ASD population, but only covertly affect subject's behaviour.

The present findings are consistent with evidence showing that alexithymia, which is characterized by difficulties in the appraisal and expression of emotion and in overtly use feelings to guide behaviour, considerably overlaps with ASDs (Fitzgerald & Bellgrove, 2006). Recently, Gaigg (2012) has proposed that ASDs may be better understood in terms of a disruption in the domain-general interplay between emotion and cognition. The present results are in accordance with this theoretical account and further reveal that difficulties in reflective appraisal of self-relevant emotional experience in individuals with HFA/AS also arise in private settings.

Using a gambling task, Nicolle et al. (2011)'s study showed that in typically developed participants increased subjective responsibility amplified the tendency to report high feelings of regret and, neuronal activity in the amygdala was enhanced by increased responsibility associated with this "self-blame regret" experience. These findings suggest that the experience of regret crucially depends on the level of subjective responsibility and on the personal sense of blame induced by the individual's own choice. According to this view, the inability to differentiate the affective responses associated with regret and disappointment-inducing events in our participants with ASDs might result from an impairment in attributing responsibility to internal causes and in processing the self-blame component of regret, rather than reflecting a disrupted system for conscious emotional appraisal. Nevertheless, the fact that both groups manifested regret avoidance behaviour suggests that participants made attributions of regretful events to internal factors, at least in a cover manner.

5. Conclusion

The present findings suggest that the reduced feeling of regret in individuals with ASDs would reflect an impaired appraisal system affecting the ability to make *self-relevant* affective information available for conscious evaluation and cognitive

reasoning. In accordance with the model of alexithymia proposed by Lane and Schwartz (1987), we distinguish the level of physiological arousal from the level of conscious representation of that arousal state. Impairments of the second-order awareness of bodily states, associated with emotions or interoceptive awareness, can explain alexithymic symptoms in individuals with ASDs.

The ability to incorporate affective values with reasoning processes, such as counterfactual thinking, critically relies on the OFC and on its functional connectivity with the amygdala (Coricelli et al., 2005). Since this structure has been found to be crucially involved in the ASD pathophysiology, it is likely that the lack of an amplified regret effect in participants with ASDs would reflect structural abnormalities in the amygdala and the abnormal connectivity of the fronto-limbic circuit. The present findings are in accordance with the 'Relevance Detection Theory of Autism' (Zalla & Sperduti, 2013) which posits that abnormal functional connectivity between the amygdala and the ventromedial prefrontal cortex in ASDs would lead to difficulties to focus attentional and physiological resources towards events and stimuli that have special relevance for personal safety or success, and to form of a *priority map* of self-relevant events that might be accessible to and modulated by conscious evaluative processes.

Further research is needed to investigate the impact of a diminished emotional awareness on conscious decision-making and reasoning, and the neural structures involved in this impairment in ASDs. Finally, it would be important to corroborate the present behavioural findings by using both implicit psychophysiological measures of emotions (i.e., electrodermal activity and heart rate), an explicit appreciation of the subject's emotional states in individuals with ASDs.

Conflict of interest

None.

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