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Visuospatial Working Memory in Children with Autism: The Effect of a Semantic and Global Organization

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Abstract

It has been reported that individuals with Autism Spectrum Disorders (ASD) perceive visual scenes as a sparse set of details rather than as a congruent and meaningful unit, failing in the extraction of the global configuration of the scene. In the present study, children with ASD were compared with typically developing (TD) children, in a visuospatial working memory task, the Visual Patterns Test (VPT). The VPT array was manipulated to vary the semantic affordance of the pattern, high semantic (global) vs. low semantic; temporal parameters were also manipulated within the change detection protocol. Overall, there was no main effect associated with Group, however there was a significant effect associated with Semantics, which was further qualified by an interaction between the Group and Semantic factors; there was only a significant effect of semantics in the TD group. The findings are discussed in light of the weak central coherence theory where the ASD group are unable to make use of semantics in order to construct global representations of the array.

Keywords: Spectrum Disorder (ASD); Visuospatial working memory (VSWM); Central coherence theory; Semantic organization

Introduction

The Autism Spectrum Disorders (ASD) is a neurodevelopmental disorder that is characterized by a persistent deficit in social communication and social interaction (American Psychiatric Association, 2013). The prevalence of this disorder is about the 6–7/1000, and rates of learning or constituted about one third, respectively (Fernell & Gillberg, 2010). The aetiology of the ASD is unknown but there is evidence of genetic origins (e.g., Muhle, Trentacoste, & Rapin, 2004). Also environmental factors, such as intrauterine exposures, may play a role in this syndrome (Leonard et al., 2010). Finally, in the ASD syndrome social and non-social factors are also implied.

As far as the social cognition of children with ASD is concerned, it has been suggested that children with ASD have deficits in the social interaction and in particular in the theory of mind (i.e., the automatic attribution of mental states to predict and explain behaviour) (Baron-Cohen, Leslie, & Frith, 1985). Evidences indicate that ASD children are incapable of deception (Sodian & Frith, 1992) and that they fail in understanding expressive gestures (Attwood, Frith, & Hermelin, 1988).

Beside the social impairments, children with ASD also present other peculiarities. Intriguingly, children with ASD do not present deficits in many visuospatial tasks, including processing of rotating material. To the contrary, ASD children show deficits when they have to judge what an object will look like from another person's point of view (Hamilton, Brindley, & Frith, 2009). Moreover, children with ASD usually performed better than the controls in the embedded figures and block design tests (Happé & Frith, 2006; Kuschner, Bodner, & Minshew, 2009). These results have led to the conclusion that children with ASD have the facility to segment in parts, but, conversely, that they struggle when they have to deal with a global organization of the material (Shah & Frith, 1993). These weaknesses in some aspects and the superior performances in other aspects were described as a weak central coherence (WCC; Frith, 1989). The WCC theory was considered as an explanation also of the social deficits in children with ASD, and has received a large support (see Frith, 2012 for a review); nevertheless, the theory has also been criticized (e.g., Mottron, Burack, Iarocci, Belleville, & Enns, 2003).

Due to some criticisms and new findings, the coherence account has been modified from

Frith's (1989) original conception. It has been suggested that the coherence is a cognitive style, as confirmed by the fact that the parents with children with ASD tend to have a detail-focused processing style (Happé, Briskman, & Frith, 2001). The weak coherence may be, moreover, one aspect of cognition in ASD and it does not fully account for the deficits in the social cognition (Frith, 2012). Although mixed results have been found, the WCC theory continues to provide important information on the ASD's cognitive functioning (Happé & Frith, 2006). It is worth noting that to test the WCC theory, visuospatial tasks are often used.

The present study examines the role of one of the main visuospatial processes, visuospatial working memory (VSWM); this is a system allowing us to temporarily represent visuospatial information for the duration of an on-going task. VSWM is a specific working memory component, responsible for the maintenance and processing of visual (e.g., colour, shape, texture) and spatial information (e.g., position of an object in space) (Logie, 1995). It has also been suggested that a distinction should be drawn between working memory processed based not only on the modality of the information, but also on the degree of controlled attention involved. Cornoldi and Vecchi (2003) distinguished, for example, between passive processes, only requiring the minimum manipulation and organization of the material, and active working memory processes which involve a manipulation of the information. One characteristic of active processing is the use of visual and verbal semantics in the organization of the working memory material (e.g., Belacchi, Benelli, & Pantaleone, 2011; Darling, & Havelka, 2010; Orme & Hamilton, submitted; Sun, Zimmer & Fu, 2011). For example, semantic processes in long term memory (LTM) can support chunking processes enhancing the amount of information we can hold in VSWM by facilitating the formation of gestalts in the pattern (e.g., Gobet & Simon, 1996; Rennig, Bilalic, Huberle, Karnath, & Himmelbach, 2013).

A number of visuospatial tasks have been used to investigate the WCC theory. The data in children with ASD, indeed, have shown mixed results. For example, according to Williams, Goldstein, and Minshew, (2006) VSWM is impaired in children with ASD. According to another study using a spatial task also involving VSWM (i.e., the block design) children with ASD made less mistakes but their performances were not better when compared to controls (de Jonge, Kemner, Naber, & van Engeland, 2009). Moreover, other researchers claim that the VSWM performance in children with ASD is even enhanced compared to controls (Soulières, Zeffiro, Girard, & Mottron, 2011). Due to the mixed results in the literature, it is of a particular interest to study whether or not the performances of children with ASD are the same compared to controls also using different VSWM tasks and examining the role of organization.

Many tests have been developed to measure VSWM and one of the most used is the Visual Pattern Test (VPT; Della Sala, Gray, Baddeley & Wilson, 1997). In the VPT, participants are presented with a matrix pattern with some of the cells filled, and they are asked to reproduce by memory the pattern by marking off squares in a blank grid of the same size and configuration (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999).

Patterns in the VPT can be manipulated producing arrays which are more or less amenable to configuration patterns being perceived by the participant. Research has employed a modified version of the VPT – either with the filled in cells organized in global configurations (due to the fact that they may potentially convey a visual or verbal semantic meaning we will call them here ‘high semantic’) or not (low semantic). These studies have shown an enhanced memory capacity for high semantic patterns in adult participants (Brown, Forbes, & McConnell, 2006; Brown & Wesley, 2013; Riby & Orme, 2013). A modified version of the task (i.e., the high- and low-semantic matrix patterns task) has been successfully employed by Orme and Hamilton (submitted). Orme and Hamilton, in a series of experiments, demonstrated that: (i) the high semantic material was remembered better than the low semantic; and (ii) the superiority of the high semantic stimuli could be eliminated by a reduction in encoding time.

It is worth noting that results by Orme and Hamilton (submitted) were based on a typical population of adults. Different results have been observed, for example, by Carretti, Lanfranchi and Mammarella (2013), who showed that individuals with Down Syndrome (DS) were unable to take advantage of structured high-semantic visuospatial stimuli. Carretti et al. argued that individuals with DS could not take advantage of pre-existing long term memory structural representations to support their task performance. Frith (2012) suggested that this top down influence may also be compromised in ASD, precluding the opportunity to form global representations of the array (Rennig et al., 2013). However, it should be noted that, to date, the manipulation of high- and low-semantic matrix patterns task have not been employed to test the WCC theory.

Since in the VPT performance, global (i.e., high-semantic) material can be differentiated from the local (i.e., low-semantic) one, and that this difference is likely to arise from long term memory semantics, this task seems to be particularly appropriate for evaluating the WCC theory. As proposed by the WCC theory, children with ASD tend to have a preference for a local analysis and – therefore – they should not be able to take advantage of the high-semantic material in contrast to typically developing (TD) children. To examine this issue, in the current study, high and low semantic stimuli were presented using a masked change detection paradigm, varying the encoding time. Concerning the encoding time, Orme and Hamilton (submitted) showed that when processing was constrained by a reduction in presentation time, performance was more akin to that of the low semantic matrix patterns task than the initial high-semantic task. This result is in line with other studies, using a masked change detection paradigm, which showed that when a mask is presented shortly after the to-be-memorized stimulus, memory consolidation is not possible even though the presentation time was long enough to process the stimulus (e.g., Vogel, Woodman, & Luck, 2006). This result supports the observation that the time interval between the offset of the stimulus (memory array) and the memory mask (i.e., the SOA) has an impact on the performance in VSWM tasks (Sun et al., 2011). For this reason, it can be hypothesized that shorter consolidation times may affect VSWM performance and reduce the advantages of semantic organization.

Finally, in the present research, we tested whether or not the performances of children with ASD and with typical development (TD) differed when the level of complexity of the task was manipulated, by increasing the number of filled cells in both high and low semantic patterns. We examined whether increases in complexity impaired performance as observed by Orme and Hamilton (submitted) and whether this is different for the two current groups and the two different types of material. It is in fact possible that the advantages of the organization vary according to the level of complexity, as suggested by Massironi, Rocchi and Cornoldi (2001) and that individuals with an impaired VSWM are affected by complexity to a larger extent.

In sum, the present research pursued three main aims. First, we will investigate whether the performance of children with or without ASD is different in the two semantic conditions (high and low) and the magnitude of the difference. Second, we will study if the effect of the SOA can reduce the performances in both children with ASD and TD. Finally, we will compare the overall performance between the two groups across the level of complexity of the task.

Figure 1 about here

2. Method

2.1. Participants

Sixteen participants were included in this study: 8 males with ASD without intellectual disability (IQ > 80) and 8 males with typical development (TD) (see Table 1). ASD participants were recruited from two specialized centres for children with ASD located in the north-east of Italy. ASD diagnoses were assigned by a clinical examination performed by an experienced child psychiatrist, based on the diagnostic criteria for autistic disorder from Diagnostic and Statistical Manual of Mental Disorders (DSM 5, 2013). Children with Asperger syndrome were excluded from the study. ASD participants did not show intellectual disability. Their intelligence main scores (measured with either WISC III or WISC IV) were the following: Full scale IQ = 96.13 (SD = 15.39); Verbal comprehension index = 94.00 (SD = 13.42); Perceptual organization/Perceptual reasoning index = 98.75 (SD = 12.75).

Children with typical development matched for chronological age were healthy, with no history of psychiatric, neurologic and ophthalmologic illnesses and naive concerning to the testing procedures. They were recruited from local schools and were individually tested at their own schools. The two groups were matched for chronological age [$F(1,14) = 0.19$, $p = .672$; $\eta_p^2 = .01$;

Cohen's d = 0.23, 95% CI [-0.76, 1.20]; d_{unb} = .22], years of education [F(1,14) = 0.12, p = .916; η_p^2 = .001; *Cohen's d* = -0.15, 95% CI [-1.13, 0.84]; d_{unb} = -0.14] and gender.

Table 1 about here

Material

High- and Low- Semantic Matrix Patterns Task (HLSPT). Stimuli were taken from Orme and Hamilton (submitted) and Riby and Orme (2013). The task was programmed using E-Prime 2. Participants were presented with a matrix (memory array) in which half of the cells are filled. Two type types of memory array format (i.e., high- or low-semantic) were used: the high-semantic material that could be easily chunked in a global configuration, whereas, the low-semantic condition material could not be easily chunked semantically (Figure 1). After a short interval (i.e., consolidation time) a mask was presented. The mask was created in order to have the same amount of luminosity as the memory array. After the mask presentation a short delay was introduced. Immediately after the delay, the test array was presented. The test array was the same in the 50% of the trials and was different in the other 50% compared to the memory array (Figure 1). Participants were required to press a button indicating if the grid in the test array was the same or different. A schematic description of the task is presented in Figure 2. The level of complexity of a pattern was defined as the number of filled cells and not filled cells present in the array and varied from a minimum of 4 filled cells to a maximum of 13 of filled cells. The task was self-paced, so that the trials moved on when participants provided a response for the pattern on the screen.

Figure 2 about here

2.3 Design and procedure

For the practice we presented 5 trials with a level of complexity of 4–5 elements (i.e., 4 or 5 filled squares, 8 or 10 squares in total). During the practice participants received feedback on their performance. After the practice the experimenter asked again for the rules of the task to ensure that the participant had fully understood the task. In the task procedure, the level of complexity progressively increased from 6 to 13 (filled squares). We randomly presented 20 trials (50% high and 50% low-semantic) for each level of complexity. The memory array was presented for 500 ms, we decided, following Alvarez and Cavanagh, (2004), to use an encoding time of about 500 ms. which it is sufficient for processing VSWM stimuli. The time for the presented memory array was longer than that used by Sun et al., (2011) because our stimuli were presumed to be more demanding than that used by Sun et al. Within each level we manipulated the consolidation time presenting the mask in the 50% of trials 100 ms and in the other 50% at 900 ms. after the memory array offset. The mask had an equal luminosity and was presented for 200 ms. The stimulus onset asynchrony (SOA) was measured by the time between the offset of the memory array and the offset of the mask and varied from 300 ms (100 ms consolidation + 200 ms mask) to 1100 ms (900 ms + 200 ms mask). Also SOAs were longer than that used by Sun et al., since the perceptual processing of our complex items was presumed to be more demanding compared to the stimuli in the Sun et al. study. Between the mask offset and the test array, with a blank screen, an interval of different duration (i.e., the delay; Figure 2) was introduced so that the memory duration – that is, the time between the offset of the memory array and the onset of the test array – was always 1200 ms, independent of the consolidation time. The test array remained visible for 2000 ms and was followed by a screen containing two letters, U (uguale = same) and D (diverso = different). Participants responded by pressing one of these two keys on the keyboard (Figure 2) and a symbol was added below the letters (= for the equal and ≠ for the different). A total amount of 160 experimental trials were presented and the experiment lasted about 30–40 min.

3. Results

We calculated the partial eta square (η^2_p), the Cohen's d (*d*) and the unbiased d (d_{unb}) as measures of the effect size. Due to the small number of participants we will always comment both statistical significance, which can be biased by reduced statistical power, and the magnitude of the effect (the effect size). By having an equivalent number of trials for each condition we summed together the results of the 6–7, the 8–9, the 10-11, and the 12–13 levels of complexity. We first performed a 2 groups [ASD vs. TD] × 2 semantics [high vs. low] × 2 SOAs [300 ms vs. 1100 ms] × 4 level of complexity [6–7, 8–9, 10–11, and 12–13] mixed ANOVA. As far as the main effects are concerned, we found significant effects of semantics [$F(1,14) = 15.01$, $p = .002$; $\eta^2_p = .52$] and level of complexity [$F(3,42) = 32.36$, $p < .001$; $\eta^2_p = .70$] with large effect sizes, and no statistical difference due to the SOAs [$F(1,14) = 2.74$, $p = .120$; $\eta^2_p = .16$] with a medium effect size, and to group [$F(1,14) = .42$, $p = .526$; $\eta^2_p = < .29$] with a small effect size.

There was not a 4 way interaction (groups × semantics × SOAs × level of complexity), however the effect size was medium [$F(3,42) = 2.31$, $p = .090$; $\eta^2_p = .14$]. As it can be seen in children with ASD were better than TD children with low semantic low complex stimuli. None of the 3 way interactions was significant (*F*s < .99, *p*s = .41; $\eta^2_p = < .07$) and the effect sizes were small. Concerning the two-way interactions we found a significant interaction between group and semantics [$F(1,14) = 5.53$, $p = .034$; $\eta^2_p = .28$] with a large effect size. None of the other two-way interactions was significant (*F*s < .86, *p*s = .47; $\eta^2_p = .06$) and only the semantic × level of complexity interaction had a medium effect size [$F(1,14) = 1.71$, $p = .180$; $\eta^2_p = .11$].

Figure 3 about here

Since the crucial two-way interaction between groups and semantic was significant and large, we decided to further investigate this aspect calculating the magnitude of the difference in standard units. We found a large effects of semantics on the TD group ($M_{\text{diff}} = 7.66$; Cohen's $d = 1.46$, 95% CI[.29; 2.47]; = 1.38) and a small effect in the ASD group ($M_{\text{diff}} = 1.88$; Cohen's $d = .23$, 95% CI[-0.77; 1.20]; $d_{\text{unb}} = .21$) (Figure 4).

Figure 4 about here

4. Discussion

The present study investigated the effect of visuospatial stimuli experimentally manipulated in the extent to which it afforded configural and semantic information in children with ASD compared with TD using a masked change detection paradigm. Based on the WCC theory, we hypothesized that children with ASD would not be advantaged by VPT stimuli in the high semantic condition. Second, we expected that the effect of the SOA would reduce the performances in both children with ASD and TD. Finally, we hypothesized a worse performance of the two groups on the basis of the level of complexity of the task, but we do not expect a difference in the overall performance.

The key result concerns the observation that children with ASD compared to children with TD, despite a similar overall performance in the VSWM task, were not advantaged with the high semantic stimuli in fact, only the TD group performed significantly better in the high-semantic, configural condition, compared to the low-semantic one. This finding further confirms the hypothesis that ASD children have a detail-focused processing style, as predicted by the WCC theory (Frith, 1989, 2012) and extends it to the case of VSWM. The study also confirmed that there is no overall difference between controls and ASD children in VSWM task performance in agreement with previous findings (e.g., using the block design, the embedded figures, and the Rey figure) indicating a high performance of children with ASD in visuospatial tasks (Shah & Frith, 1993). Therefore the manipulation of the semantic properties in the form of global gestalts of visuospatial material seems crucial for the identification of visuospatial weaknesses of children with ASD. Nevertheless, further research is needed to test whether the task we used could be useful in clinical settings, e.g., for detecting ASD symptoms.

Future studies should include larger numbers of participants and other clinical groups. In the present study we showed that children with ASD without intellectual disability do not take advantage from high-semantic materials in analogy with what seems to happen to intellectually disabled children (Carretti et al., 2013). It has been argued that the performance in the VPT mainly depends upon additional resources and strategies (Brown & Wesley, 2013). It has been shown that the autism characteristics can be identified in the general population (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Thus, it is possible that people with a high-autism-quotient would also differ in this task compared to people with a low-autism-quotient, as was found in other studies using different tasks (e.g., Richmond, Thorpe, Berryhill, Klugman, & Olson, 2013; Takahashi, Gyoba, & Yamawaki, 2013).

The present findings confirm that the local vs. global visuospatial preference is a crucial trait for the understanding of ASD and can be extended to the case of our VSWM task. It will be also of a particular interest to use the present task in other clinical populations (e.g., children with Williams syndrome or in children with Down syndrome). Participants with Williams syndrome present performances indicating a central coherence processing of the material (Bernardino et al., 2012). Moreover, Carretti and colleagues (2013) found that individuals with Down Syndrome took less advantage of the pattern configuration in the VPT than TD children although both groups performed better in the high semantic than in the low semantic condition. Results were explained on the basis of a strategic deficit, the use of long term memory pre-existing expertise, in individuals with Down syndrome, who should be unable to use efficient memory strategies, consistently with other studies using verbal short-term memory tasks, showing that individuals with Down Syndrome do not spontaneously use memory strategies such as rehearsal (e.g., Hulme & Mackenzie, 1992). Thus, it would be interesting to compare the performances of ASD, Williams and Down syndromes in order to analyze the differences in performing the task used in the current research. Finally, our children with ASD did not present intellectual disability. It should be interesting to compare children with ASD with and without intellectual disabilities.

The results of the present research offered support to our expectation to find no differences between the groups in the VSWM task: ASD children did not statistically differ from TD in the task we used (with a small effect size) and, importantly, they performed as well as the TD group also at higher level of complexity. On the one hand, this finding confirms that children with ASD perform as well as controls in tasks in which the target is quickly presented (McMorris, Brown, & Bebko, 2013). Moreover, both groups showed a similarly decreased performance based on the level of complexity. Our results are also in line with a large body of evidences indicating that in VSWM tasks, children with ASD and with TD do not differ overall from one another (Ozonoff & Strayer, 2001). It is worth noting that our task was quite long (included 160 trials and lasted about 30–40 min). Thus, we indirectly confirmed that children with ASD do not have problems in sustained attention tasks (Sanders, Johnson, Garavan, Gill, & Gallagher, 2008). Importantly, the performances of the two groups were similar at every level of complexity. Thus, confirming that children with ASD have good performances also when the task is more complex and requires an active (i.e., attentional controlled) process.

Although it contains some insightful findings, the present study has some limitations. While we were able to confirm our main initial hypotheses, we did not find support for the effect of the SOA. It must be noticed that, despite the absence of a statistical significance, we found a medium effect size for the SOA condition. Thus, we could expect that by increasing the sample size the effect could become significant and future studies are needed to shed more light on this respect. Moreover, we used longer SOAs than in previous research (e.g., Sun et al., 2011) and, due to the complexity of our stimuli a longer memory array duration. For these reasons, the finding of no statistical differences in the SOA condition could be due to the fact that the participants were presented with longer duration of the stimuli. In fact, it is possible that the interval between the memory array and the mask was not short enough to interrupt the consolidation of items in VSWM; in other words participants may have had sufficient time to effectively process and consolidate the VPT stimuli, making the manipulation ineffective.

This present paper has both theoretical and clinical implication. On the one hand, we have devised a new test crucial for identifying a specific weakness of children with ASD and future studies should estimate whether it could be useful in a clinical setting. Further, these new findings shed further light on the VSWM processes of children with ASD, confirming previous studies showing that they are not necessarily impaired in VSWM tasks (Griffith & Pennington, 1999; Ozonoff & Strayer, 2001; Soulieres, et al., 2011).

In conclusion, despite some limitations, the present study offers interesting results in favour of the WCC hypothesis supporting – and extending to the case of VSWM – the hypothesis that ASD children use a local strategy which does not allow them to benefit from an high-semantic, configural organization of the material. Crucially, we also introduced a new VSWM task to test the WCC hypothesis, which confirmed the results obtained with different materials, shedding an important light on the cognitive characteristic of children with ASD.

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Table 1

Characteristics of children with autism spectrum disorder (ASD) and typical development (TD).

	M-age	Education years
	M (SD)	M (SD)
ASD	161.50 (26.44)	7.75 (2.38)
TD	155.50 (28.94)	7.63 (2.26)

Note. M-age=Chronological years (months)

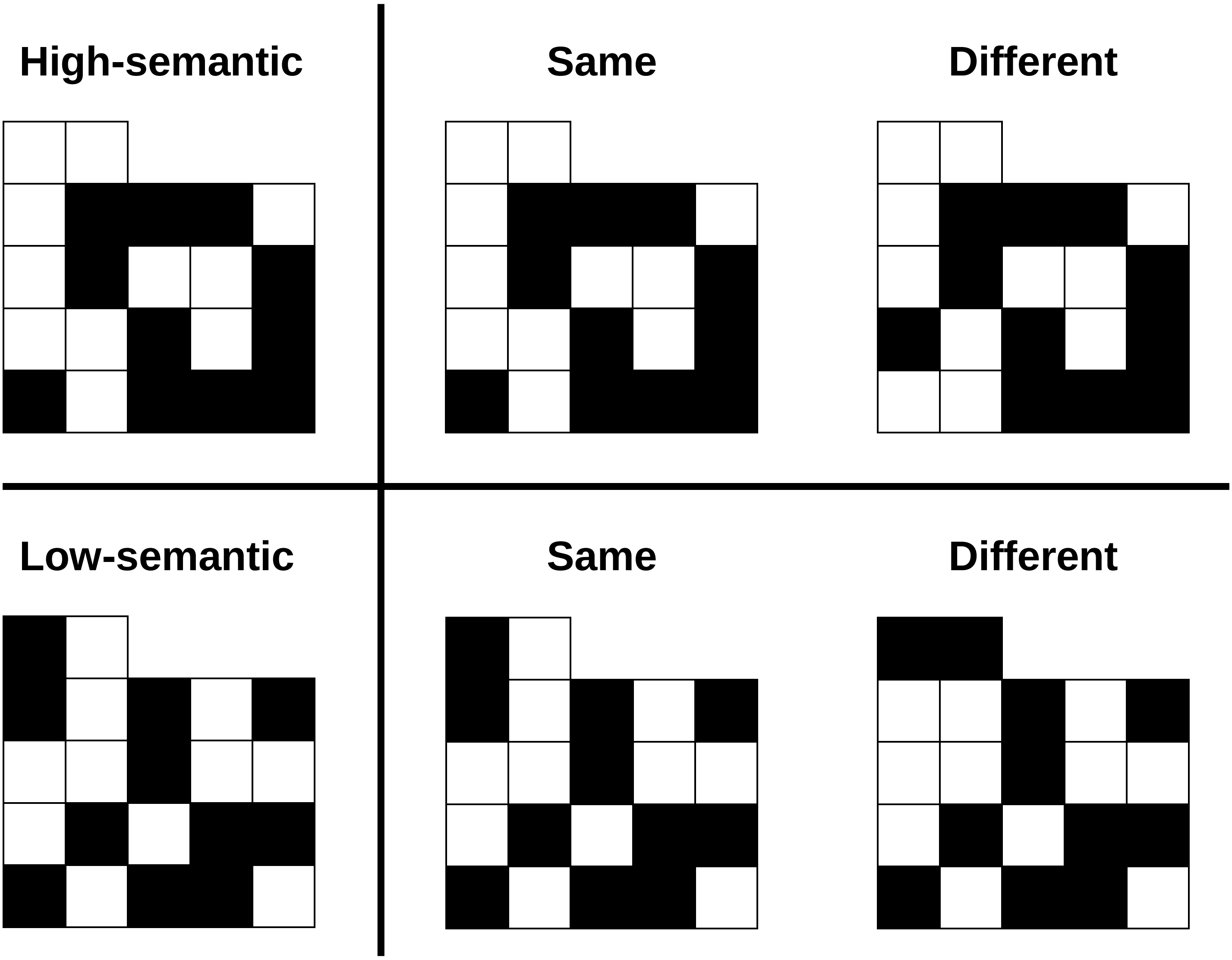

Figure 1. Examples of the semantic organization (high- and low-semantic) from level of complexity 11.

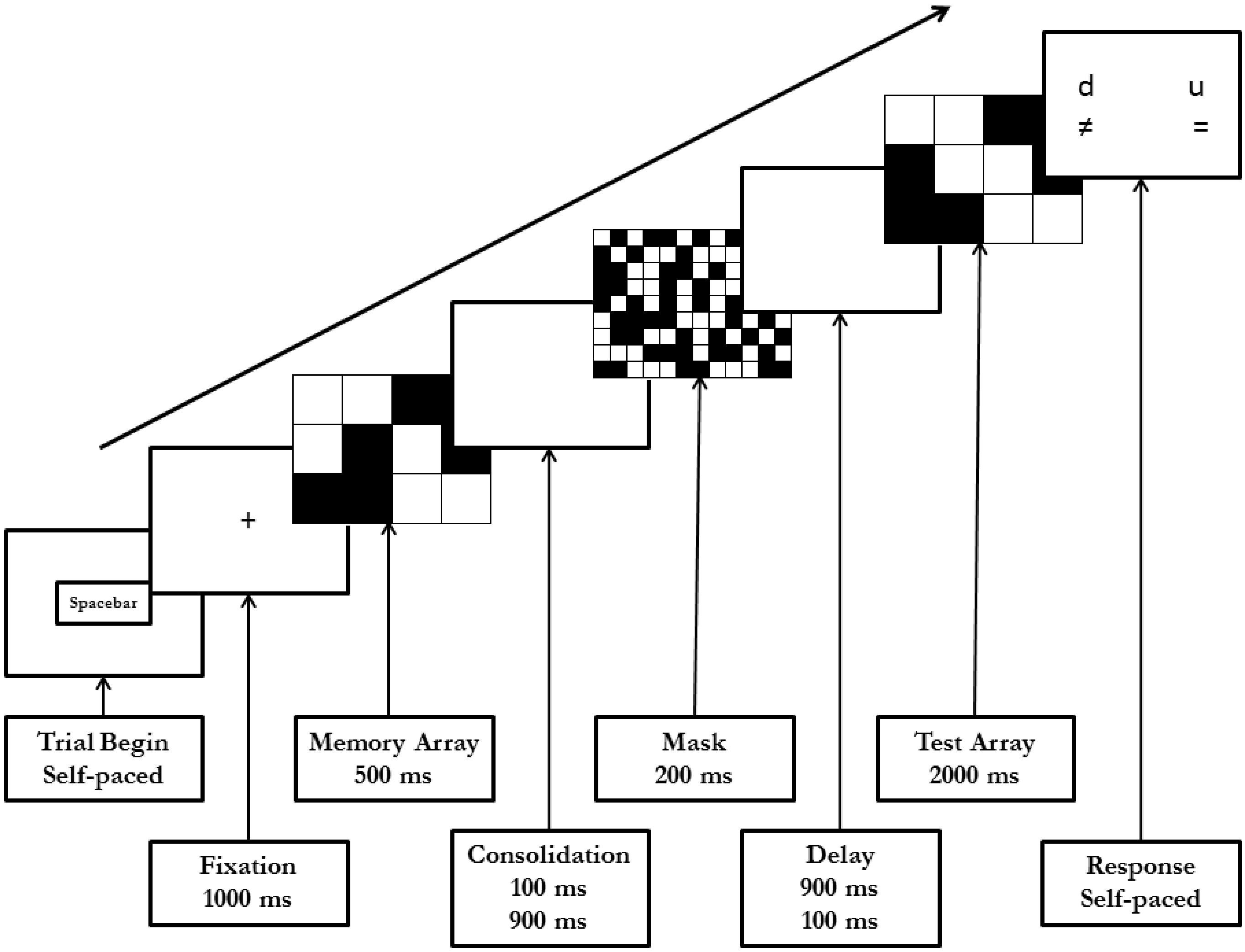

Figure 2. Experimental Procedure. D=different; U=same

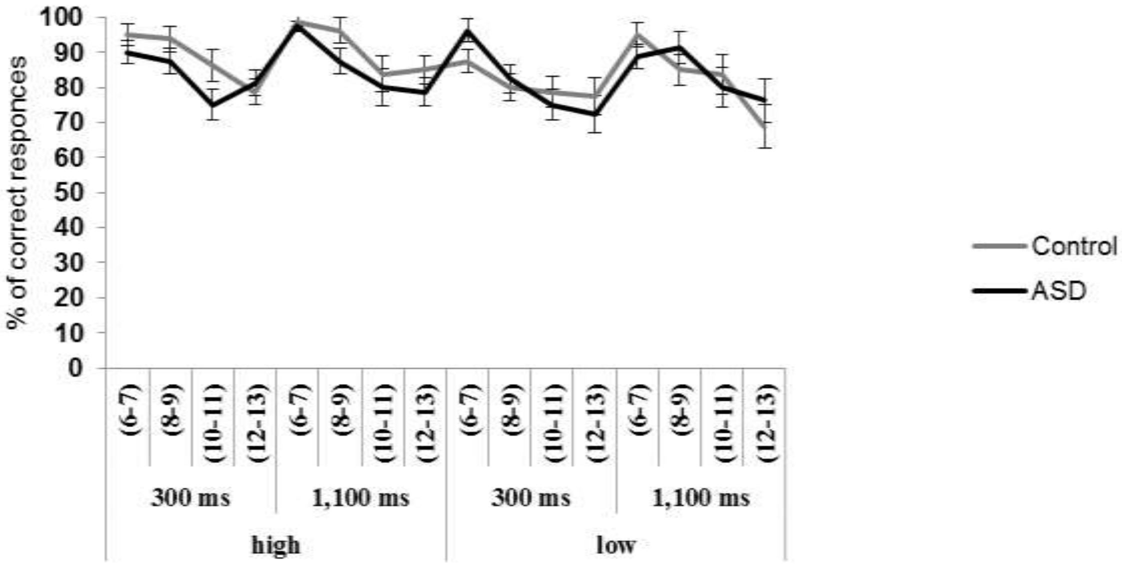

Figure 3. The four-way interaction between groups, semantics, SOAs, and levels of complexity. Error bars represent the standard error of the mean. SOAs: 300 ms and 1,100 ms. Levels of complexity are showed in parenthesis. ASD=children with autism; high=high-semantic material; low=low-semantic material.

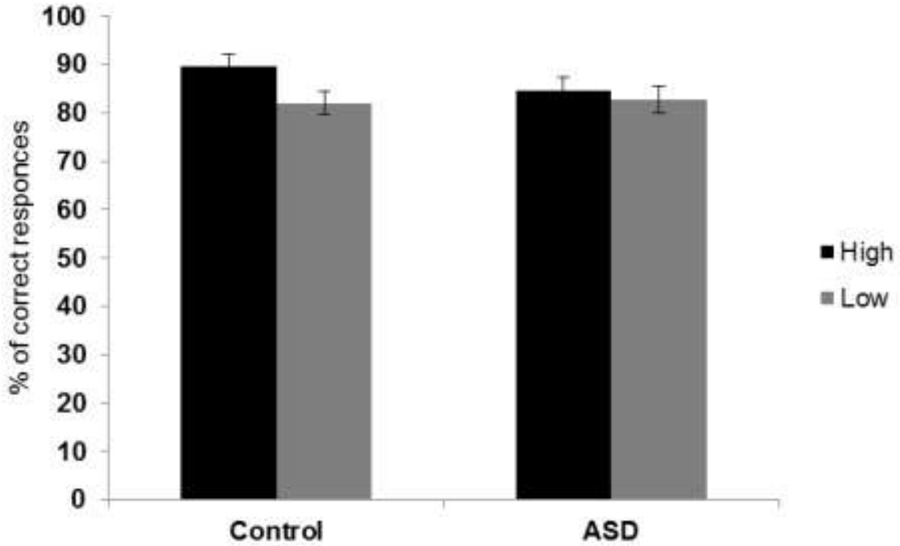

Figure 4. Effect of the semantic format (high and low) into the two groups. Error bars represent the standard error of the mean.