Phonological and Visuospatial Working Memory in Autism Spectrum Disorders

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ORIGINAL PAPER

Phonological and Visuospatial Working Memory in Autism Spectrum Disorders

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Abstract We evaluated phonological and visuospatial working memory (WM) in autism spectrum disorders. Autistic children and typically developing children were compared. We used WM tasks that measured phonological and visuospatial WM up to the capacity limit of each children. Overall measures of WM did not show differences between autistic children and control children. However, when the recall of children was examined in detail, autistic children showed reduced phonological WM compared with control children. Moreover, phonological and visuospatial WM did not increase with the age of autistic children while a development of phonological and visuospatial WM with age was found in control children. The pattern of results is discussed in terms of previous studies about WM and autism.

Keywords Autism · Phonological working memory · Visuospatial working memory

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Introduction

Autism spectrum disorders (ASD) are a group of neurodevelopmental disorders that are characterized by persistent impairments in social interaction, verbal and nonverbal communication, as well as repetitive and restricted behaviors, interests and activities (American Psychiatric Association 2000). Autistic disorder, Asperger syndrome (AS), and pervasive developmental disorders not otherwise specified are included as subtypes of ASD (Reynolds 2011). Autistic symptoms have been linked to a number of cognitive deficits, such as language impairments, problems with executive control, difficulties inferring the mental states of others, and a tendency to focus on the detail rather than the global (Kenworthy et al. 2011). These cognitive impairments have led to three major theories that attempt to explain autistic disorders from a cognitive point of view. The hypothesis of deficits in theory of mind (ToM), originally proposed by Baron-Cohen et al. (1985), states that autistic children are not able to infer the mental states of others. Since their proposal, a large number of studies have illustrated a strong association between ASD and impairments in ToM skills (Baron-Cohen et al. 1997; Ozonoff et al. 1991). On the other hand, the central coherence (CC) theory proposes that autistic individuals exhibit a qualitatively different style of information processing than normally developing individuals. Originally coined by Frith (1989), Happé (1994) and Frith and Happé (1994), this theory suggests that typically developing individuals display a natural propensity for coherence, to process stimuli as Gestalts; on the contrary, individuals with autism exhibit a weak drive for coherence, a preference for processing parts over wholes, at the expense of higher level meaning. More simply put, people with autism tend to focus on the details (local processing) rather than the big picture (global

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processing). Although empirical evidence has been found in favour of the CC theory, its validity has also been questioned due to inconsistent results (Happé 2000; Mottron et al. 1999). Finally, one of the most influential cognitive accounts for ASD is the executive dysfunction theory. Damasio and Maurer (1978) already noticed that similar behaviours were found in individuals with autism and those with frontal lobe damage. It has been suggested that most abnormalities observed in autistic individuals are related to an executive dysfunction (Ozonoff et al. 1991). Executive function is an umbrella term that includes abilities such as planning, self-regulation, inhibition and shifting, initiation and monitoring of actions, and working memory, among others. Executive deficits have been found in children with ASD in a wide number of studies (Hill 2004; Sanders et al. 2008). In the current study, we focus on a core component of executive functions in autism: working memory.

Working Memory and Autism

A core component of executive function is working memory (WM). There is no standard definition of WM (see Miyake and Shah 1999, for a review), but the most commonly used model of WM is the one proposed by Baddeley (1986) and Baddeley and Logie (1999). This model defines WM as a limited capacity system that maintains information "on-line" over brief periods of time. According to Baddeley, WM includes a primary component, the central executive, which is responsible for selecting, initiating, and terminating information processing, and it coordinates two memory subsystems. These subsystems are the phonological loop, and the visuospatial sketchpad. The phonological loop is comprised of a phonological memory store that holds verbal material for a brief period of time, and a control process by which the information in the store is refreshed through articulatory rehearsal. Similarly, the visuospatial sketchpad is responsible for the temporary storage of visual information (including spatial location), and its "on-line" manipulation.

WM is involved in complex interpersonal interactions, and it is thought to be crucial to process social and emotional cues presented in the environment (Bankó et al. 2009). Hence, it has been hypothesized that deficits in WM might result in a cascade of problems in autism, such as behaviour regulation, cognitive flexibility, social communication, abstract thinking, and control of attention (Ozonoff et al. 1991). Despite this central role that WM may play in ASD, few research works have addressed WM functioning in children with ASD. Moreover, the available set of studies has not shown a conclusive pattern of results.

In one of the first studies addressing WM in ASD, Morris and colleagues (Morris et al. 1999) examined spatial WM in individuals with AS, and IQ matched controls, with the executive golf task, a test that also measures formation of spatial strategies. Memory load was manipulated too. The group with AS showed deficits in spatial WM, but only when the memory load was high (6–8 golf balls), and they showed no impairment in formation of strategies. Similar results have been found in subsequent studies of spatial WM. For example, Landa and Goldberg (2005) employed a spatial span task in high functioning children with autism, and matched controls. They observed that children with autism committed more errors than the control group, but only when the memory load was high (8 items).

However, other studies have found no spatial WM deficit in autism. Ozonoff and Strayer (2001) used three visuospatial WM tasks (a running memory task, a spatial memory span task, and a box search task), and found no differences between a high functioning autism group and a control group. Steele et al. (2007) suggested that deficits in this domain emerge only when the task imposes heavier demands of WM. They employed the Cambridge neuropsychological test automated battery (CANTAB) a computerized test of spatial WM, and discovered that high functioning individuals with autism made more errors than control participants. Importantly, they observed a significant interaction between group and memory load: the memory load had a greater impact on the performance of autistic than control individuals. Based on this finding, they suggested that the failure of some studies to detect spatial WM deficits might be due to the use of modest memory loads. According to these authors, autistic deficits would not involve an increased rate of forgetting information over time, but a difficulty when a great amount of information needs to be kept active at the same time.

Similar to the inconsistences found between visuospatial WM and autism, conflicting results have been observed in the case of verbal WM. Williams et al. (2005) examined verbal and spatial WM in individuals with autism and matched controls. They found no differences between groups in verbal WM, as measured with an N-back letter task, while the groups differed in the spatial WM task. This was the first study to dissociate verbal and spatial WM in the same group of autistic patients. Similar results were obtained by Cui et al. (2010), in which WM of children with AS was evaluated with a battery of span and n-back tasks. Compared with a group of controls (matched on age and IQ), children with AS performed better in simple verbal span tasks, they showed good performance in complex verbal span tasks (requiring both processing and storing), but worse in visual/spatial storage span tasks. Regarding n-back tasks, the group with AS had similar accuracy as the control group, but longer response times. The authors concluded that children with AS suffer from a specific deficit in the visuospatial sketchpad in WM, and a partial deficit in central executive that explains longer response times in the n-back tasks. On the contrary, Gabig (2008) found a significant deficit in children with autism, compared with age-matched controls, in three verbal WM tasks that varied in complexity: nonword repetition, memory for digits span, and sentence imitation. Tasks complexity influenced performance outcomes in children with autism, but not in controls.

Regarding neuroimaging research, studies have not consistently found a poorer behavioural performance in WM tasks in autistic individuals, but they evidence different patterns of brain activation. For example, Koshino et al. (2005), observed similar performance in the group with ASD and the control group in a verbal n-back WM task, both in accuracy and response times. However, neuroimaging data revealed a different pattern of activation during the task in each group. Similar results have been obtained with a visual n-back WM task involving faces (Koshino et al. 2008), and with a mental rotation task (Silk et al. 2006). However, it is worth noting that all these tasks involved manipulation of information in WM, and not only temporary storage of information. The autistic group could have compensated their deficits in the maintenance of visuospatial information in WM with their proficiency in other cognitive abilities, such as mental imagery or mental rotation.

In all, the studies reviewed so far show a complex picture. Some studies have shown deficits in visuospatial and verbal WM associated to ASD while others have failed to replicate these findings. In our opinion, mixed findings about WM deficits in autism may result from a number of factors. Firstly, the selection of target and comparison groups. As Russo et al. (2007) have noticed, impairments in WM performance associated to ASD have been mostly observed when the studies include a comparison group composed by typically developing individuals, whereas intact WM functioning has been generally found when participants with autism are compared to those with intellectual disabilities. On the other hand, the choice of the ASD group is of the utmost importance. Most ASD participants in WM research are high-functioning autistic individuals (who meet the criteria for autism but have normal intellectual functioning), although this sample is not representative of the general population of individuals with autism. To illustrate, while the prevalence estimation for all forms of ASD range is around 10/10,000; the rate of high functioning autistic individuals is around 2.5/10,000 (Fombonne 2003). In a similar way, in many studies the ASD group is composed by individuals with AS, who show the highest levels of functioning (especially in the verbal domain) among individuals with ASD diagnoses. Finally, research has not usually considered the developmental level of participants; in the sense that some studies include school-age participants, but others adolescents or adults. As WM improves through normal development (mainly between the ages of 4 and 8 years) till adult performance is achieved, the developmental level of the sample evaluated is relevant to clarify WM deficits in autism.

The second confounding factor, closely related to the choice of the target and comparison groups, is IQ. Most studies include an IQ-matched comparison group to avoid this methodological concern, but this option has also its weakness. If a task largely involves verbal abilities, then matching on the basis of overall IQ leads to an underestimation of performance, whereas if the task is primarily visual-spatial, matching on IQ leads to an overestimation of performance (Russo et al. 2007). When comparing verbal and spatial WM tasks, this caveat has a great relevance. For example, in some studies that have shown deficits in ASD children compared to controls, in executive function, the difference between groups disappears when IQ is taken in consideration (Hill 2004). Similarly, there are several studies indicating that ASD children have deficits in the executive function of planning (Bennetto et al. 1996; Ozonoff and Jensen 1999). However, there is evidence that the planning ability is related to IQ rather than autism per se (Mari et al. 2003). Hence, research has not determined so far whether between-groups differences in WM are modulated by IQ. In our opinion, a good approach to control for the IQ of ASD children and control children would be not to equate them in intelligence but to control for this variable in statistical analyses when between-groups differences are found in IQ measures.

Finally, the task used to measure WM components can also influence the results obtained when autistic individuals are evaluated. In general, studies that have employed WM span tasks have found that autistic individuals perform significantly worse than controls. But, when WM tasks involved the on-line manipulation of information (such as mental rotation, or n-back tasks), no group differences have usually emerged. In addition, as we have reviewed before, there is evidence that WM load plays a crucial role in the observation of WM deficits in ASD. Tasks that place low WM demands are no sensitive to differences between children with ASD and control participants. However, when the tasks impose heavier demands, between-groups differences become apparent (Landa and Goldberg 2005; Williams et al. 2005). For example, Ozonoff and Strayer (2001) employed a spatial span task in which participants were asked to hold in memory the locations of 1, 3 or 5 geometrical shapes over a delay. The authors did not observe differences in performance between the ASD and the control group. However, when other researchers have employed this task with a memory load of 6 or 8 stimuli, children with ASD have shown a poorer performance than the control group (Goldberg et al. 2005; Steele et al. 2007).

The Current Study

The present study attempts to address the inconsistent results regarding WM in autism by avoiding the confounding variables previously mentioned. Thus, our goal is to better delineate the profile of WM impairments in ASD, by isolating intact and possible impaired phonological and visuospatial WM components. In order to prevent the mentioned caveats associated to the selection of IQ-matched groups, in our study we controlled for IQ influence in statistical analyses.

We evaluated children from 5 to 13 years of age. The criteria for selecting this range of age were based on the developmental trajectory of WM in typically developing children. It has been observed that phonological and visuospatial components of WM are present and they are relatively independent of one another at 5 years of age (Pickering et al. 1998). However, the capacity of these components increases linearly from age 5 to early adolescence (Gathercole et al. 2004).

There is a renew interest in inclusion of ASD children in general education classrooms as well as expose them to the traditional curriculum (Hunt and Goetz 1997; Kasari et al. 1999). Thus, we selected ASD children and typically developing children recruited from local area schools.

In the study, we used WM tasks to evaluate phonological and visuospatial WM span in detail. In the phonological span task, consonant–vowel–consonant (CVC) nonwords were presented and participants had to recall the nonwords with the same CVC structure with which they were presented. In the visuospatial WM span task, a sequence of squares were presented and participants had to recall them in the same order in which they were coloured. Importantly, these two tasks involved manipulation of memory load with a wide range of difficulty levels, so we were able to determine the specific span reached by participants up to their maximum WM capacity. Finally, fine-grained analyses were performed in each task in order to determine subtle between-groups differences in phonological and visuospatial WM.

Methods

Participants

This study involved 20 children with ASD, and 20 typically developing children, ranging from age 5 to 13. The ASD group mean age ($M = 8.55$, $SD = 2.30$) and the control group mean age ($M = 9.10$, $SD = 2.24$) was equated, $t(38) = 0.76$, $p = 0.45$. A total of 14 males and 6 females comprised the ASD group and 17 males and 3 females the control group. The ASD and control groups were equated in gender, $X^2 = 1.29$, $p = 0.26$. IQ was assessed with the K-BIT Brief Intelligence Test (Kaufman and Kaufman 2004). In the country of testing (Spain), children generally start school from about the age of 3 years. At this age, they begin the second cycle of primary education (3–6 years old). This second cycle is widespread in Spain. However, since this educational stage is not compulsory, care was taken when selecting the autistic children and control children to ensure that all of them started academic instruction at the age of three.

Children with ASD were recruited from normal schools. All participants met the DSM-IV criteria for autistic disorder, Asperger's syndrome, or pervasive developmental disorder not otherwise specified, confirmed by expert clinical opinion. Children were excluded if they had a history of major psychiatric disorder (e.g., psychosis), head injury, or a medical or genetic disorder associated with autistic symptoms (e.g., epilepsy). The control group was recruited from the same local schools where ASD children were included in general education classroom. None of them had known history of neurological or psychiatric disorders or developmental retardation. All children and their parents-guardians provided informed consent prior to participating in the study.

Parents completed the Social Communication Questionnaire (SCQ) (Berument et al. 1999), a parental screening questionnaire for identifying ASD. The SCQ takes advantage of two different time points, using Form A to record behaviors that have occurred at any point throughout the child's life (lifetime) and Form B to record recent behaviors, which have occurred within the past 3 months (current). A global score of 15 or higher on Form A (lifetime) of SCQ indicates a probable autism spectrum disorder. Children in the typically developing population receive an average of 5.2 on the SCQ evaluation (Happé and Ronald 2008). In our study, children with ASD showed a mean global score in the lifetime form scale above the cut-off ($M = 20.05$), while control participants showed a mean global score of $M = 5.50$; the difference between groups was significant, $F(1, 38) = 78.26$, $p < 0.001$, $\eta^2 = 0.67$. When the global score was considered in the current form scale, there were between-groups differences also, $F(1, 38) = 44.43$, $p < 0.001$, $\eta^2 = 0.54$. The mean score in the current form scale obtained by the ASD children was $M = 15.15$ while it was $M = 5.25$ in control children. Therefore, children in the test group were identified with ASD.

Materials and Instruments

The Kaufman Brief Intelligence Test (K-BIT) (Kaufman and Kaufman 2004)

This test provides a brief, individualized format for measuring verbal and nonverbal intelligence in children and adults from the ages of 4–90 years. The test consists of only two subtests: Vocabulary (verbal IQ), which measures verbal abilities, such as word knowledge, and verbal concept formation; and Matrices (non-verbal IQ), which measures non-verbal abilities, such as the ability to perceive logical relationships, and to complete visual analogies. Each test starts with an item corresponding to the chronological age of the participants, and difficulty is raised till the participant fails all the items in a difficulty level. The K-BIT generates three scores: Verbal, non-verbal and an overall IQ composite. We used raw scores to assess performance. The entire test was administered in approximately 15–30 min.

Digits Span Subtests from the Wechsler Intelligence Scale for Children (WISC-IV) (Wechsler 2003)

We considered the scores in these subtests as an overall measure of WM.[1] These tests involve the presentation of spoken sequences of digits, at the rate of one digit per second. In the forward test, participants are required to repeat the sequence of digits in the same order, and in the backward test, participants are required to repeat them at the reverse order. The forward test measures the maintenance of information in WM, whereas the backward test measures updating in WM. The starting level includes two digits, and there are two trials in each difficulty level (till nine digits in the most difficult level). The task finishes when the participant fails the two trials of a difficulty level. The participant's span is the largest difficulty level in which at least one out of the two trials is correctly reproduced.

Phonological Span Test

In order to measure the phonological span we created a memory task in which participants had to memorize and recall consonant–vowel–consonant letter trigrams (CVC pseudo-words which were pronounceable but without meaning). This task was very similar to other serial recall of nonwords tasks (e.g., Roodenrys and Hinton 2002). The version used here was created in order to make sure that the material to be memorized had no meaning in the language of testing (Spanish). Thus, trigrams were constructed so that they did not spell a word, proper name or common abbreviation (e.g., KAG, BIM, DUT, FIP, etc.). The task was organized into five levels increasing in difficulty from two-trigrams to six-trigrams. Each level included three lists of two, three, four, five and six trigrams. The total number of trigrams was 60. Each CVC combination was used only once during the experiment. In a trial, a list of trigrams was presented horizontally for 4 s. The participants had to memorize these trigrams silently without saying them aloud. Then, a black screen was presented during 15 s and, afterward, subjects had to write the trigrams by using the computer keyboard. The children received the following instructions at the beginning of the task: "some words without meaning will be shown on the screen and you have to memorize them silently. After a short delay you will have to write these meaningless words on the keyboard". The task started with two trigrams, and the difficulty level was raised by increasing the number of trigrams if the subject was correct in at least two out of the three trials. The subject's span was the largest number of trigrams in which at least two out of the three lists within a difficulty level were correctly reproduced. For example, if the children succeeded in retrieving two trials in the two trigrams difficulty level but they reproduced only one in the three trigrams difficulty level (they failed in two out of three trials); the children phonological span was two. The criterion used to determine the overall span was the same as that used in other WM tasks (e.g., Berch et al. 1998; for a methodological review).

Visuospatial Span Test

A computerized version of the Corsi Block test (Corsi, 1972) was created to measure the participants' visuospatial span. The version used in the study maintained the same structure (difficulty levels), material (randomly distributed coloured squared), than the standardized and validated Corsi block tapping test (Corsi 1972). Participants had to reproduce the sequence in which the coloured squares appeared. There were nine white squares (2 cm × 2 cm) unevenly distributed over a 16 cm × 16 cm quadrant in

[1] Digit span as an overall measure of WM. The digit span task is an omnibus measure that indexes working memory amplitude (verbal WM) and many other aspects such as word knowledge (e.g., magnitude information associated to the digits) and executive functioning (e.g., updating information in the backward version). For example, digit span shows correlation with many other executive and working memory tasks such as sentence and word reading tasks (Lehto 1996, for a systematic examination). Moreover, the recall of digits in the digit span task shows an advantage due to the increased frequency with which digits, compared to other verbal material, appear as random sequences in natural language (see Jones & Macken 2015, for a critical review). In addition, the recall of digits or words is better than the recall of nonwords (Hulme et al. 1997). This observation seems to indicate that linguistic familiar material enhances integrity of the items to be recalled probably due to the use of long-term lexico-phonological representations (e.g., Schweickert 1993). All these aspects guided us to consider the digit span task as an overall control measure of WM while we performed a detailed examination of the visuospatial and phonological WM with tasks that controlled for some factors such as word knowledge, familiarity of the material and frequency of items to be recalled (e.g., in the phonological span task meaningless CVC trigrams were used).

the computer screen. The positions of the squares were fixed. Each trial began with the presentation of the nine squares in white and then, some of them were sequentially coloured in green at a rate of one square per second. The squares remained until 500 ms after the sequence was completed. Then, a black screen was presented during 15 s. Finally, the nine white squares were again presented to be coloured in the correct order. Participants were asked to use the mouse to point to the square they wanted to colour, and they were instructed to fill the squares previously coloured in the correct order. We created three sequences of two, three, four, five, six, seven, eight and nine squares to be recalled; and they were presented in a fixed order for all the subjects (24 trials). The starting level for the task was two squares sequence. There were three trials at each difficulty level, and the difficulty level was progressively raised by increasing the number of filled squares if the subject gave the correct sequence in at least two out the three trials. The subject's span was taken to be the largest sequence in which at least two out of the three sequences within a difficulty level were correctly reproduced. For example, if the children succeeded in retrieving two trials in the three squares difficulty level but they failed in two out of three trials in the four square difficulty level, the children visuospatial span was three.

Procedure

The children were asked to complete the K-BIT test and the three cognitive tasks, in a counterbalanced order. The K-BIT test and the Digits Subtests were administered verbally by the experimenter, who wrote down children responses. The phonological and visuospatial span tests were presented in a computer, and children had to write down responses in the laptop (in the phonological test) or signal the response on the screen with the mouse (in the visuospatial test). Children received some training before completing the computerized tasks, and they performed them under the supervision of the experimenter. Care was taken to ensure that experience of children with computers did not determine their performance in the span tasks. To this end, children with reduced computer use (3 children in the ASD group and 2 children in the control group), said aloud the CVC pseudowords in the recall phase of the phonological span task and the experimenter wrote them with the computer keyboard. In the visuospatial span task, these children pointed the fingers at the desired squared and the experimenter registered the responses with the mouse. All the tasks were carried out in individual sessions that lasted no more than 1 h.

Results

Before analysing the scores obtained by children in the phonological and visuospatial components of WM, we described control measures used in the study: intelligence and overall WM (digit span). The mean K-BIT standard score is $M = 100$ ($SD = 15$). When we considered the global (composite) score obtained by children in the K-BIT test, the ASD group showed lower scores ($M = 104.45$, $SE = 4.24$) than the control group ($M = 118.95$, $SE = 4.24$), $F(1, 38) = 5.86$, $p = 0.02$, $\eta^2 = 0.13$. In the verbal IQ scores, there were differences between the ASD group ($M = 94.80$, $SE = 3.93$) and the control group ($M = 112.30$, $SE = 3.93$), $F(1, 38) = 9.90$, $p = 0.003$, $\eta^2 = 0.21$. However, there were no significant differences in non-verbal intelligence between the ASD group ($M = 117.10$, $SE = 4.40$) and the control group ($M = 124.70$, $SE = 4.46$), $F(1, 38) = 1.49$, $p = 0.23$, $\eta^2 = 0.04$. Therefore, between-groups differences in IQ were due to the lower score of ASD children relative to the control children in verbal intelligence. Thus, in order to control for this variable, it was considered as covariate factor in all subsequent analyses.

We analyzed also the score obtained by the children in the digit span test. Total scores in the digit span test ranges from 0 to 32. There were no differences between the total score obtained in the ASD group ($M = 13.00$, $SE = 0.60$), and that found in control children ($M = 14.25$, $SE = 0.60$), $F < 1$. We analysed further possible between-groups differences in each digit span subtest. The scores in the forward digit span ranges from 0 to 9. There were no differences between ASD children ($M = 4.65$, $SE = 0.21$) and control children ($M = 5.00$, $SE = 0.21$), $F < 1$. Finally, the scores in the backward span test ranges from 0 to 8 and there were no differences between the score found in ASD children ($M = 3.50$, $SE = 0.24$) and that of control children ($M = 3.80$, $SE = 0.24$), $F < 1$. Detailed analyses were also computed in order to determine subtle between-groups differences in overall WM recall. To this end, we computed the number of trials in which participants correctly recalled the sequence of numbers in the forward and backward span test. In the forward span test, there were no difference between the number of trials correctly recalled by ASD children ($M = 6.60$, $SE = 0.33$) and those recalled by control children ($M = 7.30$, $SE = 0.33$), $F(1, 37) = 2.30$, $p = 0.14$, $\eta^2 = 0.06$. Similarly, in the backward span test, the number of correctly recalled trials was similar in the group of autistic children ($M = 6.45$, $SE = 0.39$) and the group of control children ($M = 6.85$, $SE = 0.39$), $F < 1$. Therefore, when we considered an overall measure of WM, no differences were found between autistic children and typically developing children.

Phonological Working Memory

When the overall phonological span was considered as the largest number of trigrams in which at least two out of the three lists were correctly reproduced, all children in the two groups obtained the same score (phonological span = 2). Although the ASD and control children had similar phonological span when the overall measure was considered, fine-grained analyses were performed in order to capture possible between-groups differences. To this end, we computed the percentage of trials correctly recalled by each participant up to the largest block of triples reached by the children (two CVC triples). When this variable was considered, the ASD groups had lower recall of phonological information relative to control children, $F(1, 37) = 4.85$, $p = 0.03$, $\eta^2 = 0.12$ (see Table 1). Therefore, although all children showed the same overall phonological span, when a detailed inspection of recall measures was performed, ASD children showed lower phonological amplitude relative to the control group of children.

Visuospatial Working Memory

When the overall visuospatial span was considered as the largest sequence in which at least two out of the three sequences were correctly reproduced; there were no differences between ASD children and control children ($M = 2.6$ and $M = 3.3$, respectively), $F(1, 37) = 2.05$, $p = 0.16$, $\eta^2 = 0.05$. As done with the phonological span test, further analyses were performed in order to isolate possible between-groups differences by considering detailed visuospatial span measures. We computed the number of trials correctly recalled up to the maximum block reached by each participant in the test. When this measure was considered, there were no differences between the ASD group and the control group of children, $F < 1$.

Table 1 Phonological and visuospatial working memory in ASD and control children

	ASD group		Control group	
	M	SE	M	SE
Phonological working memory				
Span level	2		2	
Recall of trials (%)	41.67	6.97	70.83	6.97*
Visuospatial working memory				
Span level	2.60	0.27	3.30	0.27
Recall of trials (%)	73.05	5.59	88.17	5.59

* $p < 0.05$

The Development of Phonological and Visuospatial Working Memory with Age

We were interested in exploring whether the possible relationship between WM measures varied between ASD children and typically developing children depending on age. To this end, we computed Pearson correlations for each group of children. Correlation matrixes in each group included age and the percentage of trials correctly recalled in the phonological and visuospatial WM tests. When the control children were considered, there was a positive correlation between age and phonological and visuospatial WM measures (p s < 0.03). Hence, WM increases with age in typically developing children. However, the increase of WM associated with age was not observed in ASD children either when phonological span or visuospatial span was considered (p s > 0.38) (see Table 2).

Working Memory in Autistic Individuals Depending on Their Intellectual Functioning

We further analysed possible WM differences depending on the intellectual functioning of ASD children. To this end, median-split analyses were performed by sorting the children depending on the global score obtained in the K-BIT test. Low and high intellectual functioning groups were formed with 10 participants in each group. The low and high intellectual functioning groups differed in global IQ, $t(18) = 4.60$, $p < 0.001$, $d = 4.4$ ($M = 88.20$, $SE = 6.09$, and $M = 120.70$, $SE = 2.15$, respectively), verbal IQ, $t(18) = 3.42$, $p = 0.003$, $d = 3.3$ ($M = 81.00$, $SE = 7.01$, and $M = 108.60$, $SE = 5.26$, respectively), and non-verbal IQ, $t(18) = 3.93$, $p < 0.001$, $d = 3.8$ ($M = 102.40$, $SE = 5.32$, and $M = 131.80$, $SE = 3.56$, respectively). The two groups also differed in mean age, $t(18) = 2.07$, $p = 0.05$, $d = 2.0$ ($M = 9.50$, $SE = 0.60$, and $M = 7.60$, $SE = 8.47$, respectively). When WM measures were examined controlling for age as a covariate factor, no between-groups differences were found in the phonological span task, $F(1, 17) = 2.30$, $p = 0.15$,

Table 2 Intercorrelations among measures of working memory components and age

	ASD group			Control group		
	1	2	3	1	2	3
1. Age	–			–		
2. Phonological recall (%)	0.13	–		0.62**	–	
3. Visuospatial recall (%)	−0.21	0.08	–	0.48*	0.28	–

* $p < 0.05$; ** $p < 0.01$

$\eta^2 = 0.12$. However, visuospatial span was higher in high intellectual functioning children relative to low intellectual functioning children: between-group differences were significant in the overall visuospatial span, $F(1, 37) = 5.36$, $p = 0.03$, $\eta^2 = 0.24$, and they showed a trend toward significance in the percentage of correctly recalled trials, $F(1, 37) = 3.72$, $p = 0.07$, $\eta^2 = 0.18$ (see Table 3).

Discussion

A good deal of research has been devoted to the search of primary impairments in ASD. Among these impairments, WM deficits have been investigated. WM is a memory system that is crucial to successfully perform a number of complex cognitive tasks, such as the Wisconsin Card Sorting Test (WCST), or planning tasks. Moreover, WM is considered essential for social functioning, since social situations demand understanding the immediate environment, keeping active incoming information, and responding according to our goals. In this sense, WM deficits could underlie many of the cognitive and behavioural manifestations of the disorder. However, previous research on WM in ASD has yielded inconsistent results (Kercood et al. 2014). In the introductory section, we have outlined some potential reasons for this discrepancy. In our research, we have evaluated deficits in phonological and visuospatial WM in the same group of ASD children and controls, avoiding some confounds of previous studies. Firstly, we have controlled the influence of IQ on WM performance; secondly, we have manipulated memory load, in order to better delineate the memory performance of children with ASD; finally, fine-grained analyses have been used to determine subtle between-groups differences in memory recall. Our results indicated that ASD children showed deficits in phonological WM compared to controls, even when the task involved small memory load (2 items). Although the phonological span was similar in ASD and control children, ASD children showed a lower number of recalled trigrams than control children. On the contrary, we did not find differences between groups neither in the visuospatial span nor in the overall number of recalled trials in the visuospatial task.

In our study, we evaluated autistic children with relatively normal intellectual functioning. This was done in order to make comparable our research with previous work about WM and ASD in which high functioning autistic individuals are usually tested (e.g., Andersen et al. 2013; Barendse et al. 2013; Baron-Cohen et al. 1997; Landa and Goldberg 2005; Koshino et al. 2005; Williams et al. 2006). However, when ASD individuals were compared depending on their intellectual functioning, the autistic children with low IQ showed reduced visuospatial span relative to children with high IQ. Therefore, this pattern of results highlight the relevance of taking into account the intellectual functioning of children when WM is evaluated in autism.

As we commented in the introduction section, previous research has provided inconclusive evidence about whether children with ASD are impaired in visuospatial WM. To illustrate, visuospatial WM deficits in ASD participants have been found in the spatial WM task of the CANTAB battery (Landa and Goldberg 2005; Steele et al. 2007). In this task, several boxes are presented and participants have to discover a hidden token by touching boxes at several locations and avoiding revisiting a box in which a token was already found. In several studies, ASD participants show reduced efficiency in this task compared to control participants. However, these WM deficits in autism seems to be exacerbated by lower IQ of autistic children (Salmanian et al. 2012). In our study, the IQ of ASD children was lower than that of control children; however, the influence of this variable was controlled in the analyses so it cannot explain the absence of between-groups differences found in the visuospatial memory task. Moreover, it has been argued that reduced performance on the CANTAB task may not depend on impaired visuospatial WM but on other cognitive processes such as the ability to plan a sequence of movements when performing the task. In fact, when a "cleaner" visuospatial WM task is used, no

Table 3 Phonological and visuospatial working memory in high/low intellectual functioning ASD children

	High functioning ASD Group		Low functioning ASD Group	
	M	SE	M	SE
Phonological working memory				
Span level	2		2	
Recall of trials (%)	50.00	0.31	33.33	8.96
Visuospatial working memory				
Span level	2.90	4.44	2.30	0.15*
Recall of trials (%)	87.78	0.77	58.33	12.48~

* $p < 0.05$; ~ $p = 0.07$

differences are found between ASD children and typically developing children (Ozonoff and Strayer 2001). In our study, we used a simple visuospatial WM task to avoid the involvement of other cognitive processes (e.g., planning). Therefore, the results found in our study agrees with previous evidence showing that when IQ is controlled and simple tasks are used, no visuospatial WM deficits are found in autism.

When we move to phonological WM, previous evidence about deficits in autistic individuals is inconclusive. However, our results are consistent with a number of studies that have found deficits in phonological WM. For example, Gabig (2008) found that children with autism performed significantly worse than age-matched controls in three verbal WM tasks. One of these tasks (non-word repetition) resembles the phonological task we have employed. Alloway et al. (2009) also found a selective deficit in verbal short term memory in children with ASD. These authors employed three verbal memory tasks: digit recall, word recall and nonword recall, in which children heard a sequence of verbal items, and had to recall each sequence in the correct order. No between-groups differences were found when comparable visuospatial tasks were used. Thus, it seems that evidence supports the existence of a phonological WM deficit in ASD patients in spite of preserved visuospatial WM.

Since a core feature of autism is a severe impairment in verbal communication, it would be reasonable to anticipate phonological WM deficits in this disorder. Indeed, deficits in phonological WM could underlie the common problems of language and communication in autism. Deficits in WM contribute to individual differences in language skill acquisition in healthy children (Gathercole and Baddeley 2014, for a review). The relationship between WM and the behavioural manifestations of the disorder is closely linked to the question about the primacy of deficits. There has been controversy about whether a primary deficit could account for the diversity of symptoms in ASD. Whereas some authors (Happé and Ronald 2008) stated that no unitary account could be able to explain the complete phenotype of ASD, some others (Barendse et al. 2013), have asserted that cognitive deficits could be considered to lie beyond emotional and social dysfunction in ASD. In this line, Bull et al. (2008) have found that WM is required in both simpler and complex theory of mind tasks. From this view, deficits in emotion, perception and theory of mind would correlate as a consequence of a core WM deficit.

A critical finding in our study was the absence of relationship between age of ASD children and recall measures of phonological and visuospatial WM. In fact, while control children showed an increase in phonological and visuospatial WM with age, this development was not found in autistic individuals. In typically development children, measures of phonological and visuospatial WM show a steady increase from the preschool years through to adolescence (Gathercole et al. 2004, for a review). The development of phonological WM in typically development children involves the use of rehearsal of phonological information with age and improvements in the speed of memory scanning of phonological information during retrieval (Cowan et al. 1992). In contrast, the absence of correlation between phonological WM and the age of autistic individuals would be in line with previous observations that children with autism do not spontaneously use linguistic cues to facilitate the retrieval of information (Tager-Flusberg 1991). On the other hand, typically developing children show developmental increases in visuospatial WM which seems to reflect changes in the storage capacity of visuospatial information (Logie and Pearson 1997), and the use of long-term knowledge about visuospatial structures to support the maintenance of information in WM (Pickering 2001, for a review). The lack of visuospatial WM development in our sample of ASD children would support previous research showing that autistic children have developmental problems in memorizing visual sequences for later recall (Boucher and Warrington 1976; Minshew et al. 1997; Rapin 1996).

The search of cognitive deficits in ASD has relevance not only at a theoretical level, but also for applied settings. In our study, age-matched controls were used as a comparison group. As Gabig (2008) states, it is important to investigate how ASD children perform relative to their same-age peers (especially regarding verbal WM), because there is a renew interest in inclusion of ASD children in general education classrooms. The discovery of selective deficits in WM could lead to the development of training programmes. Despite its relevance, there is a paucity of studies regarding WM training in ASD. It would be crucial to evaluate whether WM can be trained, and, if so, whether WM training would improve language skills and academic performance. In a pioneering study, Baltruschat et al. (2011) tested the use of positive reinforcement in the training of three WM tasks. Although the sample size was small (n = 3), all of the children demonstrated improved WM performance with positive reinforcement; and improvement generalised to different stimuli and responses. Later, Broadbent, and Stokes (2013) reported that children with ASD showed an improved performance in the WCST after the use of positive feedback. Although additional research about WM interventions needs to be conducted, preliminary results of cognitive improvement after training are very encouraging.

The pattern of results found in this work has relevant implications also in the context of preschool and elementary education (Prince and Gifford 2016). Studies with preschoolers and children in elementary school have revealed the key role of WM in the emergence of initial literacy. In addition, WM predicts academic performance of children such as reading and writing (Alloway and Copello 2013). Thus, it would be fundamental to implement teaching strategies to develop WM in autistic children. Recent studies have emphasized this issue. For instance, the use of the Memory Booster program, an school intervention program which involves the strategies of repetition, visual images, storytelling and grouping, improves WM performance of children between ages 5–8 (St Clair-Thompson and Holmes 2008; St Clair-Thompson et al. 2010; see also the Jungle Memory computer program, Alloway et al. 2013). This type of intervention programs are needed to foster WM development in autistic individuals at school.

To conclude, the results found in the current study showed reduced phonological recall in autistic individuals relative to typically developing children even when the phonological span level reached by the children was the same in all participants. Importantly, phonological and visuospatial WM developed with age in control children while autistic individuals did not show this developmental pattern. Additional research is needed to outline clinical and pedagogical implications of the link between WM and autism.

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Compliance with Ethical Standards

Conflict of interest Pedro Macizo, María Felipa Soriano and Natalia Paredes declared no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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

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