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BRIEF REPORT

Brief Report: Reduced Optimism Bias in Self-Referential Belief Updating in High-Functioning Autism

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Abstract Previous research has demonstrated irrational asymmetry in belief updating: people tend to take into account good news and neglect bad news. Contradicting formal learning principles, belief updates were on average larger after better-than-expected information than after worse-than-expected information. In the present study, typically developing subjects demonstrated this optimism bias in self-referential judgments. In contrast, adults with high-functioning autism spectrum disorder (ASD) were significantly less biased when updating self-referential beliefs (each group $n=21$, matched for age, gender and IQ). These findings indicate a weaker influence of self-enhancing motives on prospective judgments in ASD. Reduced susceptibility to emotional and motivational biases in reasoning in ASD could elucidate impairments of social cognition, but may also confer important cognitive benefits.

Keywords Autism · Belief updating · Optimism bias · Rationality · Judgment · Learning

Introduction

The most prominent characteristics of high-functioning autism spectrum disorder (ASD, referring to high-functional individuals with ASD throughout the paper) are impairments of social communication and interaction, and a restricted repertoire of activity and interests. However, there is another characteristic that has received only little attention in research, but is well known in clinical practice: persons with ASD tend to demonstrate increased rationality in their judgment and decision making. Thus, they favor explicit and rule-based, rather than intuitive and implicit, information processing, and as a consequence they are less biased by emotional and motivational influences (Brewer et al. 2015; De Martino et al. 2008; Harris et al. 2013; Kuzmanovic et al. 2011). In a financial task for example, individuals with ASD were significantly less biased than typically developing (TD) persons by the way how choice options were emotionally framed, highlighting either losses or wins (De Martino et al. 2008). Thus, individuals with ASD showed an increased logical consistency, as their decision making was less influenced by loss aversion (Tom et al. 2007). A cognitive style with an increased rationality may critically interfere with social functioning, because the interpretation of complex social situations often requires spontaneous conclusions guided by ambiguous communicative cues and their emotional significance. On the other

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hand, however, it may have the valuable benefit of a more objective and unbiased reasoning.

In the present study, we investigate whether individuals with ASD show increased rationality in their formation of beliefs about future outcomes. In the TD population, it could be robustly shown that people demonstrate unrealistic optimism, as they tend to overestimate their chances of experiencing positive outcomes, but underestimate their risks of experiencing negative outcomes (Weinstein 1987). In addition, more recent work could show that when people *update* their beliefs, they tend to take into account good news, but neglect bad news (Eil and Rao 2011; Sharot et al. 2011). Although the extent of this optimism bias in belief updating can considerably differ across individuals depending on age, trait optimism, depression, and reduced neural tracking of estimation errors (Chowdhury et al. 2014; Garrett et al. 2014; Korn et al. 2014; Kuzmanovic et al. 2015, 2016; Sharot et al. 2011), the effect was significant at the group level in all the mentioned studies (for healthy participants). In fact, this robust phenomenon appears to generalize beyond belief updating, and to represent a genuine feature of human reasoning, as the preferential use of positive information and the neglect of negative information have also been shown in classical reinforcement learning (Lefebvre et al. 2016; Sharot and Garrett 2016). Nevertheless, the bias in belief updating may also fluctuate depending on the motivational self-relevance of beliefs, or features of the current environment, such as the amount of threat or uncertainty (Sharot and Garrett 2016). Thus, depending on its size and the situation-specific adjustment, the optimism bias can have far-reaching consequences, ranging from protective effects of stress reduction and of increased persistence in reaching goals, to detrimental phenomena, such as risky behavior in health and financial domains (Shepperd et al. 2013).

A first investigation of the optimism bias in individuals with ASD has provided evidence for less biased belief updating (Harris et al. 2013). When updating beliefs about adverse future events, the ASD group had a less pronounced asymmetry in reliance on good and bad news. However, this study has not been published in a peer-reviewed journal and revealed surprising findings with respect to positive future events, indicating that judgments about positive and negative events may not be directly comparable in the tested protocol (for more details see Garrett and Sharot 2016; Kuzmanovic et al. 2015; Sharot and Garrett in press).

In order to reexamine the hypothesis of reduced optimism bias in autism, in the present study, we used a recently modified belief updating paradigm. The new task assesses the optimism bias more precisely because it relies on an optimized trial structure, includes negative events only, and differentiates between judgments relating to oneself and to a similar other (Kuzmanovic et al. 2015, 2016). The comparison between judgments relating to oneself and those relating to others is important because the motivation to adopt the most favorable future outlooks is likely to be particularly strong for one's own future. Subjects were asked to estimate their risks of experiencing different adverse events in the future, and were then presented with the actual base rate of the respective events. Subsequently, they were given the opportunity to make a second estimate, i.e., to adjust their initial belief to the new information. Critically, the base rates could reflect good or bad news. With respect to adverse future events, base rates that were lower than expected were *desirable* and were associated with an estimation error of *positive valence*. By contrast, higher-than-expected base rates were *undesirable* and associated with *negative* prediction errors. Formal learning theories predict that updating after an estimation error should be independent of the error valence. If, however, this prediction is violated, and updates after desirable information happen to be larger than those after undesirable information, and if this asymmetry is stronger for self-referential than for other-related judgments, then this pattern of updating would indicate an optimism bias. Ultimately, such a behavior would enable the maintenance of favorable self-relevant perspectives despite disconfirming evidence. Given the increased logical consistency in ASD (De Martino et al. 2008), and the initial evidence for less biased belief updating in ASD (Harris et al. 2013), we expected to find a weaker optimism bias in ASD as compared to TD individuals.

Methods

Participants

Twenty-one adults with ASD, and twenty-one control participants (CON), matched for age, gender, education years, and IQ were recruited. Participants' characteristics and related statistics are summarized in Table 1. The groups differed with respect to the autism spectrum quotient (AQ), as higher AQ-scores in the ASD group correspond to the increased expression of autistic traits. Furthermore, depression has been shown to represent a common comorbidity in ASD (Stewart et al. 2006). We thus also assessed depression symptoms with the Beck depression inventory (BDI scores) to control for the greater depression symptom level in the ASD group.

All participants with ASD were diagnosed and recruited (by mail or e-mail) in the Autism Outpatient Clinic at the Department of Psychiatry at the University of Cologne, Germany. As part of a systematic assessment, the diagnoses were made independently by two specialized clinicians in accordance with ICD-10 criteria, and were supplemented by an extensive neuropsychological assessment. First, a

Table 1 Demographic and neuropsychological variables

	ASD		*CON*		Statistics	
	M	*SD*	*M*	*SD*	*t*(*df*)	p
Gender (m:f)	17:4		19:2		$\chi^2(1) = 0.778$	.378
Age (y)	42.05	10.53	38.10	9.74	1.26 (40)	.214
FSIQ	115.25	18.99	110.19	11.07	1.05 (39)	.301
HIQ	109.25	20.39	107.19	11.37	0.40 (39)	.690
VIQ	117.90	16.39	111.05	11.96	1.54 (39)	.133
Education (y)	17.81	4.09	18.38	2.76	−0.53 (40)	.599
BDI	13.86	11.22	4.95	4.75	3.35 (40)	.002
AQ	40.95	4.48	16.24	5.01	16.86 (40)	.000

The IQ test could not be conducted with one ASD participant due to time constraints. Instead, a short IQ estimation test, the WST, (Schmidt and Metzler 1992), was applied with a resulting IQ score of 110. *ASD* autism spectrum disorder; *CON* control group; *m* male; *f* female; *y* years; *FSIQ, PIQ, VIQ* full Scale IQ, performance IQ, and verbal IQ, assessed with the Wechsler Adult Intelligence Scale, third edition, German version (von Aster et al. 2006); *BDI* Beck depression inventory, German version, (Hautzinger et al. 2005); *AQ* autism spectrum quotient, German version (Wheelwright et al. 2006)

specialized consulting clinician interviewed patients who were referred to the department by a practicing psychiatrist or neurologist in order to verify the presumptive diagnosis of an ASD. In cases in which this first interview supported the diagnosis, patients underwent a neuropsychological assessment resulting in a detailed written summary of the neuropsychological profile including comments on the behavior of the patients during the testing. In a final interview with the patient, the decision was made by a second, independent consulting physician under consideration of the previous indices. Inclusion criteria for both groups were: (i) no history of neurologic or psychiatric disorders (ASD group: other than ASD), and (ii) age between 18 and 60 years. Additional inclusion criteria for the ASD group were: (i) diagnoses childhood autism (F84.0) or Asperger's autism (F84.5), and (ii) an IQ > 70. Control participants were recruited through flyers and online announcements.

Procedure

Optimism bias was assessed by the belief updating experiment, which was carried out on a laptop using the software Presentation (Neurobehavioral Systems, Inc., Version 15.1; mean duration of the experiment = 20.96 min, no group difference, p = .195). In each trial of the experiment (44 trials in total), subjects (i) had to estimate the risk of experiencing an adverse event in the future (first estimate, *1st E*), (ii) were presented with the general population base rate (*BR*) of the respective event, and (iii) had the opportunity to adjust their initial estimate to *BR* (second estimate, *2nd E*). The estimation error (*EE*) was computed as the absolute difference between the first estimate and the base rate, i.e., $EE = |1st\ E - BR|$. *EE*s in trials with lower *BR* than *1st E* had a positive valence (*POS)*. Conversely, trials with greater *BR* than *1st E* were assigned to the negative valence condition (*NEG*). Belief update (*UPD*) was computed as the difference between *1st E* and *2nd E*, while taking into account the expected direction of updating. In *POS, UPD* = *1st E* − *2nd E*, and in *NEG, UPD* = *2nd E* − *1st E* (see also Fig. 1b for examples). This procedure ensured that the *UPD* were always positive when congruent with the *BR*, and allowed us to directly compare *UPD* across valence. The update only resulted in a negative value when subjects updated in an unexpected direction (e.g. *1st E* = 20 %, *BR* = 10 %, *2nd E* = 25 %, *UPD* = −5). However, such unexpected behaviors were indeed rare (<3 %, no group difference, p = .869). Finally, a subject demonstrated an optimism bias if his or her updates were on average larger after better-than-expected *BR* (*POS*) than after worse-than-expected *BR* (*NEG*). Participants were free to report a probability anywhere between 1 and 99 %. They selected the desired probability by using two buttons to increase or decrease the number displayed at the screen, respectively, and a third button to finally affirm the selected choice. Thus, along with presenting all events (*1st E, BR, 2nd E*) subsequently within one trial, the response noise was significantly reduced as participants were less likely to misremember and mis-select task-related likelihoods.

In order to enable comparisons between judgments that refer to oneself and those referring to others, participants were instructed to estimate risks for themselves in one-half of the trials (*SELF*), or, in the other half of trials, for a similar other person of the same age, sex and socioeconomic background (*OTHER*). To control for the valence and distributions of the estimation errors, base rates were systematically manipulated, unbeknownst to the participants. In each trial, a random value (ranging from 1 to 25) was subtracted from (*POS*) or added to (*NEG*) the first estimate (resulting in a mean *EE* of 12.91, no group difference, p = .289; see Fig. 1b for examples; and see Kuzmanovic et al. 2016 for more details).

Based on previous studies (Kuzmanovic et al. 2015), we used 44 short German descriptions of adverse life events as stimuli (e.g., dementia, domestic burglary, see Supplementary Materials for a complete list). The assignment of the stimuli to the experimental conditions and the order of trials were randomized anew for each participant. This procedure controlled for the possible effects of stimulus characteristics on belief updating.

Before the experiment, all subjects underwent a standardized, computerized instruction including practice trials with stimuli not used within the experiment. They were instructed that there were no right or wrong answers as we were interested in their subjective judgments. They were also informed that the population base rates were derived from the German

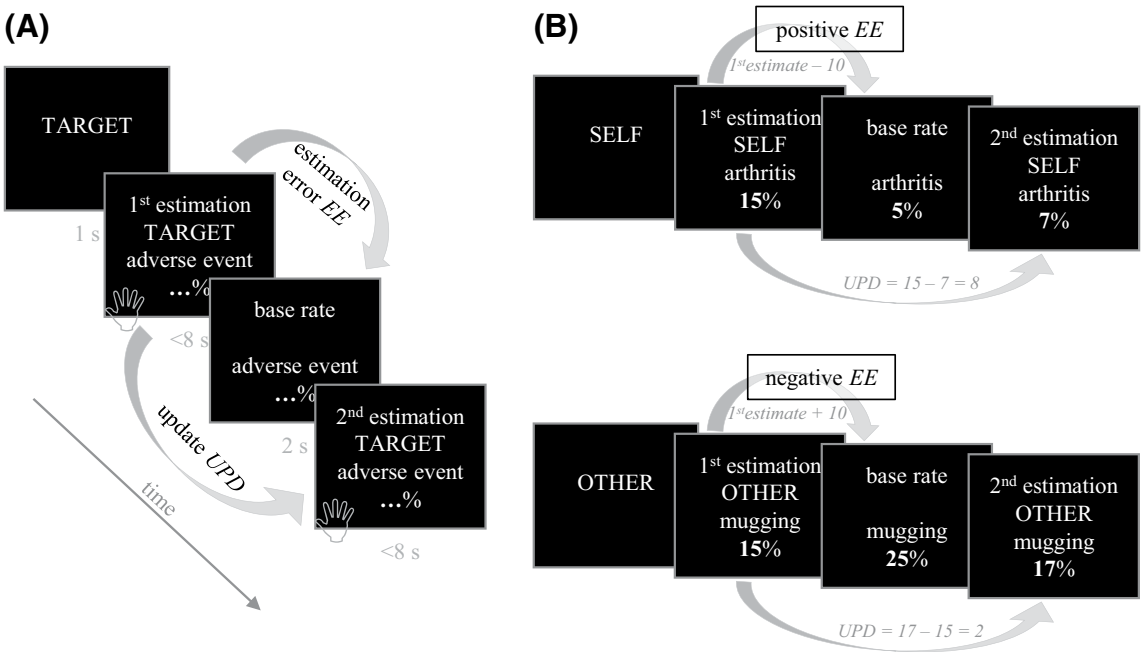

Fig. 1 The general structure of the belief update paradigm (**A**) and examples of different experimental conditions (**B**). **A** Each trial started with a cue indicating the target person of the upcoming judgment (*SELF* or *OTHER*). Next, subjects had to make a first estimate relating to the probability of experiencing a specific adverse event in the future (at least once in the life time), then they were presented with the actual base rate (*BR*) of this event, and finally they had the opportunity to update their initial estimation. The difference between the first estimate and the presented base rate indicated the estimation error (*EE*), and the difference between the first and the second estimate the update (*UPD*). Note the timing details included underneath the trial elements. **B** The upper part shows an example of a *SELF* trial (judging the probability that oneself experiences future events) with a *positive EE* (*POS: BR* lower than expected, i.e. *BR* of 5% is lower than the first estimate of 15%). *BR*s were manipulated and computed based on the first estimates made by subjects. Randomly selected values ranging from 1 to 25 (in this example 10) were subtracted from the first estimate to generate a desirable *BR* and a positive *EE*. Because second estimates were expected to be smaller than the first ones in the *POS* condition (i.e., following *BR* that was lower than the first estimate), *UPD*s were computed as first estimate—second estimate (signed values). The lower part shows an equivalent example of an *OTHER* trial (judging the probability that a similar other person of the same age, sex and socioeconomic background experiences future events) with a *negative EE* (*NEG: BR* higher than expected, i.e. *BR* of 25% is higher than the first estimate of 15%). The undesirable *BR* was generated by adding a randomly selected value (in this example again 10) to the first estimate. Because second estimates were expected to be larger than the first ones in the *NEG* condition, *UPD*s were computed as second estimate—first estimate (signed values).

Federal Statistical Office ("*Statistisches Bundesamt*"), and that they should consider this information during their second estimation. After the experiment, participants rated all 44 stimulus events with respect to their personal experience (7-point rating scale ranging from 1, *unknown event*, to 7, *currently affected*). Following trials were excluded prior to analyses (mean number of trials per subject 39.24, no group difference, $p = .300$): (i) trials with events by which a subject was currently affected or more than once affected (i.e., trials scoring 6 or 7 on personal experience, e.g., it does not make much sense to estimate the likelihood of suffering from hay fever, when a participant was already suffering from hay fever during the experiment), (ii) trials with missing responses, and (iii) trials with $EE = 0$ (e.g., in a *POS* trial, when *1st E* = 1%, no lower *BR* than 1% could be computed). In a final debriefing after the experiment, a funneled procedure was used to ensure that subjects did not suspect the manipulation of the base rates, or the purpose of the study. Subsequently, we informed subjects that they had been deceived about the source of base rates, and explained the methodological reasons for this procedure.

Statistical Analyses

Data were analyzed using MATLAB (MathWorks, Version R2014b), and SPSS (IBM SPSS Statistics, Version 22). To assess the optimism bias, we tested whether updates were larger after positive than after negative *EE*s. For this purpose, we conducted a regression analysis to assess whether trial-by-trial *UPD* would be predicted by the valence of *EE*s (*VALENCE, POS* vs. *NEG*). For each subject, we fitted two separate models for *SELF* and *OTHER* trials, respectively. Thus, the two regression coefficients of *VALENCE* assessed the optimism bias relating to *SELF* (OB_{SELF}), and the optimism bias relating to *OTHER* (OB_{OTHER}; positive regression coefficients reflected an optimistic bias). We included *EST1* and *EE* into these models to control for their influence on the update behavior (*UPD, EST1* and *EE* were z-sored).

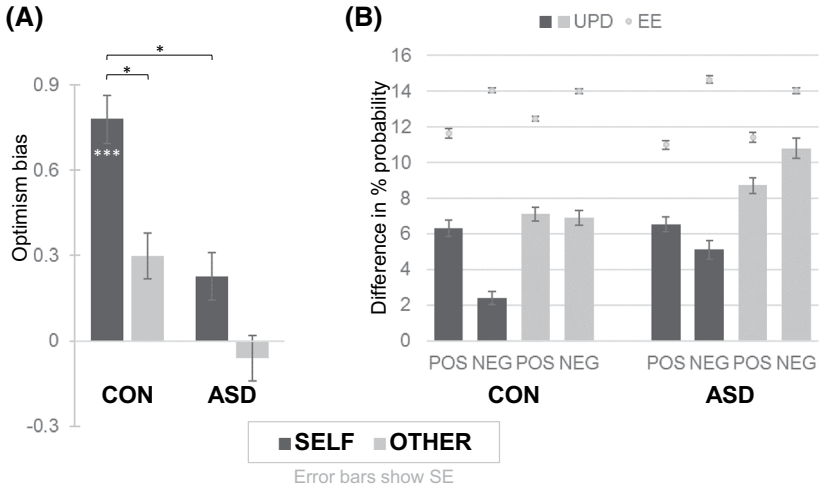

Fig. 2 Mean optimism biases (**a**) and mean updates (**b**) of the control (CON) and the autism spectrum disorder (ASD) group. **a** Two biases were computed separately for each subject: one bias for judgments relating to oneself (*SELF, dark grey*), and the other for judgments relating to a similar other (*OTHER, light gray*). Positive values indicate an optimism bias, i.e., that updates (*UPD*s) were larger after positive (*POS*) than after negative (*NEG*) estimation errors (*EE*), and negative values indicate that *UPD*s were larger for *NEG* than for *POS*. Note that optimism bias was computed by using z-sored *UPD* values, while controlling for the trial-by-trial sizes of estimation errors (*EE*) and first estimates (also z-scored). The *ASD* group was generally less optimistically biased than the CON group, and this difference was significant for *SELF*, but not for *OTHER*. In addition, only the CON group demonstrated a self-related optimism bias (i.e., significantly different from zero), and a significantly stronger optimism bias for *SELF* than for *OTHER*. In contrast, the ASD group showed neither a significant self-related optimism bias, nor a significant difference between biases relating to *SELF* and *OTHER*. *p < .05, ***p < .001. **b** For descriptive purposes, we plotted mean *UPD* and *EE* per condition ($SELF_{POS}$, $SELF_{NEG}$, $OTHER_{POS}$, $OTHER_{NEG}$), separately for the two groups. Note that both *UPD* and *EE* indicate a difference in probabilities (the former between the first and second estimate, and the latter between the first estimate and the presented base rate). The *UPD* pattern in the CON group indicates that *UPD*s were lower specifically after undesirable self-relevant information ($SELF_{NEG}$), while the *UPD* level was similarly high for all the other conditions. The ASD group had higher *UPD*s and a greater reliance on *EE*s in the *OTHER* condition, while the *UPD*s drop after undesirable self-relevant information was less pronounced

Subsequently, using SPSS, we performed a second-level analysis on OB_{SELF} and OB_{OTHER} by using a repeated measures ANOVA (rmANOVA), with a within-subject factor *PERSON* (*SELF* vs. *OTHER*), a between-subject factor *GROUP* (*CON* vs. *ASD*), and BDI as a covariate. The measures OB_{SELF} and OB_{OTHER} did not differ from gaussianity in any of the groups, all $D(21) < 0.11$, all $p > .120$. Also, for OB_{SELF} and OB_{OTHER}, the variances were similar across the ASD and CON groups, both $F(1,40) < 1.17$, both $p > .280$. Upon inspection, no outliers were detected. In addition, one-sample *t* tests were performed on individual OB_{SELF} and OB_{OTHER} values to test whether they were significantly different from zero, separately for the two groups (two-tailed, Bonferroni-corrected for multiple comparisons). Finally, we report correlations between BDI scores and OB_{SELF} and OB_{OTHER} (two-tailed, not corrected for multiple comparisons).

Results

The rmANOVA revealed a significant main effect of *GROUP*, after controlling for the effect of BDI, $F(1,39) = 5.84$, $p = .020$, $\eta_p^2 = 0.13$, indicating that the optimism bias was greater in the control group than in the ASD group (see Fig. 2a). There was no significant *GROUP* × *PERSON* interaction, $F(1,39) = 0.37$, $p = .544$ $\eta_p^2 = .01$. However, the simple main effect of *GROUP* was significant only for *SELF*, $F(1,39) = 4.82$, $p = .034$, $\eta_p^2 = .11$, but not for *OTHER*, $F(1,39) = 2.20$, $p = .146$, $\eta_p^2 = .05$, indicating that the control group had a stronger optimism bias than the ASD group specifically with respect to self-referential judgments. Furthermore, the simple main effect of *PERSON* was significant only in the CON group, $F(1,39) = 5.14$, $p = .029$, $\eta_p^2 = .12$, but not in the ASD group, $F(1,39) = 1.83$, $p = .184$, $\eta_p^2 = .05$, indicating that the self-referential optimism bias was significantly stronger than the other-referential optimism bias only in controls, but not in the ASD group. BDI did not have a significant relationship to the optimism bias measures (BDI, and *PERSON* × BDI, all $p > .271$). Given that the regression slopes were not equal across groups, because the relationships between the covariate BDI and OB_{SELF} and OB_{OTHER} were different across the ASD and the CON groups (see below for correlation analyses), we re-conducted the rmANOVA while including the BDI x *GROUP* interaction. While the interaction effect was indeed significant, $F(1,38) = 4.40$, $p = .043$, $\eta_p^2 = .10$, the results did not

considerably change, except that the main effect of *GROUP* was stronger, $F(1,38) = 10.71$, p = .002, $\eta_p^2 = .22$.

In the *CON* group, only OB_{SELF} was significantly different from zero, $t(20) = 4.35$, p = .001, $r = .70$, $M = 0.74$, $SD = 0.78$, but not OB_{OTHER}, $t(20) = 1.98$, p = .248, $r = .41$, $M = 0.24$, $SD = 0.56$. In the *ASD* group, none of the biases significantly differed from zero, OB_{SELF}, $t(20) = 1.89$, p = .296, $r = .40$, $M = 0.27$, $SD = 0.65$, OB_{OTHER}, $t(20) = -0.01$, p = 1, $r = .00$, $M = -0.00$, $SD = 0.81$.

In the ASD group, BDI did not correlate with OB_{SELF} ($r = .24$, p = .289) or OB_{OTHER} ($r = .35$, p = .122). In the control group, BDI correlated significantly with OB_{OTHER} ($r = -.46$, p = .038), but not with OB_{SELF} ($r = -.12$, p = .621). Further, in the ASD group, AQ correlated significantly with OB_{OTHER} ($r = -.47$, p = .031), but not with OB_{SELF} ($r = -.19$, p = .417). In the CON group the correlations between AQ and the bias measures were not significant (OB_{SELF}: $r = .19$, p = .419; OB_{OTHER}: $r = -.02$, p = .942). In addition, we tested for all possible correlations between task performance (OB_{SELF} and OB_{OTHER}) and participants' characteristics.[1] Significant relationships were found in the CON group between OB_{SELF} and intelligence-related measures (OB_{SELF} and FSIQ, $r = .48$, p = .030; OB_{SELF} and VIQ, $r = .53$, p = .013; OB_{SELF} and education years, $r = .43$, p = .049). None of these correlations were significant in the ASD group (OB_{SELF} and FSIQ, $r = -.23$, p = .334; OB_{SELF} and VIQ, $r = -.32$, p = .116; OB_{SELF} and education years, $r = .16$, p = .491).

The debriefing revealed that none of the subjects were aware of the task purpose relating to the optimism bias in belief updating. Also, none of the subjects doubted the authenticity of the base rates. Participants reported that some base rates appeared surprisingly low or high, but that was usually attributed to the fact that the probabilities were related to the whole population and to the entire lifetime. In fact, even after being informed about the task purpose and the manipulation of the base rates after the experiment, none of the subjects declared that they had been aware of either of these.

Discussion

Optimism bias in belief updating was generally weaker in the ASD group than in the control group. The groups differed with respect to the optimism bias particularly when judgments related to oneself, but not when they referred to others. Only the control group, but not the ASD group, demonstrated a significant self-related optimism bias in the first place (significantly greater than zero), and a significant difference between the biases relating to oneself vs. others. Thus, value-dependent asymmetry in belief updating was present solely in the control group for judgments relating to oneself, but was not evident for judgments relating to a similar other, or for any judgment in the ASD group. The reported effects were significant even after controlling for the influence of depression symptoms and the size of trial-by-trial estimation errors and initial risks estimates.

In accordance with previous studies (Eil and Rao 2011; Garrett and Sharot 2014; Korn et al. 2012; Kuzmanovic et al. 2015, 2016; Sharot et al. 2011), typically developing individuals tended to make larger self-related updates after good news (base rates of adverse events better than expected) than after bad news (base rates worse than expected). In addition, we have previously shown that the ventromedial prefrontal cortex tracks the positive value of self-related belief updates, as its activity increased both with increasing favorable and with decreasing unfavorable updates (Kuzmanovic et al. 2016). This region is one of the central nodes of the neural reward circuitry and has been robustly linked to the representation of positive values of rewards (Chase et al. 2015). Together, these findings support the critical role of motivational factors in the formation and maintenance of optimistic beliefs. While the task clearly triggers complex computations including episodic and inferential cognitive functions, in typically developing persons, these processes may be guided by a self-enhancing motive to reach a desired end-state of judgment (Hughes and Zaki 2015; Leary 2007). For instance, when estimating the risk of suffering from a heart attack and confronted with an undesirable base rate, a person may recall her healthy life style, but not her family history, and thus reach the conclusion that she has a lower risk than the average population, and that the presented base rate can thus be neglected.

We find it interesting that participants were not aware of value-dependent asymmetry in belief updating. Thus, when present, optimism bias in self-related belief updates appears to be a spontaneous phenomenon, unnoticed by the judging person. Moreover, solely in the control group, the self-related optimism bias correlated positively with the full scale and the verbal IQ, and with years of education. Given that the optimism bias in belief updating indicates deviations from formally rational learning, it is worth noting that higher intelligence and education did not prevent such irrational behavior, but that they were even associated with stronger influences of self-enhancing motives.

In contrast, individuals with ASD did not demonstrate systematically larger updates after desirable than after undesirable new information, independent of whether judgments related to themselves or to others. Thus, they showed

[1] Trait optimism was assessed only in the control group by using LOT-R, and correlated significantly with OB_{SELF} ($r = .58$, $p = .006$), but not with OB_{OTHER} ($r = .39$, $p = .081$), or with the difference between these two measures ($OB_{SELF} - OB_{OTHER}$; $r = .22$, $p = .332$). Note that this is not in full accordance to prior findings (Kuzmanovic et al. 2015, 2016).

a reduced susceptibility to the optimism bias in belief updating. Relative to the control group, the optimism bias was reduced particularly when judgments related to one's own future. Together, these findings corroborate the previous evidence for an increased rationality in in belief updating in ASD (Harris et al. 2013). In line with previous work showing equivalent results for the framing effect (De Martino et al. 2008), effort-based decisions (Damiano et al. 2012), and moral acceptability (Brewer et al. 2015), judgments of persons with ASD appear to be less strongly influenced by an initial emotional or motivational evaluation of the available information (Kahneman and Frederick 2007).

The present findings contribute to the understanding of difficulties in social communication and interaction in individuals with high-functioning autism. Interacting with others and understanding their intentions often requires the integration of emotional and motivational meanings of social cues, rather than the use of rule-based inferential reasoning (Schilbach 2015). More precisely, this emotional and motivational information has been shown to generate biases in judgment and decision making in typically developing individuals (De Martino et al. 2006; Kuzmanovic et al. 2016), but not in ASD (De Martino et al. 2008). Thus, the weaker influence of emotional value (here, the positive value of favorable self-related beliefs) and motivation (here, to adopt the best possible future outlook) on decision could generalize to the social cognition domain. Individuals with ASD indeed seem to have a reduced motivational predisposition to respond to social stimuli (especially subtle nonverbal signals), rendering these stimuli less able to bias (or guide) attention and conclusions (Klin et al. 2003; Kuzmanovic et al. 2011; Sevgi et al. 2016). Thus, rule-based or goal-oriented reasoning is well mastered in ASD, while the processing and integration of emotionally meaningful cues represents a serious challenge (Klin and Jones 2006; Klin et al. 2003; Kuzmanovic et al. 2011). In line with this, high-functional individuals with ASD were well able to understand the actions of others with respect to the assumption of rationality, i.e., the expectation that agents' actions are directed to a goal and are "the most functional way to achieve the goal within the constraints of the situation" (Marsh and Hamilton 2011; Marsh et al. 2015; Vivanti et al. 2011, p. 2). However, this ability was attenuated when nonverbal signals such as head and gaze direction had to be incorporated (Vivanti et al. 2011).

Given that ASD is a pervasive developmental disorder, it is likely that the enhanced rationality and the difficulties in social cognition influence each other in a bidirectional manner over the course of development. ASD-associated symptoms emerge in the first 2 years of life and affect multiple developmental domains, including not only social cognition, but also regulation and integration of attention, cognition, and emotion (Zwaigenbaum et al. 2013). As a consequence, cognition is less influenced by emotionally meaningful social cues, calling for, or allowing for a less biased reasoning.

On the other hand, enhanced rationality and reduced optimism bias in belief updating may also provide substantial resources. In contexts such as marketing and politics, a smaller susceptibility to emotionally and motivationally significant cues that are non-informative for the actual aim of the decision may be beneficial. Also, enhanced objectivity may be advantageous when planning complex projects, in which overconfidence and the neglect of possible obstacles would foster planning fallacy, and financial and psychological harm (Bortolotti and Antrobus 2015; Makridakis and Moleskis 2015).

Notably, reduced optimism bias in belief updating has not only been demonstrated in ASD, but also in individuals with depression (Garrett et al. 2014; Korn et al. 2014). Thus, although different underlying mechanisms are assumed, the expected performances in the belief update task would be identical for these two very different diagnoses. In depression, changes in emotional and motivational experience are attributed to phasic disturbances of brain function, with first onset usually in adulthood (Kessler et al. 2007). It is thus critical that we can assume that the reduced optimism bias in ASD cannot be attributed to increased depression. The group difference in optimism bias in the present study was significant despite controlling for depression scores. Moreover, depression sores did not have a significant effect on the update behavior, nor did they correlate with the size of the optimism bias in the ASD group. Only in the control group did depression scores correlate with the other-related optimism bias: the more depression symptoms participants reported, the less biased they were in judgments relating to others. Moreover, we found an inverse relationship between AQ scores and other-related optimism bias in the ASD group, indicating that the more autistic traits were reported, the smaller was the optimism bias in other-related judgments. However, as the other-related optimism bias was relatively small in both groups, we do not regard these relationships as meaningful.

Future research may benefit from extended experimental designs assessing the subjective perception of estimation errors, which is dependent on the base rate a subject initially assumed (for more details see Garrett and Sharot 2014; Kuzmanovic et al. 2015; Kuzmanovic and Rigoux 2016; Shah et al. 2016; Sharot and Garrett in press). Moreover, computational modeling may allow to identify different phenotypes of decision making for diagnostic purposes. In depression, such computational phenotypes may relate to reduced hedonic capacity, or to lower expected values of outcomes and greater attention to negative stimuli, while in autism the failure to contextualize cues may be more influential (Friston et al. 2014; Huys et al. 2015, 2013; Pizzagalli et al. 2008). In addition, neuroimaging techniques could be used to identify

specific neurobiological substrates that may provide additional empirical support for differential mechanisms underlying increased rationality in ASD and depression.

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Author Contributions B. Kuzmanovic and K. Vogeley developed the study concept and the research question. B. Kuzmanovic developed the experimental design. B. Kuzmanovic and L. Rigoux performed the data analysis. B. Kuzmanovic drafted the manuscript, and K. Vogeley and L. Rigoux provided significant and extended further contributions. All authors approved the final version of the manuscript for submission.

Compliance with Ethical Standards

Conflict of Interest All authors declare that they have no conflict of interest.

Ethical Approval All procedures performed were in accordance with the ethical standards of the local ethics committee of the Medical Faculty of the University of Cologne, Germany and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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