

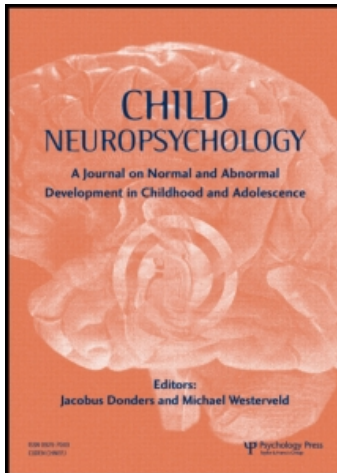
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WORKING MEMORY AND COGNITIVE SKILLS IN INDIVIDUALS WITH DOWN SYNDROME

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This work is aimed at analyzing working memory (WM) components and their relationships with other cognitive processes in individuals with Down syndrome (DS). Particular attention is given to examine whether a verbal WM deficit is due to difficulties in verbal abilities often showed by individuals with DS, or whether it is a deficit per se. A group of 20 individuals with DS was compared to a group of 20 typically developing (TD) children matched on vocabulary comprehension and to a group of 20 TD children matched on general verbal intelligence. The groups received a battery of 3 verbal and 3 visuospatial WM tasks requiring different degrees of control, and tests assessing verbal abilities (WPPSI verbal scale, PPVT), nonverbal skills (WPPSI performance scale), and logical thinking (LO). The results revealed that individuals with DS have deficits in both central executive (control) and verbal components of the WM system, and the latter one is independent of the general verbal abilities deficit. The data suggest that the development of central executive proceeds at a slower rate in individuals with DS and differently from TD children with comparable verbal abilities. The performance of individuals with DS on high-control WM tasks requires additional general resources that are strictly linked to intelligence.

Keywords: Down syndrome; Intellectual disabilities; Working memory; Verbal memory; Logical thinking.

INTRODUCTION

Down syndrome (DS) is caused by abnormalities of Chromosome 21, in particular Trisomy 21, which is the most common karyotype accounting for 95% of cases. It affects about 1 in 1000 live births (McGrowther & Marshall, 1990). The great majority of people with DS have mild to severe levels of intellectual impairment and a wide range of associated physical, medical, and cognitive deficits, including language impairment. The severity of language impairment is highly variable, and different components of the language system are affected to a different degree. In general, expressive language is affected to a greater extent when compared to receptive language and/or language comprehension (e.g.,

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Miller, 1992; Rondal, 1996). Characteristic patterns of inefficient language skills in individuals with DS include deficits in phonology and speech intelligibility (Dodd & Thompson 2001; Kumin, 1994; Miller; Rosin, Swift, Bless, & Vetter, 1988), in language production when compared to comprehension and nonverbal cognition, and in syntax when compared to lexicon and pragmatics (Cardoso-Martin, Mervis, & Mervis, 1985; Chapman, 1997; Miller; Rosin et al., 1988). At the same time, individuals with DS show relatively intact visuospatial abilities. There are a number of studies that had examined memory system, structure, and processes in individuals with DS (for a review see Baddeley & Jarrold, 2007 or Lanfranchi & Vianello, 2006). One framework often used to capture diverse memory processes is Baddeley's (Baddeley, 1986) multicomponent model of working memory (WM). Baddeley described WM as a limited capacity system in which the central executive component interacts with a set of two subsidiary subcomponents used to temporarily store different classes of information: the speech-based phonological loop and the visuospatial sketchpad. The phonological loop is responsible for the temporary storage of verbal information; items within it are of limited duration and are maintained via the process of articulation. The visuospatial sketchpad is responsible for the storage of visuospatial information over brief periods and plays a key role in the generation and manipulation of mental images. Both storage systems are dependent upon the central executive, an attentionally limited control system.

The distinctions made between the central executive system and specific memory storage systems (i.e., the phonological loop) in some ways parallel the distinctions made between WM and short-term memory (STM). WM is referred to as a processing resource of limited capacity involved in the preservation of information while simultaneously processing the same or other information (Baddeley & Logie, 1999). In contrast, STM typically involves situations where small amounts of material are held passively, and minimal resources from long-term memory are activated to perform the task. STM tasks require the material to be reproduced in a sequential fashion; that is, participants are asked to reproduce the sequence of items in the order they were presented (digit or word span tasks).

More recently, Cornoldi and Vecchi (2003) hypothesized that STM and WM tasks may be described according to two continuous dimensions: the horizontal continuum, which refers to the type or format of stimulus characteristics (e.g., verbal, visual, spatial, and so on), and the vertical continuum, which refers to the degree of control. Control is defined on the basis of the degree of active processing required to manipulate information currently maintained in a temporary memory system. Control may range from a simple rehearsal activity to a more complex one, such as order change, selection, inhibition, transformation processes, or, at the higher end of the continuum, dual processing. In other words, we define control as the degree of central executive involvement required to perform a task at hand.

Several recent studies that examined WM in DS pointed out the possible deficits in the verbal component of WM system, while visuospatial is usually found to be relatively intact (Hulme & Mackenzie, 1992; Jarrold & Baddeley, 1997, 2001; Jarrold, Baddeley, & Hewes, 2000; Kanno & Ikeda, 2002; Lanfranchi, Cornoldi, & Vianello, 2004; Marcell & Cohen, 1992; Marcell & Weeks, 1988; Seung & Chapman, 2004; Wang & Bellugi, 1994). Moreover, Lanfranchi and her colleagues (2004) found that the differences in scores on WM tasks between children with DS and typically developing (TD) children matched on mental age increased as the task's requirement for more of the central executive involvement also increased. This result has been observed for both verbal and visuospatial WM tasks. A similar finding was obtained in a study by Vicari, Carlesimo, and Caltagirone (1995).

Taken together, these results lead to the hypothesis of a double deficit, which assumes that individuals with DS have deficits in both verbal and control (central executive) components of WM. However, the control deficit may not be specific to DS disorder, but rather be associated with overall intellectual abilities. Studies that used a similar research design also found deficits in the control processing in individuals with intellectual disabilities caused by organic (Lanfranchi, Cornoldi, & Vianello, 2002) and other genetic syndrome deficits (Lanfranchi, Cornoldi, & Vianello, 2003; Lanfranchi, Cornoldi, Drigo, & Vianello, 2009). These outcomes are within the lines of current Piagetian, Neopiagetian, and other cognitive theories of development and indicate a link between WM and intelligence (e.g., Case, 1987; Engle, Thulowski, Laughin, & Conway, 1999). At the same time, these results go a step further to hypothesize that this relationship may be moderated by the degree of WM control.

Based on previous research findings, a verbal WM deficit appears to be specific to DS; it was not found to be present in either individuals with Williams syndrome (WS; e.g., Jarrold, Baddeley, & Phillips, 1999; Wang & Bellugi, 1994) or those with Fragile X syndrome (Lanfranchi et al., 2009). Consequently, it would be of interest to determine whether the verbal WM deficit in individuals with DS reflects a general WM deficit per se or whether it depends on a verbal impairment related to Trisomy 21.

Earlier studies excluded suppositions of a verbal WM deficit to be related to hearing difficulties (Jarrold & Baddeley, 1997; Marcell & Armstrong, 1982; Marcell & Cohen, 1992; Marcell, Harvey, & Cothran, 1988) or to problems in articulation (Brock & Jarrold, 2004, 2005; Jarrold, Baddeley, & Hewes, 2000; Marcell & Weeks, 1988). Both hearing and articulation difficulties are found to be relatively common in individuals with DS. Several researchers have proposed that low verbal WM performance in individuals with DS could be explained by their overall verbal impairment (for reviews, see Dykens, Hodapp, & Finucane, 2000 and Vianello, 2006). In other words, the difficulty in verbal WM could be attributed to a generalized difficulty in performing tasks requiring verbal processing, as a result of overall low linguistic competence often present in individuals with this syndrome. Of course, the direction of the relationship could be opposite, and it is possible that deficits in verbal WM system would affect and determine (at least in part) the low level of verbal skills. Experimental evidence coming from research studies with neuropsychological patients (e.g., Baddeley, Papagno, & Vallar, 1988) as well as with TD children (e.g., Gathercole, Hitch, Service, & Martin, 1997) suggests that WM is critical to successful language development in many areas, particularly in vocabulary acquisition (for a review see Baddeley, Gathercole, & Papagno, 1998) and expressive language development (Adams & Gathercole, 1995). However, the significant relationship between verbal abilities and short-term verbal WM skills has not always been established in children with specific learning disabilities (Bishop, North, & Donlan, 1996), adults with intellectual disabilities (Numminen, Service, Ahonen, & Ruoppila, 2001), and individuals with DS (Jarrold & Baddeley, 1997). Therefore, the primary research question guiding the present work is to examine whether poor performance of children with DS on verbal WM tasks is attributed to their general verbal impairment or reflects specific WM deficit.

The present study extends the previous work by Lanfranchi et al. (2004), which analyzed WM in individuals with DS by comparing them with TD children of the same mental age. The participants in that study were administered four verbal and four visuospatial tasks requiring different degrees of control. The results revealed that the TD group outperformed the DS group on verbal WM tasks and tasks requiring high control. Moreover, the differences between individuals with DS and those with TD increased as the difficulty of the task increased and the demands on central executive also increased. The present work builds on the previous procedures outlined in Lanfranchi et al.'s study

(2004). Our objective was to further analyze the relationship between WM and cognitive abilities (such as vocabulary, verbal abilities, performance abilities, and logical thinking) in children with DS by comparing them with TD children. In sum, the present study extends the previous one by comparing individuals with DS with two control groups of TD children matched on the basis of different aspects of verbal abilities. Moreover, the study is extended by shifting its focus from WM to other aspects of cognitive functioning, such as logical thinking, verbal and visuospatial abilities.

Therefore, one of the main goals of this study was to determine whether the cause of low verbal WM performance in individuals with DS was a result of overall low verbal skills or was due to a more specific WM deficit. To test this hypothesis, the study compared performance of individuals with DS with that of TD children matched on language abilities. As noted by Ypsilanti and Grouios (2007), the studies focusing on cognitive abilities in individuals with DS have to face difficulties in selecting the appropriate control group. The empirical studies published to date have employed various procedures in matching experimental groups. Some of the most commonly used procedures include matching on mental age, chronological age, receptive vocabulary, and productive language.

In the present study we choose to match the groups on the basis of our independent variable, language abilities, in order to explore its effects on working memory performance. This matching choice is also in line with Karmiloff-Smith's (e.g., 1998) developmental disorder theory. According to this theory, behavioral outcomes in developmental disorders could stem from different cognitive processes. Thus, it would be more appropriate to match control groups on the basis of behavioral outcomes (in our case language abilities) rather than underlying cognitive processing.

It has been repeatedly documented (e.g., Miller, 1992; Rondal, 1996) that children with DS exhibit an unusual disparity between expressive and receptive language, despite of what would be expected based on their mental age. Therefore, we decided to include two different control groups. The first control group of children was matched on the basis of their receptive vocabulary. Our assumption was that this area of language system would be less impaired in students with DS. The second control group was matched on the basis of their performance on more complex verbal measures assumed to be more focused in assessing students' productive language. Because the low performance on verbal WM tasks of individuals with DS could be attributed to the impairments in different aspects of language skills, two control groups were included in order to test two alternative hypotheses and determine which specific aspects of language system might affect verbal WM performance in individuals with DS. If a significant difference in verbal WM is found between the DS and TD groups, matched on vocabulary, but not the DS and TD verbal groups, we would assume that the deficits in productive language negatively affect the verbal WM performance of the individuals with DS. On the other hand, if the difference is found between DS and TD matched on verbal skills, but not the DS and TD vocabulary groups, we would hypothesize that the impairments in receptive language affect the performance on verbal WM tasks of individuals with DS. Finally, if a significant difference between DS and both TD groups is found, we would assume that a verbal WM deficit in DS is not due to the language impairments often showed by these individuals. Regardless of what the outcome is, the results of the first part of the study will help us better understand the relationship between verbal working memory and language in DS. One possible result could be that language impairment causes lower performances in WM tasks. In the opposite case, the results could offer support to the hypothesis that in DS a WM deficit could affect performance on all linguistic tasks that require registry.

Another focus of the study was to analyze the relationship between WM and logical thinking, vocabulary, and verbal and visuospatial intelligence in individuals with DS. These abilities were chosen because they are found to be strongly related to WM (e.g., see Baddeley, 2000, regarding the relationship between WM and verbal and visuospatial abilities; Piaget & Inhelder, 1968; Vianello & Marin, 1997, as to the relationship between WM and logical thinking). Despite the extensive research in these cognitive areas and the evidence to support their relationship, the findings from the studies on DS remain controversial. For example, Jarrold and Baddeley (1997) did not find any statistically significant relationship between the scores on digit span forward and verbal abilities as measured by verbal comprehension and vocabulary in a group of 15 individuals with DS compared to a control group. The study also failed to find a significant relationship between the performance on the Corsi Block Tapping task (Corsi, 1972) that assesses spatial working memory and general visuospatial abilities, as assessed by Differential Ability Scales performance subtests (Elliot, 1990). Numminen et al. (2001) also obtained similar results. Their study found no significant relationship between the scores on tasks analyzing phonological processing (digit span, nonword span, and nonword repetition task) and language skills (vocabulary, sentence comprehension, and rapid naming), and between performance on tasks assessing visuospatial activity (Corsi Block-Tapping Task and memory for patterns on a matrix) and nonverbal intelligence (Raven's Coloured Progressive Matrices). On the other hand, there are a number of studies with individuals with DS that have found a significant relationship between phonological memory and expressive language (Laws, 1998, 2004) or between phonological memory and sentence comprehension (Miolo, Chapman, & Sindberg, 2005).

Finally, of interest was to explore the relationship between WM and logical thinking. In a previous work with typically developing adults, Friedman et al. (2006) found that not all executive functions were related to intelligence. In particular, only a working memory updating task was highly correlated with intelligence measures, but not the tasks tapping either inhibition or shifting. Moreover the results from previous studies with individuals with intellectual disabilities (Lanfranchi et al., 2002, 2003, 2004) suggest that the relationship between WM and intelligence might be moderated by the degree of executive control. If this assumption is true, then we would find a significant correlation between high-control tasks and logical thinking, and this relationship should remain significant even when the effect of storage (a low-control task) is partialled out of the analysis.

To summarize, the main goal of the study was to explore the relationship between WM and verbal abilities in DS and, in particular, to determine whether their low verbal WM performance is linked to their overall low verbal abilities. In addition, we were interested in exploring the relationship between WM, visuospatial abilities, and logical thinking. Our aim was not only to compare the performances of individuals with DS and TD children matched on mental age but also to explore whether the pattern of relationship between WM and other cognitive abilities is similar between the two groups. So far these research questions have been addressed in separate studies. However, for several reasons we believe it is important to combine them in a single study. First, we are interested in determining to what extent different cognitive domains could interact. Several studies that had examined developmental disorders (e.g., Ypsilanti & Grouios, 2007, for a review) suggested a certain level of interdependence between different cognitive systems. We think that it could be interesting to determine whether and how different aspects of language abilities could influence working memory performance and also to what extent more domain-general cognitive resources support WM performances in individuals with

DS. To this regard, a recent theory (Karmiloff-Smith, 1998) hypothesizes that cognitive problems in DS could stem from a failure to progressively specialize or modularize as a function of development in certain areas of cognitive functioning. If this is the case for working memory, then we would expect that the relationship between working memory and intelligence is stronger in individuals with DS than in TD children.

In addition, we think that the WM comparison of individuals with DS with that of TD children is important, as it allows us to examine the quantitative differences (by finding strengths and weaknesses in the DS cognitive profile), as well as qualitative differences. A growing number of studies (e.g., Karmiloff-Smith, 1998, for a review) supports the hypothesis that in developmental disorders the whole cognitive system differs in processing ability compared to a nonaffected cognitive system. Moreover, it could be that individuals with DS (or other intellectual disabilities) follow a different developmental trajectory than TD children, and where in individuals with DS normal behavioral levels are found in a given domain, they might be achieved by different cognitive processes (Karmiloff-Smith, 2006).

METHOD

Participants

The sample consisted of a group of children with DS and two control groups. There were 20 students in each group. The first control group (TD-VOC) included students matched on a case-by-case basis for vocabulary level to allow us to test the hypothesis whether verbal working memory deficit in children with DS was due to language impairment. The subgroup was assessed on the Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn & Dunn, 1981) administered in its Italian version (Stella, Pizzoli, & Tressoldi, 2000). This measure was utilized, as the recent research points to a strong link between verbal STM and vocabulary acquisition in TD children (see, for example, Baddeley et al., 1998, for a review). However, since in individuals with DS different components of the language system are affected to various degrees (e.g., Miller, 1992; Rondal, 1996), the second control group of children was also included in the present study. This subgroup comprised of TD students matched on a case-by-case basis on verbal skills (TD-VERB) as measured by Wechsler Preschool and Primary Scale of Intelligence (WPPSI; Wechsler, 1967) verbal subtests, which are assumed to measure productive language. There were no statistically significant differences between the DS group and the control groups on the matching variables, $t(38) = 0.14$, $p = .888$ for the TD-VOC group and $t(38) = 1.10$, $p = .28$ for TD-VERB group. Participants' details are provided in Table 1.

Age-equivalent scores are shown to facilitate readers in understanding the groups' characteristics. Although age-equivalent scores are reported in the table, both control groups were matched based on the students' raw scores. A raw score on the PPVT-R of every individual with DS was used to find a matching child for the TD-VOC group. Similarly, a composite raw score (the sum of the raw scores from all subtests) from WPPSI was used to identify a matched child for the TD-VERB control group. It is important to note that the TD-VERB group was one year younger than TD-VOC.

The individuals with DS were recruited through several local associations for children with Down syndrome. The children for both control groups were recruited through four different kindergarten centers, two of them located in an urban area and

Table 1 Descriptive Statistics (In Years and Months) for the Participants.

Variable	Group					
	DS ^a		TD-VOC ^b		TD-VERB ^c	
	<i>M (SD)</i>	Range	<i>M (SD)</i>	Range	<i>M (SD)</i>	Range
Chronological age	13.10 (3.1)	8.0–19.10	4.11 (0.9)	3.8–6.1	3.11 (0.10)	2.10–6.3
Mental age	4.10 (0.9)	4.0–7.4				
Vocabulary level	4.10 (1.6)	2.6–7.3	4.10 (1.6)	2.6–7.7	3.8 (0.11)	2.5–6.8
WPPSI (verbal)	4.3 (0.6)	3.3–5.3	5.6 (0.9)	4.7–5.10	4.5 (0.6)	3.6–5.4

^a*N* = 20. ^b*N* = 20. ^c*N* = 20.

TD-VOC – Typically developing matched on vocabulary.

TD-VERB – Typically-developing matched on verbal skills.

two in a rural area. Children with any kind of psychological, physical, or language problem were excluded.

Parental consent to participate in the study was obtained prior to testing.

Tasks and Materials

The following abilities were assessed in the three groups.

Receptive vocabulary. Vocabulary knowledge was measured by the Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn & Dunn, 1981) in its Italian version (Stella et al., 2000). Students were presented with a small easel upon which four pictures were displayed. After hearing a word spoken in isolation, students were required to select the picture that matched the meaning of the word. Word presentations gradually increased in difficulty.

Working memory. Three verbal and three visuospatial working memory tasks, requiring different degrees of control (low, medium, and high) were administered. These tasks were taken from the battery of tasks used in our previous study (Lanfranchi et al., 2004). However, only three verbal and three visuospatial tasks (four measures in each domain were administered in the previous study) were chosen to reduce the time of task administration. In order to ensure that the effects of the degree of control were not due to the task difficulty, the tasks varied in the degree of required control, but not in the degree of difficulty. To achieve it, the amount of processed material within the tasks of different degrees of control varied. We expected that manipulating the degree of control in tasks containing similar quantities of processing material would add difficulty to the task. Therefore, we reduced the quantity of material in the most controlled tasks and, based on a pilot study, we selected the tasks requiring different degrees of control. At the same time, TD and DS children had comparable scores on these tasks. The tasks also had to be relatively simple and easy for the children with intellectual disabilities. A brief description of the administered tasks is provided below (for a complete description of the tasks, refer to Lanfranchi et al., 2004). The tasks are divided into verbal and visuospatial. The Cronbach alpha reliabilities of all WM raw score measures were computed for the total sample. The majority of the alpha coefficients were within an acceptable range for basic research, around .70 (e.g., Nunally & Bernstein, 1994).

Verbal Tasks

Word span task. Each child was presented with a list of words and was instructed to recall the words immediately after presentation in the order presented. Lists gradually increased in a set size, from a minimum of two words to a maximum of five.

Selective span task. Each child was presented with one or two lists of words and was asked to repeat the first word from each list after the entire set of words was presented. There were four levels of task difficulty, depending on the number of lists (one or two) and the number of words (two or three) in each list. To help students understand the concept of a series, the presented words were written on colored cards. The words from the same list were written on the same color cards, and each new list was written on a different color card. The tester read the words from the cards and the children were not allowed to see the written words. After reading each word, the tester would put the card on the table with the written side down and then ask, for example, to name the first word card and the first word from the blue card.

Verbal double task. A child was presented with a list of two to five words and was asked to remember the first word on the list and to tap on the table when the word "PALLA" (ball) was presented. Tapping in this case served as a secondary task.

Visuospatial Tasks

Pathways. Each child was shown a path taken by a small frog on a 3×3 or 4×4 chessboard. The child had to remember the pathway immediately after presentation and was asked to move the frog from cell to cell, just as the tester had done. There were four levels of difficulty, depending on the number of steps in the frog's pathway and the dimensions of the chessboard (3×3 with two steps at the first level, and 4×4 with two, three, and four steps for levels 2, 3, and 4, respectively). Steps were presented at the rate of approximately one step every 2 seconds.

Starting position selection. A child was shown one or two paths taken by one or two frogs on a 4×4 chessboard, as in the previous task. He or she was instructed to remember the frog's starting positions. The task had four different levels of difficulty, depending on the number of pathways and the number of steps in each pathway. At levels 1 and 2, one pathway with two steps and one with three steps were performed. At levels 3 and 4, two pathways with two and three steps were presented. For these latter levels, two different pathways were taken by two different frogs to facilitate a child's understanding of where the pathway ended.

Visuospatial double task. A child had to remember a frog's starting position on a pathway on a 4×4 chessboard, where 1 of the 16 cells was colored in red. The child also had to tap on the table when the frog jumped onto the red square. The task had four different levels of difficulty, depending on the number of steps involved in the pathway: two, three, four, and five steps, respectively.

Overall, for all six WM tasks the scores ranged between 0 and 8, with the score of 1 given for every correct trial. For both double tasks, the score of 1 was given only when the child remembered correctly the first item and performed the concurrent tapping task. Otherwise, the score of 0 was given.

Verbal Abilities

The verbal subtests from Wechsler Preschool and Primary Scale of Intelligence (WPPSI; Wechsler, 1967) were administered to assess verbal abilities. The subtests measure language expression, comprehension, listening, and the ability to apply these skills to solving problems in children ages 4 to 6. The test questions were orally presented to each child, who were then asked to provide a verbal response. The following subtests were administered: vocabulary, similarities, arithmetic, comprehension, and sentences.

Visuospatial abilities. To assess visuospatial abilities, the Performance scale of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI, Wechsler, 1967) was administered. The following subtests were used: animal pegs, picture completion, mazes, geometric design, and block design.

WPPSI scales were used in the study because of the mean mental age of individuals in the DS group ($M = 4.10$, see Table 1), as well as the chronological age of the two TD groups.

Logical thinking. The Logical Operations test (Vianello & Marin, 1997), an intelligence test that provides a Mental Age measurement in terms of logical thinking development and is particularly suitable for children with cognitive impairments, was administered to the three groups. The test, based on Piagetian cognitive theory, is comprised of 18 tasks that assess such areas of logical thinking as seriation, numeration, and classification. In comparison with Wechsler Intelligence Scales, the Logical Operations (LO) test is less influenced by cultural and verbal components (correlation between WISC-R and LO test is $r = .68$). In comparison with the Columbia Mental Maturity Scale, the Logical Operations test requires fewer demands on visuospatial processing (correlation between LO and Columbia Maturity Scale is $r = .78$).

Procedure

All the tasks were administered individually in three sessions separated by approximately 1 week, with each session lasting approximately 30 minutes. In a first session, participants completed the PPVT-R and WPPSI verbal scale. Subsequently, the participants completed the three verbal and the three visuospatial WM tasks, the WPPSI performance tasks and the LO test. The order of presentation of the tasks was counterbalanced across participants, alternating verbal and visuospatial memory tasks to avoid testing effects.

RESULTS

Preliminary Analysis

Table 2 provides age-equivalent scores for vocabulary, verbal, visuospatial abilities, and logical thinking for the three groups.

The table also shows the results of a series of univariate analysis of variances (ANOVAs), comparing the groups on each dependent variable measure. As can be seen from the table, the scores on measures related to logical thinking and visuospatial intelligence were statistically comparable among the three groups. Although the TD-VOC and DS groups were matched on receptive vocabulary, their scores differed significantly with regard to their verbal abilities ($p < .001$). The group of individuals with DS still performed

Table 2 Age-Equivalent Scores (in Months) for Vocabulary, Verbal, Performance Abilities, and Logical Thinking for the Three Groups Including Univariate ANOVA Comparisons Results.

Variable	Group						F	Post Hoc
	DS		TD-Voc		TD-Verb			
	M	SD	M	SD	M	SD		
PPVT	57.6	17.9	58.4	17.6	44.2	11.3	5.03**	DS = TD-VOC>TD-VERB
WPPSI (verbal)	51.1	6.5	65.6	8.7	53.2	6.5	24.01***	DS = TD-VOC<TD-VERB
WPPSI (perf)	61	10.4	63.8	10.4	58.3	9.7	1.88	
Logical thinking	58.1	8.8	58.3	8.6	55.3	8.8	0.99	

Note. DS – Down Syndrome. TD-VOC – Typically developing matched on vocabulary. TD-VERB – Typically developing matched on verbal skills.

** $p < .01$. *** $p < .001$.

at a lower level when compared to children in the TD-VOC group ($p < .001$). However, previous findings also reported that the level of receptive language in individuals with DS was generally higher when compared to their expressive language (Vianello, 2006) and therefore could inflate and overestimate the overall verbal abilities in individuals with DS. This, again, justifies our decision to include the second control group of TD children, matched on more comprehensive verbal abilities.

Looking at the results in Table 2, we should note, that WPPSI age-equivalent scores for both typically developing control groups are 5–6 months above their chronological age, which, in our opinion, should not affect the results since raw scores were used for the matching. Age equivalent scores were computed only in order to better describe sample characteristics.

Working Memory Analysis

The subgroup differences on measures related to working memory were examined by using a two-way analysis of covariance (ANCOVA), between-group design, with chronological age partialled out. This was done to ensure that age differences between groups did not affect the results. Considering the small number of participants in this study, we decided to run two separate ANCOVAs, one with verbal tasks as dependent measures and the other with visuospatial tasks.

Verbal working memory. The performance on verbal working memory tasks was analyzed by a 3 (tasks) \times 3 (groups) ANCOVA. Results revealed a significant task effect, $F(2, 112) = 6.854$, $p < .01$, $\eta^2 = 0.11$, group effect, $F(2, 56) = 11.863$, $p < .0001$, $\eta^2 = 0.298$, and approaching significance a Task \times Group interaction effect, $F(4, 112) = 2.038$, $p = .094$, $\eta^2 = 0.068$. Further post hoc group comparison tests (with Bonferroni correction for multiple comparison) revealed that the DS group performed significantly lower than TD-VOC and TD-VERB groups on all three verbal tasks ($p < .0001$ and $p < .05$ for TD-VOC and TD-VERB, respectively). No significant differences were found between TD-VOC and TD-VERB groups ($ps > .05$). The results are displayed in Figure 1, which shows that both control groups outperformed children in the DS group. Moreover Cohen's d values for each comparison pair are reported in Table 3.

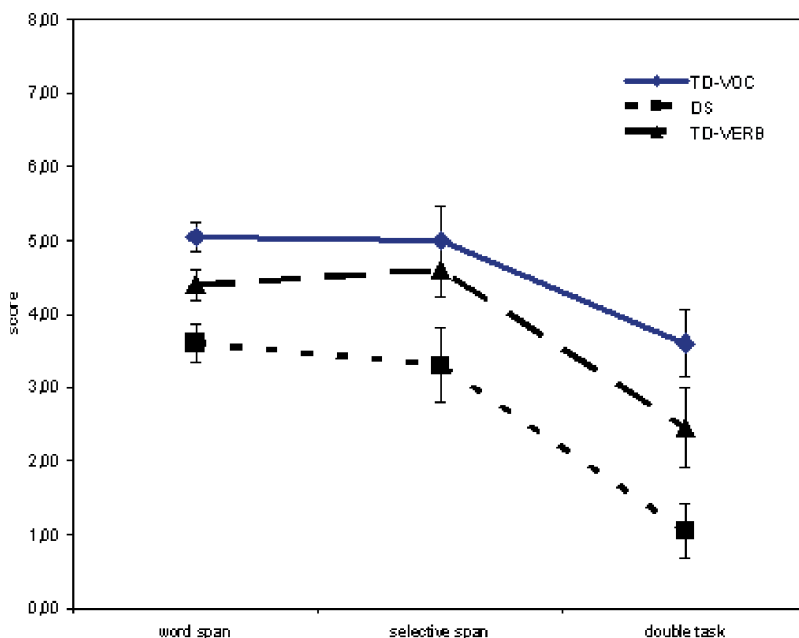


Figure 1 Performances of the three groups in the three verbal working memory tasks (bars represent standard errors).

Cohen's criterion was used for the interpretation of d values (Cohen, 1988). According to Cohen's criterion, effect sizes around a 0.2 magnitude are considered small, those around 0.5 are considered medium, and those of 0.8 are large.

Large effect sizes were found for every comparison between individuals with DS and the two TD groups. Although the comparison between the two TD groups is not statistically significant, it is necessary to note that for two out of three verbal tasks, a medium effect size was found, with higher performance for the TD-VOC group. This result is important in helping to interpret the relationships between verbal skills and WM.

Visuospatial working memory. A 3 (tasks) \times 3 (groups) ANCOVA, with chronological age effect partialled out, was performed on measures related to visuospatial WM. Results showed significant main effects for the Task, $F(2, 112) = 7.235, p < .001, \eta^2 = 0.114$, and for the Group, $F(2, 56) = 5.123, p < .01, \eta^2 = 0.155$. In addition, there was a significant Task \times Group interaction effect, $F(4, 112) = 3.691, p < .01, \eta^2 = 0.116$, and the nature of this interaction is displayed in Figure 2.

A series of post hoc comparisons (with Bonferroni correction for multiple comparisons) revealed no significant differences between the groups in *Pathways* and *Starting Position Selection* tasks. However, individuals with DS performed significantly worse than TD-VOC and TD-VERB group ($p = .001$ and $p < .05$, respectively) on the *Visuospatial double task*. This result is supported also by Cohen's d values (Table 3).

Correlational Analysis

To examine the relationship between WM and cognitive abilities, a series of correlations was performed. Since the purpose of this analysis was to compare the relationship

Table 3 Cohen's *d* Value for Post Hoc Comparisons between DS, TD-VOC and TD-VERB Groups in Verbal and Visuospatial WM Tasks.

Groups	Cohen's <i>d</i>
Word span	
TD-VOC DS	1.4
TD-VERB DS	.8
TD-VOC TD-VERB	.7
Selective span	
TD-VOC DS	.6
TD-VERB DS	.6
TD-VOC TD-VERB	.1
Verbal double task	
TD-VOC DS	1.4
TD-VERB DS	.7
TD-VOC TD-VERB	.5
Pathways	
TD-VOC DS	.05
TD-VERB DS	.05
TD-VOC TD-VERB	0
Starting position	
TD-VOC DS	.4
TD-VERB DS	.09
TD-VOC TD-VERB	.6
Visuospatial double task	
TD-VOC DS	1.2
TD-VERB DS	1.0
TD-VOC TD-VERB	.4

between WM and cognitive variables in children with DS and in TD children, the data for the two control groups were aggregated. We are aware that by combining the two control groups we could lose some information about TD children (we should also remember that the two groups are 1 year apart), but because the number of participants in each group is relatively small, we decided to focus our analyses on differences between typical and atypical development. Nonetheless, it is important to consider the differences in sample sizes when comparing the pattern of correlations for the two groups, since some of the differences might be due to power alone. The correlations between working memory, vocabulary, verbal and performance abilities, and logical thinking for the two groups (DS group and TD-combined control group) are presented in Table 4.

The pattern of correlations between verbal WM tasks and language (both vocabulary and verbal skills) is not very different between the two groups. At the same time, the relationships between visuospatial WM and performance abilities in both groups were significant and support previous assertions about visuospatial intelligence in individuals with DS to be relatively intact (e.g., Vianello, 2006). Interestingly, the largest and strongest correlation in the DS group was between the verbal WM task requiring a high degree of control and logical thinking ($r = .67$). A similar strong relationship was observed in this group between the high-control visuospatial WM task and logical thinking ($r = .64$). Therefore, we would argue that there is a relationship between a high degree of control and logical thinking in DS.

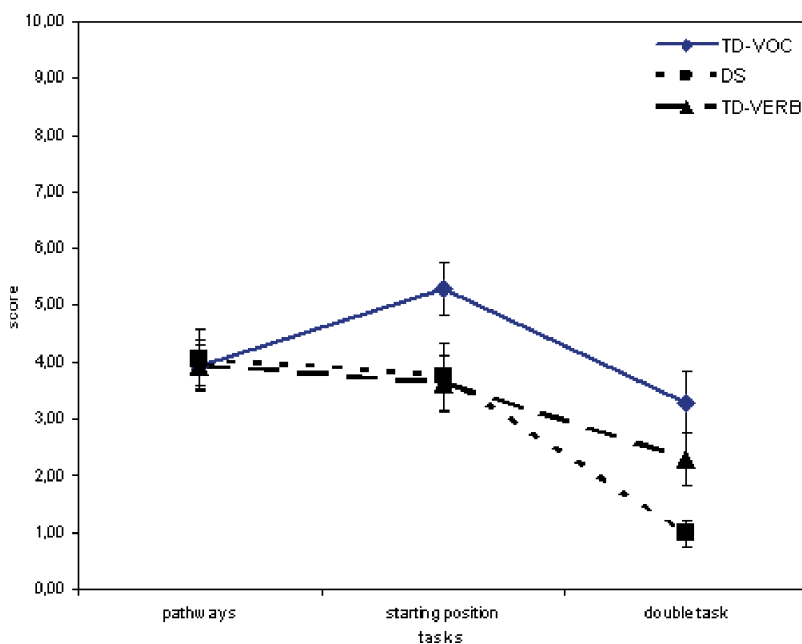


Figure 2 Performances of the three groups in the three visuospatial working memory tasks (bars represent standard errors).

Table 4 Correlations of Vocabulary, Verbal Skills, Performance Skills, and Logical Thinking with the Working Memory Tasks in the Two Groups.

Variable	Group					
	DS			TD		
	Low-Control WM Task	Medium-Control WM Task	High-Control WM Task	Low-Control WM Task	Medium-Control WM Task	High-Control WM Task
Verbal WM & verbal skills	.504*	.065	.239	.464**	.319*	.397*
Verbal WM & vocab	.369	.210	.43	.408**	.367*	.064
Verbal WM & log. thinking	.358	.368	.666**	.026	.401*	.255
VSWM & log. thinking	.533*	.493*	.637**	.439**	.315*	.448**
VSM & perf. skills	.561*	.467*	.530*	.603**	.491*	.659**

* $p < .05$. ** $p < .001$.

To test this hypothesis, we calculated partial correlations between high-control working memory tasks (both verbal and visuospatial) and logical thinking while controlling for the storage component (low-control verbal and low-control visuospatial WM tasks). It was our assumption that the performance of a *double task* puts demands on both the short-term memory storage system and the executive control processes; the latter being strongly related to intelligence. If a significant relationship exists between executive control and intelligence in the DS group, then performance on the reasoning task should be correlated with both verbal and nonverbal control tasks, when the influence of STM is

partialed out. Results showed that the correlation between the high-control verbal task and logical thinking remained significant when performance on the low-control verbal task was partialed out ($r = .602, p < .01$). Similarly, the correlation between the high-control visuospatial task and logical thinking was significant when the performance on the low-control visuospatial task was considered ($r = .518, p < .05$). Both these correlation values were nearly significant in the TD group ($r = .270, p = .08$ for the verbal task and $r = .291, p = .07$ for the visuospatial task).

DISCUSSION

The results from our previous study (Lanfranchi et al., 2004) revealed that individuals with DS had lower performance on verbal tasks and verbal and visuospatial WM tasks requiring a high degree of control when compared to TD children of the same mental age. Further, the differences between the two groups increased as the required degree of control increased.

The goal of the present study was to extend our previous findings and to examine the relationships between WM components and other cognitive processes, such as verbal and visuospatial intelligence and logical thinking. Specifically, we wanted to test whether verbal WM deficits in individuals with DS were due to general language impairment, often exhibited by individuals with DS or whether verbal WM deficits were specific to the WM system and independent of general language and verbal skills.

Prior to discussing the study results in more detail, it is important to mention that the present findings confirmed the results of our previous work (Lanfranchi et al., 2004) in two major ways. First, the DS group performed at a lower level across all verbal working memory tasks when compared to two control groups of TD children. Second, the performance of the DS group on visuospatial WM tasks requiring a high degree of control was inferior to that of both control groups.

Overall, the main finding of the study is that verbal WM deficit in individuals with DS cannot be attributed to general language impairment, often associated with this syndrome. Our data suggest that, when compared to TD children of the same vocabulary level or the same verbal ability level, individuals with DS still have lower performance across all verbal working memory tasks.

One possible way to conceptualize and explain the nature of this deficit is in terms of phonological loop impairment (e.g., Brock & Jarrold, 2005; Jarrold et al., 1999). As described by Baddeley's model (1986), verbal material is stored in a limited-capacity phonological store and rapidly decays unless it is refreshed by an active rehearsal mechanism. Although experimental data show that individuals with DS do not appear to engage in the rehearsal process, neither do the individuals they are usually compared with, i.e., TD children, ages 7 and younger (Jarrold et al., 2000). Therefore, the rehearsal problem cannot account for the low verbal working memory performance in individuals with DS. Rather, it is possible to attribute these differences to some kind of deficit in the phonological store. For instance, Brock and Jarrold (2005) argue that this deficit reflects a reduction in storage capacity or an increase in the rate of decay. Certainly further work is required to explore this issue.

The results of this study are in agreement with other studies that failed to find a significant relationship between verbal working memory and language abilities in individuals with DS (e.g., Numminen et al., 2001). We argue that this result could be due to the fact that both verbal working memory and language abilities in DS could be impaired

independently. When matched on the basis of a measure of verbal abilities, the DS group still showed lower performance on verbal WM tasks.

However, the significant relationship found in the DS group between verbal skills and performances in verbal WM tasks suggests that in DS WM and language abilities are not completely independent. On the contrary, our results offer support for the hypothesis that verbal WM (and in particular low-control WM) is crucial to language development and may be affecting vocabulary and language production in individuals with DS. This hypothesis, broadly discussed in a recent review by Ypsilanti and Grouios (2007), has been supported by several studies. For example, Chapman and Hesketh (2001) demonstrated that auditory short-term memory and chronological age were predictors of early vocabulary registry in individuals with DS. Moreover, Laws (1998) found that individuals with DS had low performances in word and nonword repetition tasks, which predicted receptive vocabulary and comprehension. Finally, according to Ypsilanti and Grouios (2007), the support for the hypothesis that a deficit in short-term memory may be causing downstream effects on language comes from comparative studies of linguistic performance of individuals with DS, WS, and SLI (Specific Language Impairments). In fact, individuals with WS, who do not exhibit problems in verbal STM, show higher expressive language skills when compared to individuals with DS. On the other hand, individuals with SLI, who also demonstrate difficulties in verbal STM, exhibit difficulties in language production similar to individuals with DS (Ypsilanti & Grouios, 2007). This seems to be true even for TD children. For example, Baddeley and his colleagues (1998) suggest that verbal WM plays a significant role in language acquisition and processing, and it could be important for learning words (e.g., Baddeley, Papagno & Vallar, 1988), syntax acquisition (e.g., Ellis & Sinclair, 1996), and comprehension (e.g., Vallar & Baddeley, 1984).

However, the medium effect sizes found in comparing the two TD groups on two of three verbal WM tasks (with the better performances for the TD-VOC group) suggest that verbal abilities have a certain influence on WM performances in TD children. One possibility is that verbal knowledge stored in long-term memory is activated in WM in order to be processed, rehearsed or retained for immediate use, as suggested, for example, by Conway and Engle (1994) or by Cowan (1993). This is supported by evidence showing that memory performance is higher when the stimuli to remember are familiar words rather than unfamiliar words or nonwords (e.g., Gathercole, Pickering, Hall, & Peaker, 2001; Turner, Henry, & Smith, 2000). Based on our data, however, the support for these assumptions does not apply to the individuals with DS.

Moreover, our findings indicate that visuospatial working memory in DS children is relatively intact, specifically when the demands on a task require a low and/or medium degree of control. Our results also show significant correlations between visuospatial working memory and performance abilities in both groups.

It appears that the main impairment of individuals with DS when compared to TD children is in performing both verbal and visuospatial high-control WM tasks. Moreover, our data show that the differences between the DS and the control groups increased as the degree of control required by the task also increased. This effect is more evident in the visuospatial domain and supports Lanfranchi et al.'s (2004) hypothesis that individuals with DS also have a deficit in their executive control functioning. Our data show that in individuals with DS, the magnitude of the relationship between logical thinking and high-control working memory tasks remained significantly strong even

when the effect of storage was partialled out. This result might be explained within Case's theory of cognitive development (Case, 1985). Case proposed that developmental increases in children's memory span reflect progressive decreases in the demands or in the proportions of general working memory capacity required for the successful processing of a memory task. Decreasing demands, consequently, release additional resources, which should then support other cognitive functions, such as intelligence. Although students' performance on both high-control tasks in the DS group was lower than that of controls, the relationship between high-control tasks and logical thinking was stronger. We assume that for the DS group, performance on a high-control WM task required a big proportion of the general capacity related to intelligence; consequently, only a few resources were available for storage and, therefore, the performance on these tasks was low. For the TD group, on the other hand, performance on high-control tasks was more automatized and required fewer general resources (which explains why the relationship between high-control tasks and logical thinking only approached the significance level) and, at the same time, freed additional space for the storage (which explains their better performances on STM tasks).

From another point of view the fact that we found a stronger relationship between WM and domain-general processes in individuals with DS than in TD children supports those theories (e.g., Karmiloff-Smith, 1998) that suggest a failure in modularization processes in individuals with DS.

The results of this study can be interpreted within both Baddeley's (1986) and Cornoldi and Vecchi's (2000) WM models. According to Baddeley's model, individuals with DS show a double deficit in the phonological loop and in the central executive. However, Cornoldi and Vecchi's model offers an additional explanation of the pattern of increasing differences in WM performance among children with and without this developmental disorder: within their framework, the performance of individuals with DS is determined by the degree of control of a WM task.

It is possible to hypothesize that if the verbal working memory deficit is specific to DS cognitive profile, then the executive control deficit is not specific to Down syndrome and it could also be extended to other populations with mental retardation, as a feature of their developmental disorder. For example, a similar deficit was found in individuals with mental retardation due to fragile X syndrome (Lanfranchi et al., 2009). Further, we could hypothesize that the executive control deficit might be linked to an executive function deficit. In fact some recent studies found deficits in executive function in individuals with DS (Kittler, Krinsky-McHale, & Devenny, 2008; Rowe, Lavender, & Turk, 2006). In this sense, we think that it is important to carry out further studies to determine the degree, to which deficits in the executive control dimension of WM are related to more general executive function deficit in these atypical populations.

To summarize, the present research has offered new insights into our better understanding of the nature of working memory in individuals with DS. The present findings should be useful for planning interventions and educational training for these children. We believe further in-depth studies need to be carried out to examine these cognitive deficits in DS and to enhance our knowledge about the causal factors associated with the memory impairments in phonological and central executive systems.

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