Retrieval Effects of Observationally Acquired Stimulus-Response Bindings in Participants With High and Low Autistic Traits

Carina G. Giesen, Lena Husken, and Dana Schneider
Department of Psychology, Friedrich Schiller University Jena

The present study sought to use a paradigm that allows the study of mental representations of observed actions. We investigated whether retrieval of *observationally acquired stimulus–response bindings* are impaired in participants with high (compared with low) autistic traits. In an extreme group comparison, participants with high versus low autistic traits worked through an observational SR binding and a standard SR binding task (to control for general deficits in cognitive performance). As expected, groups did not differ with regard to retrieval of transient bindings between stimuli and self-performed responses (standard SR binding & retrieval effects). Against our expectations, the same was true for the retrieval of observationally acquired SR bindings, which was of comparable magnitude in both high and low autistic trait groups. Bayes Factor analysis indicates that our evidence for this null finding has to be regarded as weak evidence. Our findings provide tentative evidence against the view that imitative effects are reduced (hypo-imitation) or increased (hyper-imitation) when autistic trait expression is high.

Public Significance Statement
This study shows that individuals with high autistic trait expression do not differ from individuals with low autistic traits in their capability to mentally represent actions that were observed in another person. This argues against any autism-related impairment of mentally representing observed actions. Mental representation of observed actions is comparable with mental representation of self-initiated actions in individuals with high autistic trait expression. Individuals with high autistic traits therefore show effects of imitative action regulation, reflected in automatic retrieval of transient episodic associations between stimuli and observed responses, to a similar degree as individuals with low autistic trait expression.

Keywords: action imitation, autism-spectrum disorder, autistic traits, observational learning, stimulus-response binding

A prominent finding from research on mental action representation shows that action observation will activate corresponding motor representations in the observer, which means that observed and to-be-executed actions are mentally represented in the same format (e.g., common-coding view, Hommel et al., 2001). Evidence for this comes from behavioral studies on stimulus–response compatibility tasks in which participants have to execute actions that are (in-)compatible with observed actions (e.g., *automatic imitation* task; Brass et al.,

2001; Heyes, 2011). This assumption is further supported by findings from neurophysiological studies on so-called *mirror neurons* in monkey as well as human brains. These neurons discharge both during action observation and action execution and thus presumably play a fundamental role in understanding actions of others, action imitation, and observational learning (e.g., Rizzolatti & Craighero, 2004).

Interestingly, action observation will not always automatically activate corresponding motor representations in observers. Indeed, a range of findings suggest that this process is possibly impaired in individuals with an autism spectrum disorder (Chan & Han, 2020; Dapretto et al., 2006; Spengler et al., 2010; Vivanti & Hamilton, 2014; Williams et al., 2006). The autism spectrum disorder (ASD) is a neurodevelopmental disorder with core deficits affecting social interaction and communication, a marked preference for restrictive and repetitive patterns of behavior, limited imagination and perspective-taking skills, as well as narrow interests (American Psychiatric Association, 2013; Schneider et al., 2017). Social impairments include difficulties interpreting social cues (Moriuchi et al., 2017), difficulties coordinating attention (Mundy et al., 1994) and interactive turn-taking (Trevarthen & Daniel, 2005) as well as difficulties in tracking the mental states of others (Schneider et al., 2013).

To examine how the mental representation of observed actions might relate to ASD, we took a dimensional/continuum approach and compared performance in individuals with low levels of subclinical, autistic-like features with those who exhibit high levels of autistic traits. This approach models ASD and offers several advantages that can outweigh the disadvantage of not examining an ASD population directly (Landry & Chouinard, 2016). For example, this dimensional approach of studying autism traits in the general population allows increased ability to control for IQ differences and comorbidity, which can confound clinical ASD research. At the same time, participants with higher autism traits may demonstrate just as much relative difficulties in basic motor or executive functioning when compared with low autism trait individuals (Curioni et al., 2017). In fact, there is now much research indicating that differences in social behavior processing extend into the nonclinical population with higher autism traits (Amoruso et al., 2018; Jameel et al., 2014; van Boxtel et al., 2017). In summary, there is an increasing appreciation that cognitive, perceptual, and behavioral anomalies associated with autism traits in the general population can provide valuable insight into understanding ASD.

Theoretical Views on ASD-Specific Discrepancies

According to some researchers, these ASD-specific discrepancies in mentally representing observed actions are a consequence of atypical functioning of the mirror neuron system (*Broken Mirror Theory*, Iacoboni et al., 1999; Ramachandran & Oberman, 2006). Assuming that the mirror neuron system is (a) relevant for mentally representing observed actions but (b) impaired in ASD, a straight-forward prediction emerges: Individuals with ASD should perform worse than control participants in behavioral tasks for which mental representation of observed actions is essential (Williams, 2008). However, alternative theories are also discussed. For instance, some researchers assume that ASD is characterized by deficient *control* of the mirror neuron system (rather than by a deficient mirror neuron system itself), which implies that individuals with ASD cannot mentally distinguish between self and other and hence have a deficit in *controlling* imitative behavior, which can lead to hyper-imitation (excessive imitative behavior), rather than reduced imitative behavior (Spengler et al., 2010). Finally, according to the social top-down response modulation (STORM) account (e.g., Forbes et al., 2016; Wang & Hamilton, 2012), basic mechanisms that are involved in imitation are intact in individuals with ASD. However, these individuals fail to respond on social cues (e.g., eye-contact or gaze) that indicate whether actions should be copied or not.

Evidence for ASD-Specific Discrepancies in Mentally Representing Observed Actions

To date, empirical research findings that test the various theoretical accounts are inconsistent, at least when compatibility-based measures of observed action representation are used. A number of studies compared performance of individuals with ASD and typically developed control participants in the *automatic imitation* task (e.g., Brass et al., 2001). Whereas some studies indeed report stronger imitation effects in ASD individuals compared with controls (Spengler et al., 2010; for a detailed overview and discussion, see Cracco et al., 2018), other studies report that performance of individuals with ASD in the automatic imitation task was (at least) comparable with controls (Gordon et al., 2020; Hamilton et al., 2007; Press et al., 2010; Sowden et al., 2016), thus reflecting neither hypo- nor hyper-imitation. This conclusion is supported in a recent meta-analysis which did not find performance differences in the automatic imitation task between individuals with ASD and controls (Cracco et al., 2018). In addition, in a joint compatibility task (the *joint Simon* task), Sebanz et al. (2005) compared performance of individuals with ASD and controls and also failed to find any group-specific performance differences, indicating that individuals with ASD represent (observed) actions of their coactors to a similar extend as controls.

Tentatively, these findings argue against ASD-specific discrepancies in mentally representing observed actions from others, at least when compatibility-based measures are concerned. However, this conclusion is somewhat compromised because both discussed paradigms are confronted with a number of challenges. For instance, there is an ongoing debate whether the automatic imitation task allows to study effects of individual differences of social personality dimensions (including autistic traits, Butler et al., 2015; Genschow et al., 2017; Hedge et al., 2018; for a discussion, see Ramsey, 2018). With regard to the joint compatibility task by Sebanz et al. (2003), research has recently promoted alternative, nonsocial interpretations. According to the *referential coding* view (Dolk et al., 2013; see also Dittrich et al., 2012), joint compatibility effects may arise from any sufficiently salient, attention grabbing event that provides a reference for coding one's own action spatially. For instance, Dolk et al. (2013) demonstrated a joint compatibility effect in *nonsocial* conditions, that is, when participants sat next to a Japanese waving cat or a prominent clock while performing the task. Thus, it is possible that the joint compatibility effect in individuals with ASD (Sebanz et al., 2005) emerged because these participants were particularly prone to referential coding and coded their action in spatial terms. This alternative interpretation implies that finding robust joint compatibility effects in ASD individuals cannot unequivocally be interpreted as evidence for action corepresentation.

Against this background, we aimed for an independent, conceptual replication of the findings yielded with the automatic imitation and joint Simon task when comparing performance of individuals with ASD and controls. To this end, we used the *observational stimulus-response binding* paradigm that allows to study mental representation of observed actions.

The Observational Stimulus-Response Binding Paradigm

Executing a response to a stimulus will result in a transient stimulus-response (SR) binding in memory (Frings et al., 2020; Hommel et al., 2001). If, for instance, the stimulus is repeated on a subsequent encounter (e.g., the next trial), the entire SR binding is retrieved, including the associated response, which will facilitate or hamper performance (depending on whether the retrieved response is appropriate or not). Intriguingly, findings from Giesen and colleagues (2014, 2017, 2018, 2021) document that SR bindings can be acquired solely on the basis of observing a response in another person. Similar to bindings between stimuli and self-executed responses, observationally acquired SR bindings can be

retrieved from memory by stimulus repetition on a subsequent trial.

Retrieval of observationally acquired SR bindings depicts a situation in which responses that were merely observed in others are used in the service of one's *own* action regulation. There is a close resemblance between observationally acquired SR bindings and phenomena known from *Social Learning Theory* (e.g., Bandura, 1986). These resemblances concern a range of moderating conditions which determine whether an observed action will also be shown in one's own action repertoire or not. For instance, stimulus-based retrieval of observationally acquired SR bindings occurs only if responses were observed in (a) socially relevant others, as for instance, interaction partners with whom one is cooperating or competing (Giesen et al., 2014), or one's own romantic partner

(Giesen et al., 2018). Furthermore, retrieval of observationally acquired SR bindings is contingent on (b) vicarious reinforcement and is pronounced for observed actions that were followed by positive feedback (Giesen et al., 2017). Together, these findings support the view that retrieval of observationally acquired SR bindings is responsive to social states modulations. However, it is yet unclear whether the task is also responsive to modulations of social traits, which motivated the present study.

The observational SR binding paradigm (Giesen et al., 2014) consists of a color categorization task that is shared between two participants who sit opposite to each other in front of two computer screens (Figure 1a). Participants classify the color of word stimuli as red or green via key press in an alternating fashion. The task has a sequential design: One participant is the *actor* and sees

Figure 1

Schematic Display of Experimental Set-Up and Trial Procedure for (a) the Observational SR Binding Paradigm and (b) the Standard SR Binding Paradigm
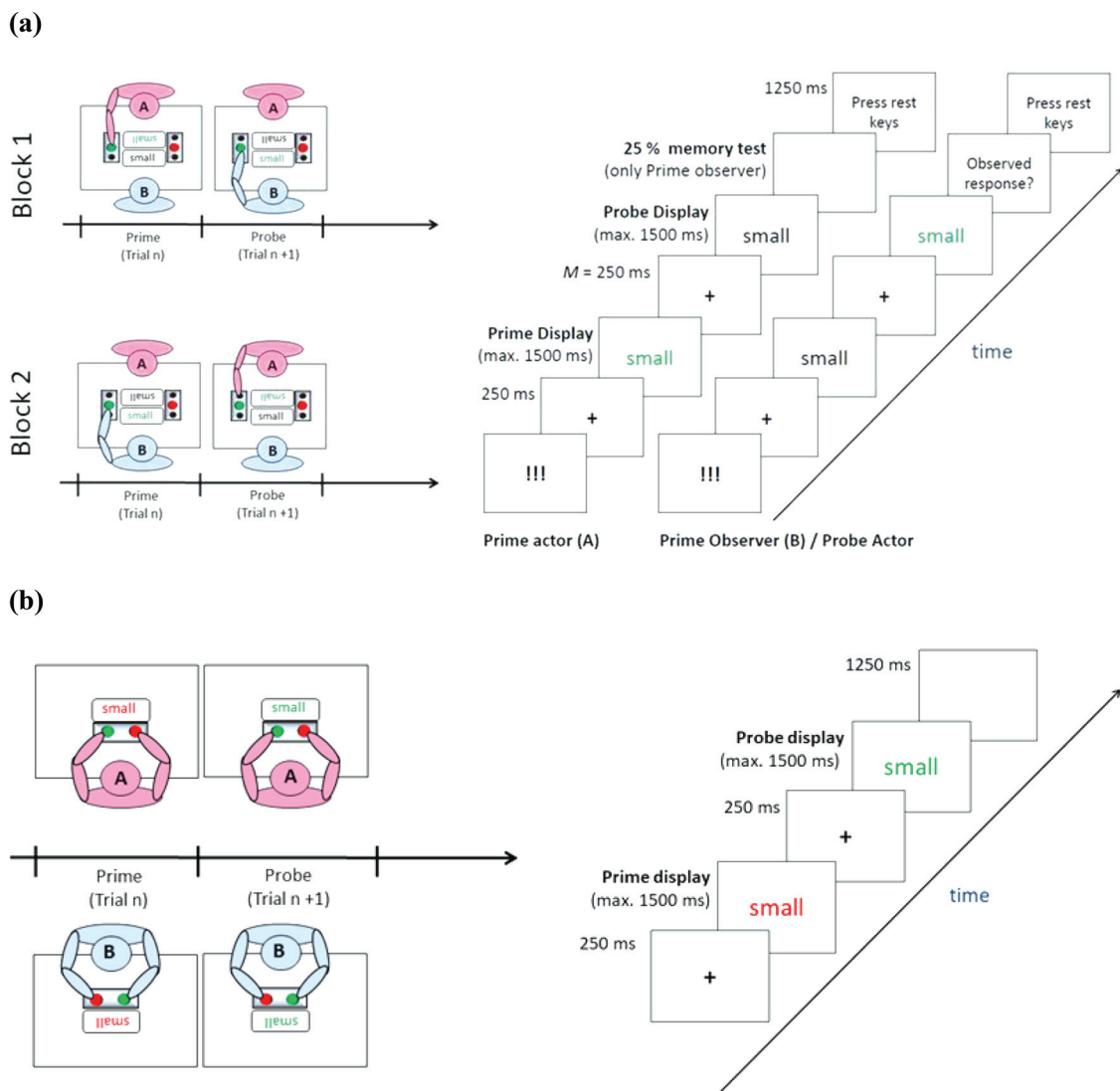
Note. SR = stimulus repetition. For illustrative purposes, background and neutral font colors are inverted. Stimuli are not drawn to scale. See the online article for the color version of this figure.

the word stimulus in red/green and has to classify the color in a first (*prime*) trial; the other participant is prime *observer* and sees the same word, but only in white font, and has to observe the response of the actor. In the subsequent (*probe*) trial, participants switch roles, meaning that the former prime observer becomes actor in the probe and has to classify the color of a red/green word; in turn, the former prime actor becomes probe observer and sees the word only in white font and has to observe the actor's response. Across a sequence of prime-probe trials, words can either repeat or change from prime to probe (factor Stimulus Relation). Required probe responses are either compatible or incompatible with observed prime responses (factor Response Compatibility). If observing the response of another person to a presented word stimulus is sufficient to create a transient SR binding in prime observers, repetition of the previous prime word in the subsequent probe trial should trigger retrieval of the observed response when prime observers become actors during the probe trial. If the retrieved observed response is compatible with to-be-executed probe responses, this speeds up response selection, which is reflected in faster probe performance (compared with prime-probe sequences with different words in prime and probe trials). However, when the retrieved observed prime response is incompatible with to-be-executed probe responses, retrieval interferes with response selection, which impedes probe performance on sequences with stimulus repetition versus stimulus change. Thus, retrieval of observationally acquired SR bindings is reflected in performance benefits (on sequences in which observed prime and to-be-executed probe responses are compatible) and performance costs (on sequences in which observed prime and to-be-executed probe responses are incompatible). Analogously to retrieval of SR bindings with self-performed responses, the net effect of both performance benefits and costs attributable to stimulus-based retrieval of observationally acquired SR bindings is reflected in a Stimulus Relation $\times$ Response Compatibility (S $\times$ C) interaction for probe trials.

Aims of the Present Study

The present study investigated whether acquisition and retrieval of observational SR bindings differs between participants with high degree levels of autistic traits. Ultimately, this not only gave us the opportunity to explore ASD as a further potential moderator. It also gave us the chance to test, for the first time, whether the observational SR binding paradigm is related to social traits, which would be an important new insight in the process of construct validating the observational SR binding paradigm. Thus, we were interested whether participants which high autistic trait expression would show any evidence for retrieval of observational SR bindings (Research Question 1). Furthermore, we were also interested in comparing retrieval effects of observational SR bindings between participants with high versus low autistic traits (Research Question 2).

To address both questions, participants were invited based on their Autism-Spectrum Quotient score (AQ; Baron-Cohen et al., 2001), sampled in a prescreening. Participants with a high versus low degree levels of autistic traits then worked through the observational SR binding paradigm and a standard SR binding paradigm. The latter was added to control for general deficits in cognitive performance in the high AQ sample. Assuming that action observation will not automatically activate motor representations in high AQ participants or will do so only in a reduced

manner, we expected that retrieval effects of observationally acquired SR bindings should be reduced in this sample. Accordingly, retrieval effects of observationally acquired SR bindings should not differ from zero in high AQ participants (Research Question 1) and should also be significantly reduced compared with low AQ participants (Research Question 2). When we planned the study, we expected to observe reduced retrieval effects in high compared with low AQ participants, which is consistent with the hypo-imitation pattern predicted by the Broken Mirror Theory. Thus, Research Question 2 was initially planned as a directional test. However, we want to point out that we can also derive conclusions regarding the other theoretical accounts based from the present data. In detail, increased retrieval effects would indicate hyper-imitation (following the idea that self-other differentiation is impaired in ASD, Spengler et al., 2010). Comparable retrieval effects between high and low AQ participants, in turn, would support the STORM account (Wang & Hamilton, 2012), indicating that basic imitative mechanisms are intact even in individuals with high autistic trait expression We want to point out that this insight was post hoc and occurred to us only after the data were analyzed (see Result section for details). Third, we did not expect any group-specific differences with regard to retrieval of SR bindings between stimuli and self-executed responses. Hence, significant retrieval effects of self-executed SR bindings should be obtained in high AQ participants; furthermore, these retrieval effects should not differ from low AQ participants.

Method

Required Sample Size

Research Question 1 corresponded to a directional *t* test against zero for observationally acquired S $\times$ C interaction (S$\times$C$_{observe}$) effect scores within the high AQ subsample (see Table 1 for computation of effect scores). We performed a mini meta-analysis on published studies with the observational SR binding paradigm ($k = 3$, Giesen et al., 2014, 2017, 2018). For Stimulus Relation $\times$ Response Compatibility interaction effect scores (within participants comparison) in the observational SR binding paradigm, the analysis yielded a mean effect size of $dz = .40$; for modulations observationally acquired SR binding and retrieval effects, the analysis yielded a mean effect size of $d = .37$. According to the G*Power software package (Faul et al., 2007), $n = 41$ participants are needed to detect an effect of $d_z = .40$, with $\alpha = .05$ and $1 - \beta = .80$, in a one-tailed *t* test (one-sample case). Research Question 2 was planned to test predictions derived from the Broken Mirrors theory, which corresponds to a directional, independent-samples *t* test to compare observationally acquired S $\times$ C interaction effect scores between high and low AQ participants. According to G*Power, n = 92 participants per group are needed to detect an effect of $d = .37$ with $\alpha = .05$ and $1 - \beta = .80$, in a one-tailed *t* test (independent groups). We want to inform the reader that during the review process, we detected an error in the computation of effect size estimates for the minimeta analysis. Thus, the effect sizes that were used for a priori power calculations were overestimated when we planned how many participants had to be recruited. We corrected this and now report the proper effect

Table 1

Sample Demographics, Means (M), and Standard Deviations (SD) for Manipulation Checks and Probe Performance in the Observational and Standard SR Binding Paradigm

	Group				Group comparison		
Measure	Low AQ ($\leq$14)		High AQ ($\geq$17)		$t(74)$	p	d
Demographics							
Sample size *n*	35		41				
Gender *n* female (%)	18 (51%)		22 (54%)				
M Age (*SD*)	21.2 (3.1) y		23.6 (6.6) y				
M AQ Score (range)	10 (4−14)		21 (17−35)		13.17	<.001	3.02
Manipulation checks, observational SR binding task							
Situation perceived as…							
…comfortable (1) vs. uncomfortable (7)	2.86 (1.08)		2.86 (0.98)		0.02	.984	0.00
…cooperative (1) vs. competitive (7)	2.71 (1.60)		3.29 (1.79)		1.47	.145	0.34
Partner perceived as…							
…agreeable (1) vs. disagreeable (7)	2.05 (0.91)		2.06 (1.01)		0.04	.969	0.01
Acquaintance							
not at all (1) vs. very well (5)	1.91 (1.29)		1.43 (1.12)		1.72	.090	0.39
Memory test performance, *M* error rate (*SD*)	2.22 (2.95)		2.44 (3.33)		0.29	.771	0.07
Probe performance	C	IC	C	IC			
Observational SR binding paradigm							
Stimulus repetition (SR)	457 (42)	471 (47)	471 (70)	474 (74)			
Stimulus change (SC)	465 (42)	470 (44)	477 (72)	472 (69)			
ΔSC–SR	8 [2.6]	−1 [2.4]	6 [2.4]	−2 [2.6]			
S × C$_{observe}$	9 [3.9]		8 [3.8]				
Standard SR binding paradigm							
Stimulus repetition (SR)	351 (36)	380 (42)	355 (39)	387 (50)			
Stimulus change (SC)	361 (41)	375 (38)	362 (43)	386 (48)			
ΔSC-SR	10 [1.7]	−5 [2.2]	7 [1.9]	−1 [2.2]			
S × C$_{standard}$	15 [3.1]		8 [3.1]				

Note. C = compatible; IC = incompatible; AQ = Autism-Spectrum Quotient score. S × C interaction effect scores are computed as net effects of stimulus repetition effects (Δ SC–SR) for compatible minus incompatible sequences (S × C = [SC − SR]C − [SC − SR]IC); positive values reflect stimulus-based retrieval of previous responses, due to benefits for prime-probe sequences with compatible responses and costs for sequences with incompatible responses Standard error of the mean in brackets.

sizes that were yielded in the mini meta-analysis (see previous paragraph). Based on recruited sample sizes, we have sufficient power to address Research Question 1 but are underpowered to address Research Question 2. We come back to this issue in the Discussion.

Participants

The study took place during a predetermined time period during which the lab was available. However, recruitment was more challenging than expected. In the given time window, we managed to recruit 76 students from the Friedrich-Schiller-University Jena. Participants were recruited based on their AQ scores (Baron-Cohen et al., 2001; full version; German version by Freitag et al., 2007), collected in screening studies organized by the authors. We focused on extreme groups, thus only people with low AQ ($\leq$ 14; *n* = 35) or high AQ ($\geq$ 17; *n* = 41; see Table 1 for demographics of extreme groups) scores were analyzed. Experimental sessions lasted 50–60 minutes. Participants gave written informed consent and received partial course credit or 6€ and sweets for their participation. Ethical approval of this study was granted by the Ethics committee of the FSU Jena (FSV19/01).

Design

Both experimental paradigms (i.e., the observation and standard SR binding paradigm) used a 2 × 2 × 2 mixed factor sequential prime-probe design with the within subject factors stimulus relation and response compatibility and the between subject factor group. Stimulus relation was manipulated by repeating or changing the stimulus word from prime to probe (50% stimulus repetition, e.g., small-small; 50% stimulus change, e.g., quiet-small). Response compatibility was manipulated by requiring probe responses that were in-/compatible with self-executed or observed prime responses (50% compatible, e.g., red-red/green-green; 50% incompatible, e.g., green-red; red-green). Prime word color was counterbalanced. Group was manipulated by testing participants with high and low AQ scores, respectively. Probe reaction time (RT; measured as release of rest-state keys in the observational SR binding task and as key press in the standard SR binding task) served as dependent variable.

Procedure

Always two participants took part in an experimental session. Participants performed the standard SR binding task alone (see Figure 1b). The observational SR binding task was performed by both participants together (see Figure 1a). Order of tasks was counterbalanced across pairs of participants. Both tasks were programmed with E-Prime 2 and used short and neutral German adjectives (e.g., quiet, small, etc.) as stimuli, presented in Times New Roman 16 pt. font in the center of a black screen.

Observational SR Binding Paradigm

Participants performed the observational SR binding task in pairs (see Figure 1a). Both participants sat opposite each other at a

table, each with a 19" monitor in front of them (blocking direct eye-contact). Participants were not allowed to talk or communicate with each other. Responses were collected with two response pads, connected to the computer via a parallel port. Each response pad had a large red or green buzzer button in the middle, framed by two small rest-state keys in front of/behind the buzzer button. Response pads were fastened to the table on the left and right side of the monitor. Participants placed their left and right hands on each rest-state key in front of them and kept these constantly pressed. Only if they had to execute a color categorization response, participants let go of the respective rest-state key to hit the corresponding red or green buzzer button. Instructions were given on screen. The task started when both participants finished reading the instructions and signaled their readiness by pressing down both rest-state keys. Both participants (termed A and B) had the task to categorize the color of word stimuli. Importantly, this task was executed in an alternating fashion, meaning that only one participant executed the color categorization task, whereas the other participant observed the response that was executed.

Each prime-probe sequence started with a ready signal ("!!!," 500 ms), followed by a fixation cross (250 ms) presented in white font on a black screen. Then, the prime display started in which a word stimulus appeared. The word was identical for both participants. However, only participant A (the prime actor) saw the word stimulus in red or green and was able to execute the color categorization task; the other participant B (prime observer) saw the same word stimulus in white font only. The word stayed on screen until the prime actor executed the color categorization response or until 1500 ms had elapsed. Then, another fixation cross appeared (250 ms), followed by the probe display in which another word stimulus appeared. Again, both participants saw the same word; however, this time, participant B (probe actor) saw the word in red or green and had to execute the color categorization response, whereas participant A (probe observer) saw the word in white font only. Again, the probe word stimuli remained on screen until the probe actor executed the color categorization response or until 1,500 ms had elapsed. In 25% of all prime-probe sequences, a memory test appeared after the probe display that was visible only for prime observers/probe actors (i.e., participant B). They were asked to indicate which response they observed by pressing down the corresponding color key. For the other participant A, the screen stayed black during the memory test. The sequence ended with a black screen that reminded participants to press down both rest-state keys (1,250 ms), after which the next sequence started.

Participants worked through 32 practice sequences and two blocks of 160 experimental prime-probe sequences. To get probe performance measures from both participants, they switched the roles of prime observer/probe actor between blocks (e.g., participant B was prime observer/probe actor in block 1; but participant A was prime observer/probe actor in block 2). For both blocks, participants cooperated to get an extra reward (i.e., sweets) if the performance of the pair fulfilled preset criteria for speed and accuracy ("positive interdependency" condition of Giesen et al., 2014). To maintain this cooperative focus, participants received feedback on their own and their partner's performance after a block of 40 prime-probe sequences (visible for 10 s). At the end of the observational SR binding task, participants received a brief questionnaire. On 7-point Likert scales, participants rated the experimental situation (three items: *difficult/uncomfortable/negative* [1] vs.

easy/comfortable/positive [7]; means were averaged to a *situation* score), interaction style (one item: *competitive* [1] vs. *cooperative* [7]), and agreeableness of their interaction partner (four items: *unsympathetic/insecure/unfriendly/incompetent* [1] vs. *sympathetic/confident/friendly/competent* [7]; averaged to a composite *partner* score). Furthermore, they reported the degree of acquaintance with their interaction partner (1 = *not at all*; 5 = *very well*).

Standard SR Binding Paradigm

Each participant worked through the standard SR binding paradigm individually on a notebook with 17" monitor (Figure 1b). Instructions were given on screen. For both prime and probe displays, participants had the task to classify the color of a presented word stimulus via pressing the A or L key for red or green words, respectively.

Every prime-probe sequence started with a ready signal ("!!!," 500 ms), followed by a fixation cross (250 ms) presented in white font on a black screen. Then, a red or green word stimulus appeared in the prime display (until response/max. 1,500 ms), followed by another fixation cross (250 ms). Then, another red or green word stimulus appeared in the probe display (until response/max. 1,500 ms). After a blank screen (1,250 ms), the next prime-probe sequence started. Participants worked through 16 practice and 160 experimental prime-probe sequences that were constructed according to the factorial design. After both tasks were completed, all participants were fully debriefed and compensated for their participation.

Results

Raw data and analyses scripts are available online and can be accessed at https://osf.io/fz7x5. Analyses were performed with R (Version 3.6.1). Bayes Factor computations were performed with JASP (Version .14.1).

Manipulation Checks

As expected, mean AQ scores (see Table 1) were significantly higher in the high AQ sample, compared with the low AQ sample, $t(74) = 13.17$, $p < .001$, $d = 3.02$.

We computed mean ratings for all scores of the questionnaire answered after the observational SR binding paradigm. Ratings of both subgroups (see Table 1) showed that participants perceived the situation as cooperative and comfortable and perceived their interaction partner as agreeable, Importantly, no group differences were obtained on these scores (all ps > .09, see Table 1). Thus, the induction of a cooperative focus was successful in both groups.

In addition, memory test performance (measured in mean error rates, see Table 1) in the observational SR binding paradigm did not differ significantly between participants of high and low AQ scores, $t(74) = .29$, $p = .771$, $d = .07$. Thus, we can conclude that participants of both groups attended to observed prime responses and memorized them equally well.

Probe Performance

Observational SR Binding Paradigm

Release RT of probe actors were analyzed. Prior to all analyses, prime-probe sequences with (a) erroneous responses of the prime

and/or probe actor (2.2%), (b) wrong responses in the memory test (2.4%; overall: .5%), and (c) probe release RT faster than 250 ms or slower than 1.5 interquartile ranges above the 75th percentile of the individual RT distribution were regarded as outliers (Tukey, 1977) and were excluded (3.0%). Means for the factorial design are presented in Table 1. We computed effect scores for each participant representing the Stimulus Relation × Response Compatibility (S × C) interaction which indicates stimulus-based retrieval of observed responses. To address Research Question 1, effect scores for high AQ participants were then tested against zero in a directional test. Against our expectation, this difference was significant, $t(40) = 2.10$, $p = .021$ (one-tailed), $dz = .33$, $BF_{10} = 2.362$. Furthermore, we analyzed effect scores as a function of group (Research Question 2). Whereas the Broken Mirrors Theory makes a directional prediction (i.e., greater retrieval effects in low vs. high AQ individuals), the hyper-imitation account predicts the reverse pattern (greater retrieval in high vs. low AQ individuals), whereas the STORM predicts comparable effects between high and low AQ individuals. To match the different theoretical predictions, we ran nondirectional instead of directional tests, as the directional test would only allow us to test the predictions of the Broken Mirrors account. We computed two-sided, independent samples t tests to test whether retrieval effects differ between low and high AQ participants. This difference was not significant, $t(74) = .10$, $p = .922$, $d = .02$, $BF_{01} = 3.900$ (see Figure 2a). Both findings imply that retrieval effects of observationally acquired SR bindings are robust in high AQ participants and are of comparable magnitude as in low AQ participants.

Standard SR Binding Paradigm

Only probe RT were analyzed. Prior to analyses, prime-probe sequences with erroneous prime and/or probe responses (6.0%) and probe RT outlier values (4.2%) were excluded. Means for the factorial design are presented in Table 1. As before, we computed effect scores for each participant representing the Stimulus Relation × Response Compatibility (S × C) interaction which now indicates stimulus-based retrieval of self-executed responses. Effect scores for high AQ participants were then tested against zero in a directional test. In line with our expectation, this difference was significant, $t(40) = 2.66$, $p = .006$ (one-tailed), $dz = .41$, $BF_{10} = 7.251$. Furthermore, we analyzed effect scores as a function of group in two-sided, independent t tests to test whether retrieval effects of standard SR bindings differ between low and high AQ participants. This difference was not significant, $t(74) = 1.57$, $p = .120$, $d = .36$, $BF_{01} = 1.456$ (see Figure 2b). Both findings imply that retrieval effects of standard SR bindings are robust in high AQ participants and are of comparable magnitude as in low AQ participants.

Correlations

For exploratory purposes, we ran correlations with individual interaction effect scores from both binding tasks and the AQ subscales (see Table 2). Correlations of .30 or higher are considered as informative for exploratory purposes; note however that when alpha level was Bonferroni adjusted to control for multiple comparisons, no correlation was significant (new alpha: .05/36 = .0013). In the high AQ subsample, we obtained a negative correlation between retrieval of observational SR bindings and the

Figure 2

S × C Interaction Scores for (a) Retrieval of Observationally Acquired SR Bindings and (b) Retrieval of Standard SR Bindings as a Function of AQ-Group

(a)

(b)
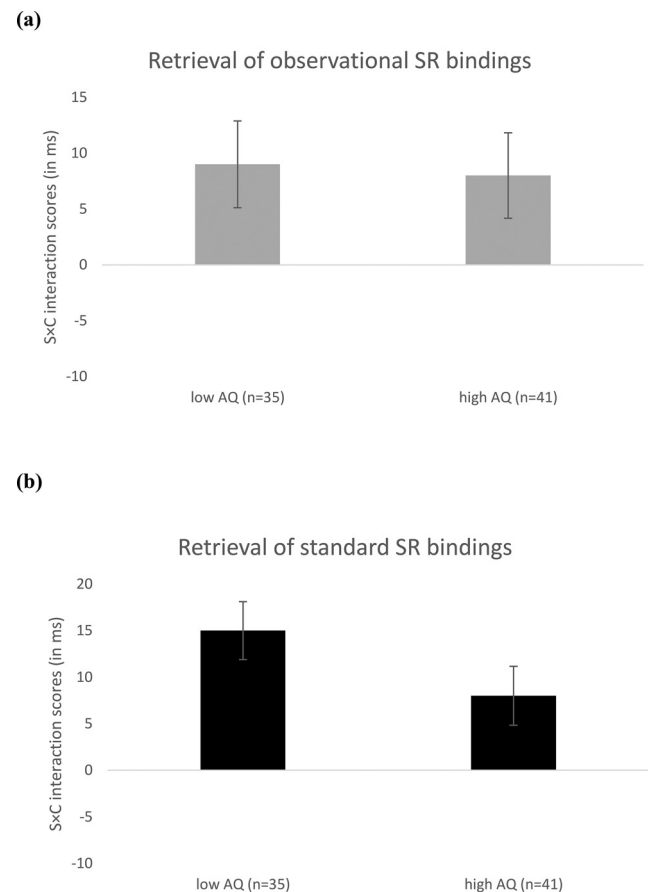
Note. S × C interaction scores are computed as net effects of stimulus repetition effects (Table 1) for compatible plus incompatible sequences (S × C = $|[SC - SR]C| + |[SC - SR]IC|$); positive values reflect stimulus-based retrieval of previous responses, owing to benefits for prime-probe sequences with compatible responses and costs for sequences with incompatible responses. Error bars depict standard errors of the mean. SR = stimulus repetition; AQ = Autism-Spectrum Quotient score.

"attention to detail" subscale, $r(38) = -.33$, $p < .044$ (meaning that exceptional attention to detail went along with reduced retrieval of observational SR bindings). Also, retrieval of standard SR bindings and the AQ total score correlated positively, $r(41) = .31$, $p = .050$ (indicating that retrieval of standard SR bindings increased with higher AQ scores). In the low AQ subsample, we found a negative correlation between retrieval of observational SR bindings and the "attention switching" subscale, $r(28) = -.36$, $p = .063$ (indicating that poor attentional switching went along with reduced retrieval of observational SR bindings), whereas this subscale correlated positively with retrieval of standard SR bindings, $r(28) = .42$, $p = .026$, (meaning that better attentional switching went along with stronger retrieval of standard SR bindings). This shows that attentional switching is important as attentional processes are beneficial for the emergence as well as retrieval of SR bindings (Frings et al., 2020). Tentatively, this could be seen as a

Table 2

Correlations Between Individual Interaction Effect Scores, Reflecting Retrieval of Observationally Acquired or Self-Performed SR Bindings (Higher Values Represent Stimulus-Based SR Retrieval), Total AQ Score, and Scores for Each of the Five AQ Subscales

Sample	AQ Score	AQ_SS	AQ_AS	AQ_AD	AQ_C	AQ_I
Full sample	n = 76			n = 66[a]		
S × C Observational SR Binding	−.04	.02	−.16	−.22	.05	−.07
S × C Standard Binding Task	−.07	−.04	.11	.00	−.24	−.08
High AQ	n = 41			n = 38[a]		
S × C Observational SR Binding	.06	.18	−.06	−.33	.29	.04
S × C Standard Binding Task	.31	.17	.12	.23	−.25	.11
Low AQ	n = 35			n = 28[a]		
S × C Observational SR Binding	−.28	−.31	−.36	−.12	−.29	−.26
S × C Standard Binding Task	−.04	−.24	.42	−.18	.11	−.10

Note. AQ = Autism-Spectrum quotient; AQ_SS = social skills; AQ_AS = attention switching; AQ_AD = attention to detail; AQ_C = communication; AQ_I = imagination; S × C = individual Stimulus Relation × Response Compatibility interaction scores (cf. Table 1 for effect computation). Unfortunately, AQ subscale scores were not permanently stored for ten participants (seven low, three high AQ subsample), who were thus not considered for correlational analyses. Reliability (Cronbach's α) for AQ scales were α = .80 (total AQ score), α = .78 (AQ_SS), α = .51 (AQ_AS), α = .70 (AQ_AD), α = .63 (AQ_C), and α = .50 (AQ_I).
[a] Reduced sample size for correlations with subscales.

first indication that especially social-attentional processes are of relevance for the observational SR binding paradigm. Clearly, independent replication of these exploratory findings is needed.

Discussion

In the present study, participants with high and low levels of autistic traits were tested with an observational SR binding paradigm which assesses transient binding effects between stimuli and responses that are observed in another person. We tested the hypothesis that acquisition of observational SR bindings is diminished in participants with high levels of autistic traits, due to an impairment of adequately representing observed actions (Chan & Han, 2020; Dapretto et al., 2006; Spengler et al., 2010; Vivanti & Hamilton, 2014; Williams et al., 2006). However, the obtained data contradict this reasoning. Retrieval effects of observationally acquired SR bindings were robust in high AQ participants and were of comparable magnitude in the high and low autistic trait group. This argues against a deficit of mentally representing observed actions in participants with high degree of autistic traits.

Limitations

We want to point out that this conclusion is based on the interpretation of a nonsignificant test result for the group comparison. One might argue that this comparison is underpowered because we did not achieve the required sample sizes as computed with the a priori power analyses. However, the nonsignificance of the group comparison simply results from the fact that high AQ participants showed evidence for retrieval of observational SR bindings (which was based on a sufficiently powered test). Thus, the *actual* pattern of effects shows that retrieval effects are present and of equal size in both groups. When evaluating these results, one also has to keep in mind that our initial hypothesis predicted smaller or even absent retrieval of observational SR bindings for the participant group with high autistic traits (which is not what we actually observed).

Tentatively, this interpretation is supported by the Bayes Factor analysis: For Research Question 1, this analysis indicates that the alternative hypothesis (presence of retrieval effect that is greater than zero) is more than two times more likely than the null

hypothesis. For Research Question 2, the Bayes Factor analysis indicates that the null hypothesis (i.e., absence of group differences in retrieval of observational SR bindings) is nearly four times more likely than the alternative hypothesis, which can be regarded as positive evidence for the validity of the null hypothesis. Our findings converge with null findings from other tasks (see below). With Bayes factors of about 2 and 4, respectively, we concede that the evidence for the null hypothesis is still weak in absolute terms (see Kass & Raftery, 1995; for an evaluation of Bayes Factors). Nevertheless, there is a need for future studies to aim for independent replication of the present data pattern, preferably in highly powered studies.

One could raise an alternative argument for the present null findings, which could be a consequence of the fact that the participants in our study simply were not impaired enough. Given that we studied only participants with high levels of autistic traits, but no clinically relevant sample, there is merit in this argument. However, we want to point out that our high AQ sample covered a broad AQ range from scores between 17 and 35. Typically, scores equal or above 32 are considered as clinically relevant (Baron-Cohen et al., 2001). Despite this, we did not observe a strong negative correlation between retrieval of observational SR bindings and AQ total scores (see Table 2). Furthermore, Sebanz and colleagues (2005) tested only participants with a clinical diagnosis of ASD and still found no reduction in joint Simon effects. The same holds true for the automatic imitation task, as Cracco and colleagues (2018) did not find evidence for impaired performance of ASD participants compared with controls. These speculations notwithstanding, it would be of merit to replicate the present study with a truly clinical sample of ASD participants.

Theoretical Implications

The *observational SR binding* paradigm can be understood as a joint compatibility task in which the observed response is of relevance for regulating one's actions, because it is either compatible or incompatible with a to-be-performed response. Like other compatibility tasks (e.g., the *automatic imitation* task; Brass et al., 2001; Heyes, 2011; or the *joint Simon* task, Sebanz et al., 2003), the accuracy and latency of executing (in-)compatible responses is

the variable of primary interest. In this respect, compatibility-based tasks differ from other imitation tasks that study imitation of gestures, postures, and so forth (also known as behavioral mimicry). In such imitation tasks, copied actions or behaviors are not directly relevant for one's own action regulation, but serve other social purposes (e.g., establishing rapport, liking, and empathy) and carry meaning in social interactions (cf. Chartrand & Lakin, 2013). Here recent tasks do report differences between individuals with ASD and controls (e.g., Forbes et al., 2016) and suggest particularly mimicry, but not goal emulation and planning processes, to be impaired in ASD (Hamilton, 2008). In turn, Genschow and colleagues (2017) found no correlation between automatic imitation, mimicry, and autistic traits, which support the differentiation of mechanisms.

It is noteworthy that our findings correspond with the null results reported in other studies which failed to find differences between individuals with ASD and controls in the *automatic imitation* and *joint Simon* task (e.g., Gordon et al., 2020; Hamilton et al., 2007; Sowden et al., 2016; Sebanz et al., 2005). One the one hand, these findings argue against the Broken Mirrors Theory to explain ASD-specific symptoms with a dysfunctional mirror neuron system as hypo-imitation was absent. Likewise, our findings do not reflect excessive imitation effects (hyper-imitation according to a deficit in distinguishing self- vs other representations (Spengler et al., 2010). As such, the data are most consistent with the assumptions of the STORM account (Forbes et al., 2016; Wang & Hamilton, 2012), which assumes that basic processes of imitative behavior are intact even in individuals with ASD. This conclusion is further supported by recent theoretical developments (e.g., Southgate & Hamilton, 2008). Note, however, that our data cannot test the main assumption of the STORM account, which assumes that ASD individuals fail to respond on social cues that indicate whether actions should be copied or not (i.e., a failure related to social control of imitative responses in ASD) as the experimental setup prevented eye-contact and nonverbal interaction and communication. On the other hand, this correspondence is all the more important, given that both other compatibility-based measures are currently under debate in terms of whether they are responsive to modulations by social traits: Evidence for effects of individual differences of social personality traits on performance in the automatic imitation task is still under discussion (Butler et al., 2015; Genschow et al., 2017; Hedge et al., 2018; Ramsey, 2018). Furthermore, the emergence of a joint compatibility effect in the *joint Simon* task can either result from action corepresentation and/or referential coding and is thus no process-pure indicator of social functioning or impairments in social traits (e.g., Dittrich et al., 2012; Dolk et al., 2013). However, it is rather unlikely that referential coding of one's own responses in spatial terms had any effect on observational SR bindings. If that were the case, that observing a left-hand response (pressing the red button) in one's interaction partner should have facilitated performance whenever participants themselves had to execute a left-hand response (pressing the green button) and vice versa for right-hand responses. However, in that case, retrieval effects should have been flipped, reflecting performance benefits for incompatible responses and performance costs for compatible responses, respectively. The obtained data pattern argues against this, which is why we can refute referential coding as an alternative explanation for retrieval effects of observational SR bindings.

In sum, the null findings on ASD-specific deficits in compatibility-based measures of mental representation of observed actions might suggest that the processes underlying compatibility-based imitation tasks are distinct from other imitation tasks and hence do not necessarily measure similar mechanisms (Genschow et al., 2017). In line with Sebanz et al. (2005) it is thus plausible to assume that individuals with ASD can actually represent observed actions to a similar degree as their own actions—at least if observed actions are simple and with direct purpose in the course of action regulation, but devoid of higher meaning or purpose in social interactions (like gestures; see also Vivanti & Hamilton, 2014). This would imply that compatibility-based imitation tasks tap low-level processes of action understanding and action representation that are functionally intact in individuals with high autistic traits or ASD (Wang & Hamilton, 2012). Tentatively, this reasoning is further supported by the finding that retrieval of standard bindings between stimuli and self-performed responses—which represents a fundamental, low level process of behavior automatization (Frings et al., 2020)—was also intact in participants with high degree of autistic traits and also did not statistically differ from individuals with low degree of autistic traits.

However, more research is necessary to support these tentative conclusions and assumptions. For instance, we have to concede that the observational SR binding paradigm itself addresses many social preferences of participants with high levels of autistic traits (e.g., direct eye contact is blocked; participants are not allowed to communicate with each other) and action observation is highly structured and incentivized (e.g., observers are instructed to attend and observe prime actors' responses, which is ensured with and occasional memory test; distribution of extra reward hinges on memory test performance). Thus, it is possible that individuals with ASD or high levels of autistic traits are capable of instructed observation but lack the ability and/or motivation to show spontaneous tuning into actions executed by social interaction partners (Ingersoll, 2008; Marsh et al., 2013).

Conclusions

So far, a range of findings attest that the observational SR binding paradigm is responsive to manipulations which are social in nature (Giesen et al., 2014, 2017, 2018). Together, these findings document that the paradigm is suitable to study phenomena of imitative action regulation and social learning. Despite this, the present study failed to find any ASD-specific deficits in acquisition and retrieval of observational SR bindings, because retrieval effects were of equal magnitude in participants with high or low autistic traits. In line with previous null-findings from other compatibility-based measures, the present findings support the view that individuals with ASD can actually represent observed actions to a similar degree as their own actions—at least if these are simple and with direct purpose in the course of action regulation.

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