Journal on Developmental Disabilities
Le journal sur les handicaps du développement
JoDD
Volume 18, Number 2, 2012
IJDS Volume 1, Number 1

The Impact of Verbal and Nonverbal Development on Executive Function in Down Syndrome and Williams Syndrome

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Keywords

Down syndrome, Williams syndrome, cognitive flexibility, working memory, verbal development

Abstract

Using Vygotsky's verbal mediation framework, we hypothesised that verbal development would be more strongly associated with executive function than non-verbal development in populations with developmental disabilities with distinct verbal/non-verbal profiles. We used correlational analyses to explore the developmental relationship between verbal and non-verbal development and the executive function components of cognitive flexibility and working memory among persons with Down syndrome and those with Williams syndrome. We found that verbal development was uniquely correlated with cognitive flexibility and working memory in both groups. We conclude that verbal development is a better predictor of both cognitive flexibility and working memory independent of non-verbal development in persons with Down syndrome and Williams syndrome.

Language development is considered by many to provide the building blocks upon which other cognitive skills can grow (Luria, 1961; Luria & Wertsch, 1981; Vygotsky, 1962). According to Vygotsky and Luria, verbalization serves to focus attention and mediate the voluntary control of behaviour, which can be operationalized by tasks measuring executive functions (EF). In typical development, support for the developmental relationship between language and EF is found in both correlational analyses and experimental studies (Joseph et al., 2005; Kirkham et al., 2003). Disentangling the roles of different aspects of cognition in the development of EF is difficult with typically developing children, because by definition, verbal IQ and non-verbal IQ develop in parallel; that is how we define typical. However, populations such as persons with Down syndrome (DS) and those with Williams syndrome (WS) provide particularly compelling opportunities to examine the relationship between language development and EF because they present opposing profiles of verbal and non-verbal IQ, despite relatively similar full scale IQs. This will allow us to tease apart the relative contribution of verbal and non-verbal skill development in the development of EF. Accordingly, we compared the relationship among the EF tasks of Dimensional Change Card Sort (DCCS; Frye et al., 1995) and Self-Ordered Pointing (SOP; Archibald & Kerns, 1999; Petrides & Milner, 1982), and measures of verbal and non-verbal development between persons with DS and WS.

The Role of Language in Executive Function

Evidence from preschool aged children suggests an important role of language in the development of EF, although the co-contribution of non-verbal development has not been fully addressed. For example, the DCCS (Frye et al., 1995) is a sorting task in which children are asked to sort first by one dimension, either colour or shape, and then to change strategies and sort by the other dimension using the same set of cards. The key feature of a task such as this is that the rules are mutually exclusive and incompatible; on any given trial, the test card matches one target card on colour, and the other target card on shape. Typical 3-year-olds can successfully sort by one dimension (pre-switch) but perseverate on the initial sorting rule when the sorting rule is changed (post-switch), regardless of which rule is presented first. However, typical 4-year-olds can switch rule sets and typical 5-year-olds can switch rapidly between rules (Frye et al., 1995; Zelazo & Frye, 1997). The ability to switch between incompatible rule sets is referred to as cognitive flexibility or set-shifting; it involves reasoning according to two contradicting pairs of rules, forcing the participants to, at first, think according to a certain rule, but to switch their mind set in order to follow a different rule if they want to succeed on a subsequent part of the task (Frye et al., 1995). The failure to switch mental sets leads to perseverative errors (Zelazo & Müller, 2002).

Performance on the DCCS appears to be verbally mediated as labelling cards according to the relevant dimension improves performance among typically developing children. The majority of 3-year-olds fail the post-switch trials (Zelazo et al., 2003), but when children are prompted to label the cards themselves, the proportion of children sorting correctly on post-switch cards increases (Kirkham et al., 2003). Labelling the relevant dimension also improves cognitive flexibility on a separate task for preschool children, the Flexible Item Selection Task (Jacques & Zelazo, 2001). Vygotsky and Luria would argue that verbal representation of the relevant dimension focuses the child's attention on the relevant attribute, guiding them to represent the problem in a new way.

Another EF task that appears to be verbally mediated is the Self-Ordered Pointing task (SOP; Petrides & Milner, 1982), a working memory task originally developed for use with adult neurological patients and modified for use with children. This task is thought to assess the capacity to initiate a sequence of responses, retain the responses, and monitor the consequences of behaviour (Petrides & Milner, 1982). The task involves participants` self-directed selection of items in an array such that all items are selected once and only once. Hongwanishkul, Happaney, Lee, and Zelazo (2005) adapted the task to make it appropriate for preschool children and found that performance improved with age between 3- and 5-year-olds. The 3-year-olds were able to successfully perform the task with an average of 4.5 items, while the 5-year-olds could successfully perform the task with an average of 6.5 items. Thus, working memory span appears to increase throughout childhood, with significant improvement during the preschool years.

The SOP is assumed to be verbally mediated because the task is considerably easier when the objects can be verbalized. Joseph et al. (2005) presented a group of typically developing children (mean age 8 years) with two versions of a SOP task, one containing concrete namable objects, and a second containing abstract non-namable objects. They found that the typically developing children committed fewer errors on the version with the concrete objects. This supports the verbal mediation model, which suggests that performance is facilitated by an internal dialogue.

We hypothesized that this internal dialogue would facilitate performance on EF tasks among individuals with DS and WS, resulting in EF performance commensurate with language development more so than non-verbal skills. Among persons with DS, language skills are an area of relative weakness, however Pennington et al. (2003) reported that children with DS did not differ in their performance on EF tasks relative to typically developing children with similar vocabulary scores. Thus, EF skills are on par with vocabulary development in DS.

Among persons with WS, language skills are an area of relative strength. Hoffman et al. (2003) concluded that persons with WS have intact executive processes because they use similar methods as verbal mental age matched typically developing persons to solve puzzles. Hoffman et al further suggested that visual-spatial difficulties may impede performance among persons with WS on EF tasks that are primarily visual-spatial in presentation. Vicari et al. (2001) tested 12 low functioning children with WS on the Tower of London, an EF task of visual-spatial planning, and found performance to be poorer than that of MA matched typically developing children, however details about verbal versus performance IQ of the participants were not provided. While poor visual-spatial skills may put individuals with WS at a disadvantage when tested with visual-spatial based materials, in accordance with the verbal mediation theory (Luria, 1961; Luria & Wertsch, 1981; Vygotsky, 1962), we would expect that among persons with DS and WS, individuals with more advanced verbal development will also show more advanced EF skills. While verbal development is not the same as verbal mediation, the verbal mediation model predicts that verbal development should be associated with EF abilities more so than non-verbal development.

Current Study

The aim of this study was to explore the differential roles of verbal and non-verbal cognitive development in the acquisition of EF abilities among children with DS and WS. We used the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997), a standardized measure of receptive vocabulary, as our estimate of verbal development and the Leiter International Performance Scale (Roid & Miller, 1997), a standardized measure of non-verbal intelligence, as our estimate of non-verbal development. We administered two tasks of EF, a test of cognitive flexibility and a test of working memory. In order to measure cognitive flexibility, we administered the DCCS (Frye et al., 1995) and to measure working memory, we administered the SOP (Petrides & Milner, 1982). In accordance with the verbal mediation model, we predicted that for both the participants with DS and those with WS that performance on the EF tasks would be more related to verbal development than to non-verbal development.

Method

Participants

The participants included 11 persons with DS and 14 persons with WS. Most of the participants were functioning in the moderate mental retardation range, however one participant with WS achieved IQ scores in the borderline to normal range. Nine of the participants with DS were recruited from a special education school and two were recruited from a service agency for persons with intellectual disabilities. The participants with WS were recruited at a National Williams syndrome conference. The ethics boards of the university and schools involved approved the study. The chronological ages (CA) and mental age (MA) equivalents of the participants are provided in months in Table 1.

Intellectual Development Measures

Verbal development. The Peabody Picture Vocabulary Test – Third Edition (PPVT; Dunn & Dunn, 1997) was used to measure verbal development. This test is a measure of one word receptive language in which respondents are required to point to a picture from a set of four that best represents a word spoken by the experimenter. For example, the child is presented with four pictures (a cat, a spoon, a crib and a dog) and is asked to "point to the picture of the spoon." The PPVT is commonly used with persons with developmental disabilities and is especially appropriate for those with particular difficulties in expressive language. Raw scores were converted into mental age equivalents.

Non-verbal development. The Leiter International Performance Scale-Revised (Leiter-R; Roid & Miller, 1997) was used to measure non-verbal development. The Leiter-R is a brief measure of non-verbal intelligence that includes 4 subtests of reasoning and visualization appropriate for individuals between the ages of 2 through 20 years of age. As the test relies on non-verbal cues to convey the instructions, requires no verbal responses and has no time limitations, it is especially appropriate for administration to individuals with developmental disabilities. Raw scores were converted into mental age equivalents.

Table 1. Chronological Ages (CA), Verbal Mental Age (VMA) Estimates, and Non-Verbal Mental Age (NVMA) Estimates of Participants, in Months

	Participant Characteristics		
	CA	VMA	NVMA
DS01	112	50	48
DS02	154	56	54
DS03	141	12	38
DS04	176	45	60
DS05	231	36	48
DS06	228	12	42
DS07	157	55	55
DS08	162	21	47
DS09	214	58	67
DS10	255	64	74
DS11	105	54	NA
MEAN	*175.9*	*42.1*	*53.3*
SD	*49.8*	*19.0*	*11.2*
WS02	120	103	110
WS06	590	153	89
WS07	154	90	94
WS09	102	52	58
WS10	73	53	48
WS11	142	NA	71
WS12	138	58	62
WS13	63	34	NA
WS14	81	58	NA
WS15	NA	122	NA
WS18	102	NA	61
WS21	NA	29	NA
MEAN	*156.5*	*75.2*	*74.1*
SD	*155.3*	*40.4*	*21.3*

Executive Function Tasks

Dimensional Change Card Sort. The DCCS (Frye et al., 1995) is a card-sorting task with three levels of difficulty. These levels are called *pre-switch*, *post-switch*, and *complex*. Participants were presented with target cards of a red boat and a blue rabbit that were affixed to two trays. The cards that the participants were given to sort included those with a blue boat and those with a red rabbit. These cards are shown in Figure 1.

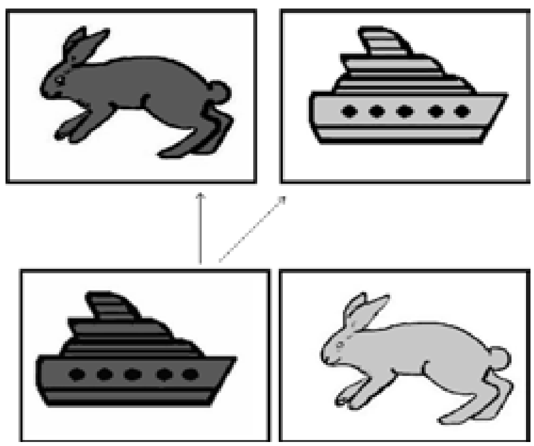

Figure 1. Target (top) and test (bottom) cards used in the DCCS. Dark shading represents blue and light shading represents red. Dark arrow represents a correct "colour" sort, while the dashed arrow represents a correct "shape" sort.

In the *pre-switch* phase, the participants were introduced to either the colour or the shape game, counterbalanced across participants. For example, in the colour game, the participants were told, "We are going to play the colour game. In the colour game, all the red ones go here," as the experimenter pointed to the tray with the red boat, "and all the blue ones go here," as the experimenter pointed to the tray with the blue rabbit. The experimenter demonstrated with one card of each colour, and then the test phase began. The participants were reminded of the rules before each card was turned over. This phase consisted of six cards. Participants who sorted five of six cards correctly were told that they would now play a different game and were administered the *post-switch* phase. Participants who were unable to sort five of six cards correctly were told the game was over and proceeded to the next task. In the *post-switch* phase, participants who initially played the colour game were told, "we are not going to play the colour game any more, now we are going to play the shape game. In the shape game all the rabbits go here and all the boats go here." The experimenter then administered the shape game in the same manner as the colour game had been presented in the *pre-switch* phase.

The participants who correctly sorted five of six cards in the *post-switch* phase progressed to the *complex* phase. These participants were shown a new set of cards in which half of the cards had black borders, and the remainder were identical to those used in the pre-and post-switch phases. The new rules were explained and demonstrated to the participant. For example, "if the card has a black border, then we play the colour game, and if it has no black border then we play the shape game. Remember, in the colour game, all the red ones go here and the blue ones go here, and in the shape game all the boats go here and all the rabbits go here." This phase consisted of 12 cards. Before each card was played, the participant was reminded of the rule that "if the card has a black border, then we play the colour game, and if it has no black border then we play the shape game". The rules concerning the *black border* were counterbalanced across participants. Across all the phases, a maximum score of three points was possible. One point was assigned for passing each of the *pre-switch* and *post-switch* phases, and one point for correctly sorting 9 of 12 cards during the *complex* phase.

Self-Ordered Pointing. This task is an adaptation of Milner and Petrides' (1982) original task, simplified for younger children. In this task, the participants were presented with drawings of objects arranged in a matrix on a 21.6 cm x 27.9 cm page in a binder. The participants were instructed to choose a picture on each page, and when the page was turned to choose a different picture from the same group of objects that were displayed in different locations. For each level, this continued until the participant pointed to every object in the array, so that three pages were seen for the level with three objects and nine for the level with nine objects. An incorrect response was scored when the participant pointed to an object that had been pointed to on a previous page in that level. An example of a three-object display is presented in Figure 2. In this scenario, if the participant pointed to the train on the first page, then pointing to either the rabbit or the crayons would be correct on the second page. On the third page, the remaining item from the rabbit or crayons that was not pointed to on the second page would be the correct response. Objects were not repeated across sets.

The task involved nine levels, each increasing the number of items in the array by one, starting with two items and ending with ten. When the participants successfully completed a level, they continued to the next one. If the participants committed an error, they were given a second chance at that level with a second set of objects. The task continued until the participant failed both sets of pictures at a particular level or passed all nine levels. The score on the task reflected the highest level that was passed. The number of items in each level is one more than the level (e.g., level five contains six items, level nine contains 10 items).

Procedure

Most participants were able to complete the cognitive measures in one session and the EF tasks in a second session on another day. Each session lasted approximately 45 minutes. On the first session, participants were administered the PPVT-III (Dunn & Dunn, 1997) and the Leiter-R (Roid & Miller, 1997) in counterbalanced order. The EF tasks were presented in counterbalanced order during the second session. A third session was included if necessary.

Results

Not all of the children in each of the groups completed both the two cognitive measures and the two EF tasks. One participant with DS did not complete the Leiter-R. One participant with WS did not complete the DCCS, four did not complete the PPVT, and six did not complete the Leiter-R. Sample sizes thus varied across groups as well as across analyses.

Performance on the DCCS and SOP tasks is provided in Table 2. The mean DCCS score for participants with DS suggests many passed pre-switch but failed post-switch, while more partic-

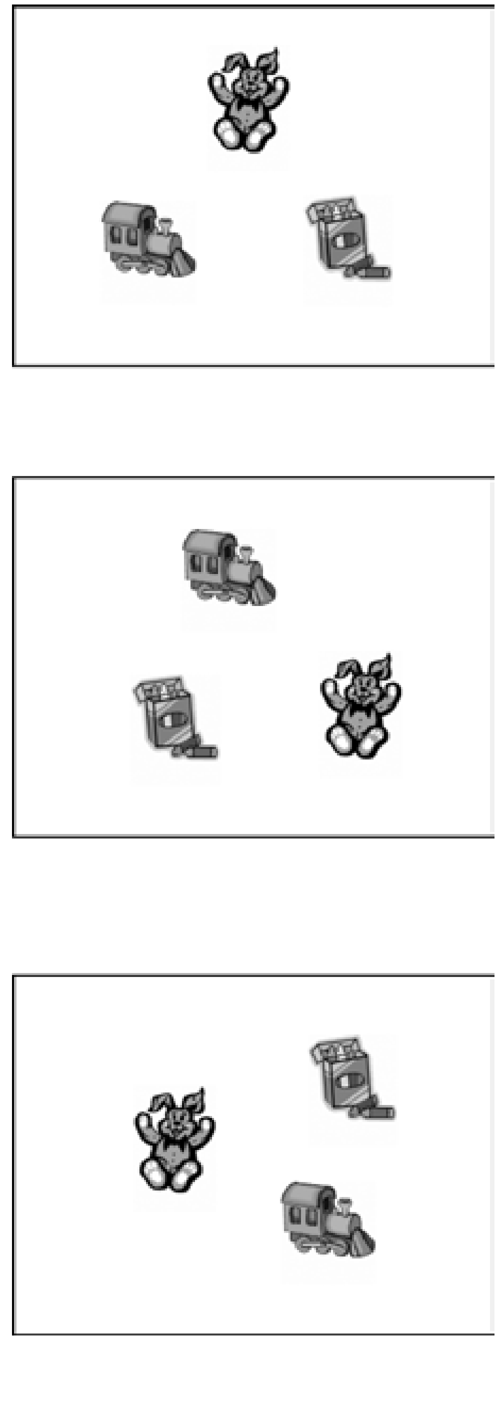

Figure 2. Sample three-item array from the SOP. The child is required to point to one item in the first array, a different item in the second array, and the remaining item in the third array.

Table 2. Performance on Executive Function Tasks for Participants with Down Syndrome and Williams Syndrome

	DCCS			SOP		
	Sample Size	*Mean*	*Standard Deviation*	*Sample Size*	*Mean*	*Standard Deviation*
DS	11	1.18	0.75	11	3.36	2.38
WS	13	1.92	0.95	14	2.93	1.59

ipants with WS passed post-switch. On the SOP, participants with DS had on average a working memory span of 3–4 items, while participants with WS had a working memory span of 2–3 items, although the average for both groups is close to 3. Comparisons were not made between groups as the groups were not matched for MA.

In an attempt to examine the relationship between measures of cognitive development and performance on executive function tasks, a series of correlational analyses were conducted. Given a priori assumptions that all correlations would be positive, one-tailed tests of significance were used to maximize power and compensate for the small sample sizes of some of the groups. Chronological age was not correlated with performance on the EF tasks; the correlation coefficients ranged from .05 to .34 and were influenced by one particularly older participant with WS.

Correlation matrices for mental ages and EF tasks for each group are presented in Table 3. Significant correlations were noted for the participants with DS for all measures. In the group with WS, the PPVT was significantly correlated with both EF measures, but the Leiter was not

Table 3. Intercorrelations Between Measures of Verbal and Non-Verbal Development and Measures of Executive Function for Participants with Down Syndrome and Williams Syndrome

		LEITER	*DCCS*	*SOP*
			Down Syndrome	
PPVT	*r*	.838**	.876**	.693**
	n	10	11	11
LEITER	*r*		.800**	.663*
	n		10	10
DCCS	*r*			.799**
	n			11
			Williams Syndrome	
PPVT	*r*	.720	.683*	.584*
	n	6	10	10
LEITER	*r*		.614	.220
	n		8	8
DCCS	*r*			.286
	n			13

* *Correlation is significant at the 0.05 level (1-tailed).* ** *Correlation is significant at the 0.01 level (1-tailed).*

significantly correlated with either EF measure. Scatterplots showing these relationships are presented in Figure 3. Next, partial correlations were used to examine the unique association between the measures of verbal and non-verbal development and the measures of EF for participants with DS. The group with WS were excluded from this analysis because no bivariate correlation was found between Leiter and the measures of EF. Again, one-tailed tests were used due to a priori assumptions that all correlations would be positive. When controlling for performance on the Leiter, there remained a significant association between the DCCS and PPVT among participants with DS, r (7) = .75, p = .01. When controlling for performance on the PPVT, no association was found between the DCCS and Leiter among the participants with DS, r (7) = .15, *ns*. When controlling for performance on the Leiter, no association was found between SOP and PPVT for the participants with DS, r (7) = .40, *ns*. When controlling for performance on the PPVT, no association was found between SOP and Leiter for the participants with DS, r (7) = .16, *ns*.

Discussion

The relationships among measures of verbal and non-verbal development and EF components of cognitive flexibility and working memory for persons with DS and WS were examined. In accordance with the verbal mediation model of Vygotsky and Luria, we expected that verbal development would be associated with performance for both executive function tasks for both groups of participants. This hypothesis was supported. In both groups, verbal development was significantly correlated with both measures of EF, but non-verbal development was also correlated with both measures of EF among the participants with DS. Partial correlations showed that the association between cognitive flexibility and verbal development was robust even when controlling for the non-verbal development, but no partial correlations with working memory were significant.

These findings can be contrasted to those of Hongwanishkul et al. (2005) who administered the same tasks to a group of 98 three to five year olds. They reported that verbal MA was significantly correlated with both the DCCS

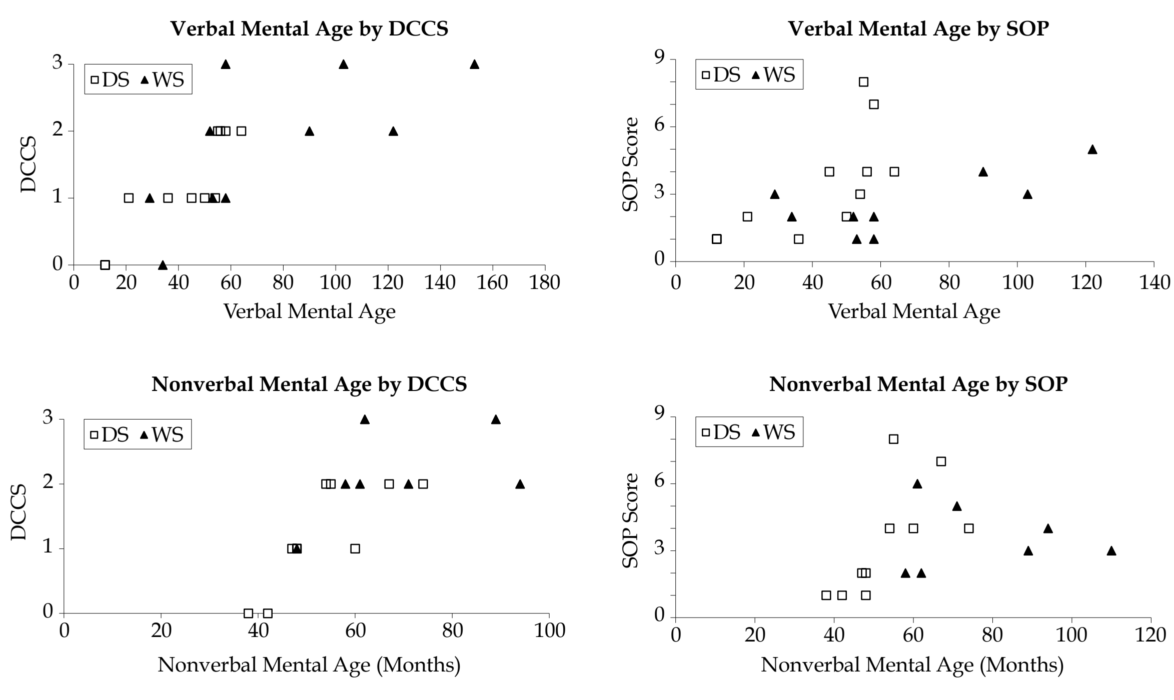

Figure 3. Scatterplots of verbal mental age and non-verbal mental age by DCCS and SOP scores for participants with Down syndrome and Williams syndrome

(.44) and SOP (.28) tasks after CA was partialled out, but that after partialling out chronological age, performance mental age was only correlated with DCCS (.46). The similarity in correlation coefficients between both measures of intellectual functioning and the DCCS support our contention that verbal and non-verbal intelligence cannot be easily parsed in typically developing children.

Likewise, our data suggest a stronger association between EF and verbal relative to non-verbal intelligence. Cognitive flexibility was positively associated with verbal abilities among the participants with DS even after controlling for non-verbal abilities, whereas non-verbal abilities were no longer correlated after controlling for verbal abilities. Among the participants with WS, verbal but not non-verbal development was associated with cognitive flexibility. These findings support the special role of verbal development in the development of cognitive flexibility. Working memory was also associated with the verbal abilities of both groups. In contrast, nonverbal abilities were only correlated with working memory among the participants with DS, although neither verbal nor non-verbal abilities were significantly correlated with working memory after controlling for the other.

The finding that verbal, and not non-verbal, abilities were associated with performance on both EF tasks among both the participants with DS and those with WS is relevant to theories of verbal mediation, as they display contrasting patterns of strength and weakness with respect to verbal and nonverbal development. The finding that performance was associated with verbal development both for children for whom language is a relative strength (children with WS) and for who it is a relative weakness (children with DS) lends support to the notion that cognitive flexibility and working memory are verbally mediated, even among persons with mental retardation of differing aetiologies. Further, experimental findings of verbally mediated performance for typically developing children (Jacques & Zelazo, 2001; Kirkham et al., 2003) suggest that, despite intellectual impairments, the developmental principles under operation for the typically developing children appear to be applicable to both persons with Down syndrome and those with Williams syndrome.

Further research is needed on the relationship between verbal and nonverbal development and EF measures in both typically and atypically developing groups. The numbers of participant in the two groups in this study were small and fell within a restricted mental age range. In addition, the broader variability in CA and MA ranges represented among the participants with WS than among participants with DS, might be partly responsible for the group differences in the correlations. Future studies could include more tasks that are appropriate to assess achievement from a wider range of mental ages, and could also be focused on the relationship between language development and additional measures of cognitive flexibility and working memory. Our failure to record gender or sociodemographic data of our participants should also be corrected in future reports of studies.

Preliminary evidence for the primacy role of language development in cognitive flexibility and working memory was provided. However, we only used one measure of verbal ability, the PPVT, which is widely used to estimate children's language level but is only a measure of children's receptive vocabulary. Further research should also include more comprehensive language measures that provide both a more global assessment of children's language development as well as the ability to break down language development to determine if any aspects are more or less pertinent to verbally mediating behaviour. The findings reported by Jacques and Zelazo (2001), Kirkham et al. (2003), and Zelazo et al. (2003), as well as those described by Luria (1961), demonstrate that typically developing children who have not yet incorporated speech into their problem solving can learn the strategy from adults. This could be useful to develop training programs for children with Down syndrome and Williams syndrome, who might have the necessary language skills but have not spontaneously developed the verbal mediation strategy.

Key Messages From This Article

Professionals: For practical skills like problem solving and planning, the language skills of the client should be considered in setting developmentally appropriate goals. Educators may want to focus on language skills in early years.

Policymakers: Individuals with developmental disabilities have a wide range of skills and skill levels and deserve opportunities to maximize their skills.

Acknowledgements

The authors thank the participants in the study, who include students from Summit School (Montreal), clients of the West Island Readaptation Center (Montreal), and attendees at the annual Williams Syndrome Conference. We thank Nicki Saros and Rhoda Root for their help in recruiting the participants with Down syndrome. The work on this project was funded an operating grant from the Social Sciences and Humanities Research Council to Jacob A. Burack.

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