Effects of categorical representation on visuospatial working memory in autism spectrum disorder

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ABSTRACT

We tested whether individuals with autism spectrum disorder (ASD) are impaired in visuospatial working memory or in the use of the semantic system, in particular in categorization processes at the service of working memory. The performance of high-functioning individuals with ASD (N = 21) in a visual same–different task adapted from Lachmann and van Leeuwen [e.g., Lachmann, T., & van Leeuwen, C. (2010). Representational economy, not processing speed, determines preferred processing strategy of visual patterns. *Acta Psychologica*, 134(3), 290–298] was compared to those of typically developed controls (N = 25). In a categorical identity task, two successive patterns had to be judged as the same if they belonged to the same equivalence set (cf. Garner, W. R., & Clement, D. E. (1963). Goodness of pattern and pattern uncertainty. *Journal of Verbal Learning and Verbal Behavior*, 2, 446–452), including all possible rotation and reflection transformations (R68 category), and as different otherwise. In a physical identity task, only patterns that matched in both shape and orientation had to be responded to as the same; all others, including category matches, had to be classified as different. Equivalence sets had different sizes (ESS). Earlier studies showed an increase in reaction time (RT) with increasing ESS and, for the physical identity task, a response conflict for category matching. Both of these effects were interpreted as evidence for a categorical code by which individual patterns are mentally represented. Assuming that categorization processes are deficient in individuals with ASD, we expected no ESS effects and, in the physical identity task, absence of a response conflict for these individuals. In contrast, we found individuals with ASD to be generally as sensitive to ESS as controls, and they showed a response conflict in the physical identity task. Thus, categorical processing seems to be intact in ASD. A strong overall group effect was found in RTs: Individuals with ASD are considerably slower than controls.

The question of whether higher order executive functioning is deficient in individuals with autism spectrum disorder (ASD) has been studied extensively over the last decades (e.g., Pennington & Ozonoff, 1996). Working memory (Baddeley & Hitch, 1974) is one central component of higher order executive functioning. It allows information to be actively maintained for brief periods of time while manipulating it or performing an online task (Baddeley & Della Sala, 1996). A number of studies investigated working memory performance in individuals with ASD using a variety of verbal or visuospatial tasks, resulting in inconsistent results. For instance, Bennett, Pennington, and Rogers (1996) found individuals with ASD, compared to controls, to be impaired in their performance of a sentence span task and a counting span task. In contrast, Ozonoff and Strayer (2001) failed to find evidence for a working memory impairment using visuospatial tasks. Williams and her colleagues (Williams, Goldstein, Carpenter, & Minshew, 2005) investigated the performance in both visuospatial and verbal working memory in the same sample of individuals with ASD and, contradicting the previously mentioned...
studies, identified deficits for the first but not the latter domain. The authors argue that this dissociation between domains can be explained by different processing demands. They provide a comprehensive account for the inconsistencies in the literature regarding working memory deficits in individuals with ASD (Williams et al., 2005). Using a parametric design, they (Steele, Minshew, Luna, & Sweeney, 2007) showed that visuospatial deficits in individuals with ASD are only evident for higher memory load conditions. This, they argue, can also explain why Ozonoff and Strayer (2001) failed to find a visuospatial deficit in individuals with ASD because the memory load in that study was rather low.

Given the link between the working memory and long-term memory via the control of an episodic buffer (Baddeley, 2000), the influence of semantics in visuospatial working memory in individuals with ASD was investigated in a study by Mammarella, Girofrè, Caviola, Cornoldi, and Hamilton (2014). These authors asked high-functioning children with and without ASD to perform a same–different task in which stimuli differed in what they called semantic organization—that is, visual patterns could be more or less amenable to global configurations. Whereas in controls this semantic organization facilitated visuospatial working memory performance, individuals with ASD had problems taking advantage of it. Thus, it can be concluded that individuals with ASD are not necessarily impaired in visuospatial working memory but are rather deficient in the use of long-term memory and conceptual mediation strategies to maintain and monitor information in working memory.

A central mechanism of the semantic system is categorization, which enables grouping and organization of individual items in our semantic system and allows us to efficiently recall and use information (Martin & Chao, 2001; Murphy, 2004). According to the enhanced perceptual processing hypothesis, these categorization processes may be impaired in individuals with ASD (O’Riordan & Plaisted, 2001; Plaisted, Saksida, Alcantara, & Weisblatt, 2003). It is assumed that the enhanced discrimination of visual patterns, observed in a study by O’Riordan and Plaisted (2001), may result in a reduction of the amount of information that can be generalized from one situation to another, which would be detrimental to categorization. However, in a study by Caron, Mottron, Berthiaume, and Dawson (2006) it is reported that locally oriented processes might be only necessary, but not sufficient for the development of these visuospatial peaks in ASD.

Several studies are decisive for this assumption because they tested the ability of high-functioning individuals with ASD to learn new artificial categories and form prototypes, which correspond to a summary representation of multiple experienced items that can go together in a category (e.g., Froehlich et al., 2012). Contradictory results were reported in these studies, with some reporting significant prototype effects similarly to what is found in individuals with typical development (e.g., Froehlich et al., 2012; Molesworth, Bowler, & Hampton, 2005), while others failed (e.g., Church et al., 2010; Klinger & Dawson, 2001). Moreover, the results of Molesworth, Bowler, and Hampton (2008) study question the homogeneity of ASD individuals’ performance in terms of the prototype effect. While two thirds of their ASD sample showed a standard prototype effect, the remaining group, defined by their performance on a control task, did not show the effect. All mentioned studies tested high-functioning children with ASD, except Froehlich et al. (2012), who tested high-functioning adult males.

Another set of studies (e.g., Bott, Brock, Brockdorff, Boucher, & Lamberts, 2006; Soulieres, Mottron, Giguère, & Larochelle, 2011; Vladusich, Olu-Lafe, Kim, & Tager-Flusberg, 2010) consistently reported unimpaired formation of new categories in high-functioning adolescents and/or adults with ASD. These individuals, however, needed more time and longer exposure to the materials—for instance, more training sessions (Vladusich et al., 2010)—to show categorization performance similar to that of controls. Moreover, in the first sessions, the groups differed (Soulieres et al., 2011). Taken together, these studies indicate that individuals with ASD show a deviation in category learning—that is, they learn slower than typically developed individuals.

To investigate the role of categorization process in visuospatial working memory in individuals with ASD, in the present study, we used a paradigm introduced by Lachmann and Geissler (2002) for a study of typically developed individuals. Lachmann and colleagues (e.g., Lachmann & Geissler, 2002, Lachmann & van Leeuwen, 2005b, 2010) presented dot patterns in a same–different task. In this task, participants had to judge whether two patterns, presented in succession with
interstimulus interval of 500 ms between them, were the same or different. The patterns, first used by Garner and Clement (1963), consist of five dots placed on an imaginary 3 x 3 grid. In total, 90 such patterns can be constructed if no row and no column are left empty. Those that can be transformed into each other by steps of 90° rotation and/or reflection operations are defined as belonging to an equivalent set (ES). An ES, of which there are 17 in total, can, depending on the symmetry of the pattern elements, be of different set size (equivalence set size, ESS). Seven sets have an ESS of 8 (ESS8), eight have an ESS of 4 (ESS4), and two, due to a maximum degree of symmetry, have an ESS of 1 (ESS1; see Figure 1).

Two versions of the same–different task have been used and led to differential task profiles. In the categorical identity task, patterns that are rotated or reflected versions of each other—that is, patterns belonging to the same category (ES)—are to be responded to as same. This results in three different types of matching: (a) pairs of physically identical patterns—that is, patterns that are the same in shape and orientation (identity match, IM); (b) pairs of categorical identical patterns—that is, patterns that are of the same shape but of a different orientation (category match, CM), both to be responded to as the same; and (c) pairs of nonmatching patterns from different sets (NM) to be judged as different. The other version, the physical identity task, involves judging CM pairs as different (see Figure 2).

Reaction times in the categorical identity task were consistently found to depend on the size of

![Figure 1](image1.png)

**Figure 1.** Examples of the patterns introduced by Garner and Clement (1963) with different equivalence set size (ESS).

![Figure 2](image2.png)

**Figure 2.** Pairs of dot patterns (Garner & Clement, 1963) representing the three types of matching introduced in Lachmann and Geissler (2002).

the sets (ESS) that the two patterns to be compared belong to (ESS effect). For each type of matching in the categorical identity task, including IM, the reaction times were found to increase linearly with increasing ESS. This was interpreted as evidence for a holistic—that is, a categorical—representation and processing for the patterns. The model proposed by Lachmann and Geissler (2002) assumes that the presentation of the patterns evokes an internal activation of the entire ESs that the patterns belong to, one if IM or CM, two if NM, followed by a serial search for the presented item in one or both of the activated memory sets representing the two patterns (i.e., the activated set could be understood as a kind of memory set in the search model by Sternberg, 1966). If both patterns belong to the same set, the search for the second item starts where the first was identified. This explains the very consistent finding that for IM, the slope of reaction times as a function of ESS is about half of that for CM and NM because for the latter, two searches have to be conducted. The theoretical memory search steps resulting from this model predicted the reaction times of same as well as of different responses very precisely (for a critical discussion see Hermens, Lachmann, & van Leeuwen, 2015).

The profile in the physical identity task is characterized by a linear ESS effect too, but only for IM and NM. For CM the ESS effect is not present. This was interpreted as evidence for a task-independent categorical group coding of the patterns, for the physical identity task resulting in a response conflict for CM because for patterns represented by the same memory code, a different response is required (Lachmann & van Leeuwen, 2005b, 2010). This response conflict leads to a considerable increase of CM reaction times, which covers any ESS effect.

The conceptual system, in particular the process categorization, was hypothesized to be deficient in individuals with ASD (O'Riordan & Plaisted, 2001;
Plaisted et al., 2003). Moreover, it has been proposed that apparent deficits in working memory in individuals with ASD are not generic, but may result from faulty links between working memory and the conceptual system. Thus, it is crucial to investigate the relation between categorization processes and visuospatial working memory in individuals with ASD to understand the nature of the deficit. The robust framework by Lachmann and colleagues (2010) offers a tool to do so and was already used for this purpose by Takahashi, Yasunaga, and Gyoba (2014; see also Takahashi, Gyoba, & Yamawaki, 2013) with typically developed adults who differed in the score levels of the General Population Quotient for Autism-Spectrum Behavior and Cognitive Properties (AQ). In their study from 2014 they used the same-different paradigm as that from Lachmann and van Leeuwen (2010) for individuals who varied in the AQ score. They found a main effect of ESS: increasing reaction times with increasing ESS, independently from AQ. For the whole sample, they reported that performance was better for ESS4 patterns than for ESS8 patterns in the categorical condition only (Takahashi et al., 2014).

In the current study, we aimed to evaluate the role of categorization processes and the activation of the representational set in a visuospatial working memory task in high-functioning individuals diagnosed with ASD. To this end, we partially replicated the study of Lachmann and van Leeuwen (2010) including both task conditions—the categorical identity task and the physical identity task—using a within-subject design.

If categorization processes in visuospatial working memory are deficient in individuals with ASD and contribute to impairments in working memory, for this population we would not expect to see a linear increase of reaction times with increasing representational set sizes (in contrast with Takahashi et al., 2014) and, for the physical identity task, no signs of a response conflict either (Lachmann & van Leeuwen. 2005b, 2010).

**Method**

**Participants**

Twenty-one high-functioning individuals with ASD (HFA, 2 females) and 25 individuals with typical development (3 females) participated in the study. The inclusion criterion for HFA was a score of 70 points or above in both the Verbal and Performance subscales of the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1996). All individuals of the ASD group received a diagnosis of autism or autism spectrum disorder based on the Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition (DSM-IV) criteria (American Psychiatric Association, 1994). The diagnostic evaluations and interviews were independently performed by two clinical staff with practical experience. To be included in this study, the diagnosis had to be confirmed by both observers.

Participants with ASD were recruited through the clinical database of the CADIN—Centro de Apoio ao Desenvolvimento Infantil (Cascais, Portugal). Control participants were recruited from the community or were students from the Faculty of Psychology of the University of Lisbon. Controls received either a 15 euro gift voucher or course credit for their participation. The groups were matched for age, general cognitive abilities (IQ measured by Raven’s Progressive Matrices), and education (see Table 1) (Raven, 1999).

Permission for the study was granted by the Ethical Committee of the Faculty of Psychology—University of Lisbon (Portugal). Each participant gave written informed consent for participation.

**Stimuli and apparatus**

A subset of the dot patterns first introduced by Garner and Clement (1963) was used for the study. Out of the 17 possible sets, two of ESS1, two of ESS4, and two of ESS8 were chosen. This results in a total of 26 individual patterns. These were combined into pairs of different types of matching. In identical matching conditions (IM), patterns are identical both in shape and in orientation; in categorical matching conditions (CM), patterns are identical in shape but different in orientation—that is, they belong to the same ES; and in nonmatching condi-

<table>
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<th>Table 1. Participants’ demographics.</th>
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<tr>
<td>Age</td>
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<td>Education</td>
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<td>IQ (Raven)</td>
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Note. HFA = high-functioning individuals with autism spectrum disorder. Age is measured in years; education is measured in terms of completed school years; and Raven are the raw scores from the Raven Progressive Matrices (Raven, 1999).
Table 2. Pattern combinations included in the physical condition block.

<table>
<thead>
<tr>
<th>Response</th>
<th>Matching</th>
<th>ESS</th>
<th>Number of sets</th>
<th>Total number of pairs</th>
<th>Frequency of pair inclusion</th>
<th>Number of pairs included</th>
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<td>8-4</td>
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<td>Total</td>
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</table>

Note. ESS = equivalence set size; IM = identical matching condition; CM = categorical matching condition; NM = nonmatching condition. Different pairs consist of patterns from two sets of either the same or different ESS. Different subsets of all of the possible pair combinations were used in order to achieve an equivalent proportion of same and different responses and types of matching.

Table 3. Pattern combinations included in the categorical condition block.

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<tr>
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<tr>
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<tr>
<td>Different</td>
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</table>

Note. ESS = equivalence set size; IM = identical matching condition; CM = categorical matching condition; NM = nonmatching condition. Different pairs consist of patterns from two sets of either the same or different ESS. Different subsets of all of the possible pair combinations were used in order to achieve an equivalent proportion of same and different responses and types of matching.

Procedure

The experiment consisted of two blocks, the order of which was counterbalanced across participants. In one block (physical identity task) participants were instructed to respond same only if the two patterns were identical in shape and orientation. In total there were 82 trials in this block. In the other block (categorical identity condition) participants were instructed to judge patterns as same in terms of shape, independently of their orientation. Thus, according to this instruction, all patterns of an ES are the same, respectively. This block comprises a total of 132 trials. Both blocks were performed within one session with a short break in between.

Each participant was tested individually in a quiet and well-lit room. Instructions for the two tasks were given in written form, and 12 practice
trials with feedback for accuracy were performed before each task started. Reaction times and accuracy were recorded for all trials.

The two patterns of a trial were presented successively. The first pattern was presented on the left side on the screen for 500 ms. After an inter-stimulus interval of 500 ms the second pattern was presented on the right side of the screen until a response was given. The next trial started after 2000 ms. Participants had to press one of two keys that corresponded to a same or different response. After an intertrial interval of 2000 ms, the next trial started automatically.

**Results**

Accuracy (percentage correct) and reaction times (RTs in ms) for correct responses were analyzed by repeated measures analyses of variance (ANOVARAs). This was done separately for the three types of matching (IM, CM, and NM) because there is no full factorial design (e.g., there is no CM for ESS1). Group (HFA versus controls) was the between-subjects variable, and ESS of pair combinations (ESS of the first and the second pattern) and task (categorical identity task versus physical identity task) were the within-subjects factors. To explain observed three-way interactions, subsequent ANOVARAs were run for each group separately. In order to better understand the two-way interactions found, t tests were used, collapsing the relevant conditions accordingly. The data from two individuals from the HFA group were excluded from the analysis, given they had less than 10% correct responses to CM trials in the categorical condition; hence, they may have not understood the instructions correctly. Trials with a reaction time outside of the outlier criterion of 150 ms < RT > x + 2.5 × SD were not considered for the analyses.

**Reaction times**

*IM.* Regarding response times for IM, we observed a main effect of group, with higher response times for the HFA group than for the control group, F(1, 42) = 15.49, p = .001, η²_p = .27, as well as a main effect of ESS, F(2, 84) = 15.37, p < .001, η²_p = .27, with increasing RTs with increasing ESS. There was a three-way interaction of Task × ESS × Group, F(2, 84) = 4.76, p = .01, η²_p = .11. Post hoc ANOVARAs were run separately for each group. For the control group, a main effect of ESS was observed with F(2, 48) = 14.71, p < .001, η²_p = .38. No main effect of task nor of Task × ESS interaction was found (all ps > .6).

For the HFA group, a main effect of ESS was found, F(2, 36) = 5.41, p = .009, η²_p = .23, as well as the Task × ESS interaction, F(2, 36) = 4.76, p < .005, η²_p = .21. This interaction can be explained by a lack of significance of ESS differences in the categorical identity task condition for HFA individuals (all ps > .27). (See Figures 3 and 4).

![Categorical Identity Task](Figure 3. Reaction times (in ms) for identity match (IM), category match (CM), and nonmatch (NM) conditions for the different equivalent set sizes (ESS) in the categorical identity task. HFA = high-functioning individuals with autism spectrum disorder.)
CM. For CM a main effect of group was observed, with higher RTs for the HFA group than for the control group, $F(1, 42) = 21.15, p < .001, \eta^2_p = .33$. There was also a main effect of ESS, $F(4, 168) = 9.20, p < .001, \eta^2_p = .18$. In CM conditions, the ESS of the first and the second pattern may or may not differ. Therefore, we have five levels in total: ESS44, ESS88, ESS14, ESS18, ESS48 (the numbers indicating the ESS of the first and the second pattern, respectively). According to the model of categorical group codes and memory search (Lachmann & Geissler, 2002), RTs are affected by the ESS of the first and the second pattern to an equal amount. There was a main effect of task, $F(1, 42) = 24.7, p < .001, \eta^2_p = .37$, with higher RT for the categorical identity task condition ($M = 899.97, SEM = 34.01$) than for the physical identity task condition ($M = 813.12, SEM = 33.26$). The one and only interaction found was that of Task × ESS, $F(4, 168) = 3.14, p = .02, \eta^2_p = .07$.

Accuracy

IM. The analysis of accuracy revealed a main effect of ESS, $F(2, 84) = 3.89, p = .024, \eta^2_p = .08$, with decreasing accuracy with increasing ESS. Another main effect was found for task, $F(1, 42) = 8.51, p = .006, \eta^2_p = .17$; accuracy was higher for the categorical identity task condition ($M = .99, SEM = .003$) than for the physical one ($M = .97, SEM = .005$) (See Figures 5 and 6.).

CM. A main effect of group was observed for CM trials, $F(1, 42) = 7.14, p = .011; \eta^2_p = .14$, with controls performing better than HFA individuals ($ps > .3$ for both IM and NM). Moreover, a main effect of ESS was observed, $F(1, 42) = 7.14, p < .001, \eta^2_p = .14$, with decreasing accuracy with increasing ESS. The Task × ESS interaction was only observed as a tendency, $F(4, 42) = 3.74, p =$
.06, $\eta^2_p = .08$. A three-way interaction of Group $\times$ Task $\times$ ESS was observed, $F(1, 42) = 9.78, p = .003$, $\eta^2_p = .19$. Post hoc ANOVAs were run separately for each group. The pattern was similar for the HFA and control groups, with significant ESS effects observed for both [HFA: $F(1, 18) = 7.93, p = .01, \eta^2_p = .3$; controls: $F(1, 24) = 10.29, p = .004, \eta^2_p = .3$]. Task main effect and Task $\times$ ESS interaction effects were not observed (all $p$s > .1).

NM. For NM main effects of ESS on the first and the second pattern, $F(4, 168) = 7.22, p < .001, \eta^2_p = .15$, and on task were observed, $F(1, 42) = 16.99, p < .001, \eta^2_p = .29$; the categorical identity task condition led to poorer performance ($M = .97, SEM = .005$) than the physical identity task condition ($M = .99, SEM = .004$). Finally, there was a Task $\times$ ESS interaction, $F(4, 168) = 3.15, p = .016, \eta^2_p = .07$, with smaller differences between ESS levels in the physical identity task than in the categorical identity task.

Discussion

In the present study, we tested whether individuals with ASD show the same effects of visuospatial working memory as those found for typically developed individuals in same–different tasks
(e.g., Lachmann & van Leeuwen, 2005b, 2010), in particular, whether they show the same automatic activation of categorical set representations of the patterns to be compared.

For both the ASD group and controls, we were able to replicate the findings of a series of previous studies with normally developed individuals, which is that RT increases, and accuracy decreases, with increasing ESS and, thus, with the size of the internally activated categorical code of the patterns to be compared. Therefore, we can conclude that for the comparison of the two patterns, even if they are physically identical, individuals with ASD, just as controls, internally activate the whole ES to which the patterns belong.

An important proof for the assumption of a categorical group code of the stimuli is the occurrence of a response conflict for CM trials in the physical identity task, where the two patterns that evoked the same group code representation had to be responded to as different (Lachman & van Leeuwen, 2005a). The response conflict is characterized by a considerable increase of RT combined with the absence of an ESS effect for CM trials in the physical identity task, contrasting a strong ESS effect for CM trials in the categorical identity task. This pattern of results was consistently found in earlier studies and was replicated in the present study for individuals with ASD as well as for controls. This finding supports the formerly drawn conclusion that individuals with ASD use a similar categorical strategy to that of controls for the tasks in the present study.

Hence, in our study, high-functioning individuals with ASD seem to implicitly activate the whole set of the visual patterns that are equivalent according to an implicit category, here the ES. This finding does not support the assumption of a deficit in the categorical strategy.

There is, however, an overall effect of group, with individuals with ASD showing considerably higher RTs than controls. This robust group effect was found for RT but not consistently for accuracy. This pattern of preserved categorization processing but slower response times is in line with and could help explain the pattern found previously (e.g., Soulères et al., 2011; Vladusich et al., 2010): a deviation (not a real deficit) and slower category learning. Having this fact in mind is actually essential when developing and exploiting learning strategies for this population, since simply adding additional or allowing longer exposures to the learning material could suffice for them to reach a normal performance.

Regarding accuracy, given that clear ceiling effects are evident, we refrain from discussing them further, particularly in the physical identity task condition. We acknowledge that these ceiling effects may reflect a limitation of our study.

Another limitation of this study as well as of earlier studies in the field is that the performance of children has not directly been compared to that of adults, and hence the developmental trajectory regarding categorization abilities in general cannot be mapped.

We have replicated the pattern of RTs results reported in Takahashi et al. (2014)—that is, increasing RT with increasing ESS. These authors used the same paradigm as that in the present study but with normally developed individuals differing in the autism quotient (AQ). Regarding accuracy, at a first glance our findings are in contrast with those from Takahashi et al. (2014). With their sensitivity measure (d’ prime) they found no differences between the low- and high-AQ groups, but an effect of ESS for the categorical identity task only. These differences could be explained by the fact that we took into consideration the type of trial, which they did not. This could have obscured the finding regarding the difference between groups in the categorical ESS8 condition.

In contrast with our predictions, we found evidence for a representational set activation in individuals with ASD: ESS effects in both tasks and a response conflict for CM in the physical identity task, replicating the pattern of results found in earlier studies for normally developed individuals (e.g., Lachmann & van Leeuwen, 2010), including individuals with nonclinical but high AQ score (Takahashi et al., 2014). This does not support the idea of impairments in a categorical representation in individuals with ASD (e.g., Plaisted et al., 2003); a representational set seems to be active and at use even when the representation based on the individual pattern feature would be sufficient, just as in normally developed individuals. Nevertheless, we have found considerably longer overall RTs for individuals with ASD, which seem not to be reflected in accuracy nor necessarily tailored to a deficient categorical processing.
Disclosure statement

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