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The Contribution of Verbal Working Memory to Deaf Children's Oral and Written Production

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Abstract

This study investigated the contribution of verbal working memory to the oral and written story production of deaf children. Participants were 29 severely to profoundly deaf children aged 8–13 years and 29 hearing controls, matched for grade level. The children narrated a picture story orally and in writing and performed a reading comprehension test, the Wechsler Intelligence Scale for Children-Fourth Edition forward digit span task, and a reading span task. Oral and written stories were analyzed at the microstructural (i.e., clause) and macrostructural (discourse) levels. Hearing children's stories scored higher than deaf children's at both levels. Verbal working memory skills contributed to deaf children's oral and written production over and above age and reading comprehension skills. Verbal rehearsal skills (forward digit span) contributed significantly to deaf children's ability to organize oral and written stories at the microstructural level; they also accounted for unique variance at the macrostructural level in writing. Written story production appeared to involve greater verbal working memory resources than oral story production.

Deaf students' difficulties in producing oral or written discourse have been addressed in a number of studies (Asker-Arnason et al., 2012; Boons et al., 2013a; Crosson & Geers, 2001; Fabbretti, Volterra, & Pontecorvo, 1998; Mayer, 1999; Schley & Albertini, 2005; Spencer, Barker, & Tomblin, 2003; Tur-Kaspa & Dromi, 2001; Wolbers, 2008; Yoshinaga-Itano & Downey, 1992). However, the role played by deaf children's memory capacities in discourse production has been largely neglected. This article addresses this issue by investigating the contribution of verbal working memory to deaf children's oral and written discourse.

Verbal working memory (WM hereafter) has been shown to influence significantly the verbal language performances of children with hearing loss (Burkholder & Pisoni, 2003; Harris et al., 2013; Pisoni & Cleary, 2003). Yet previous studies have been limited and confined mainly to exploring the contribution of WM using simple oral language and written tasks, such as word recognition, receptive vocabulary, sentence comprehension, and spelling (Colombo, Arfé, & Bronte, 2012; Harris et al., 2013; Pisoni & Cleary, 2003). Only a few studies have explored the role of deaf children's WM in more complex verbal tasks, such as reading comprehension or written text production (Alamargot, Lambert, Thebault, & Dansac, 2007; Geers, 2003), and no studies, to our knowledge, have compared the memory demands of oral and written language for these students. This article aims to fill this gap and examines the contribution of verbal WM skills to deaf children's ability to generate a story orally and in writing.

Deaf Children's Oral and Written Narrative Skills

Linguistic analyses of deaf children's oral and written narratives reveal that both oral and written storytelling are extremely challenging (Arfé & Boscolo, 2006; Boons et al., 2013a; Yoshinaga-Itano & Downey, 1996). Deaf children produce stories that have fewer words than those of their hearing peers (Spencer et al., 2003) and that are less rich and accurate in micro- and macrostructure (Arfé & Boscolo, 2006; Arfé, Nicolini, & Pozzebon, 2014; Crosson & Geers, 2001; Spencer et al., 2003; Yoshinaga-Itano & Downey, 1992). At the microstructural level, deaf children's stories contain fewer correct and complex sentences (Antia, Reed, & Kreimeyer, 2005; McAfee, Kelly, & Samar,1990; Spencer et al., 2003; Wolbers, 2008) and, in

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written production, more spelling errors than those of their hearing peers (Geers & Hayes, 2011). At a macrostructural level, they focus less on the core elements of the narration, and lack story-grammar components, or information that is necessary for the listener or reader to understand the plot (Arfé & Boscolo, 2006; Boons et al., 2013a; McAfee et al., 1990; Reuterskiold, Ibertsson, & Sahlen, 2010; Yoshinaga-Itano & Downey, 1992).

Narrative skills are the product of oral (or sign) language development and literacy experience (Carretti, Re, & Arfè, 2013; Crosson & Geers, 2001; Fey, Catts, Proctor-Williams, Tomblin, & Zhang, 2004; Ravid & Berman, 2006). Thus, deaf children's expressive and receptive oral language scores (e.g., at TACL-R [Test for Auditory Comprehension of Language-Revised] or CELF-3 [Clinical Evaluation of Language Fundamentals-III]) (Crosson & Geers, 2001; Spencer et al., 2003) and their reading comprehension abilities (Crosson & Geers, 2001; Yoshinaga-Itano & Snyder, 1985) are significantly associated with their oral and written narrative abilities. However, reading is especially important for deaf children, as their access to verbal language structures (and narratives) through speech is often limited (Mayer, 1999). Through reading, deaf children can gain experience of linguistic and discourse structures that are difficult for them to access in spoken language. Not surprisingly, the association between deaf children's reading and narrative skills is significant (Yoshinaga-Itano & Snyder, 1985) and remains so even when oral language skills are controlled (Crosson & Geers, 2001).

As well as literacy skills and linguistic abilities at word and sentence level, the production of narrative requires significant WM resources (Dodwell & Bavin, 2008; Duinmeijer, de Jong, & Scheper, 2012).

Verbal WM and Verbal Language in Deaf Children

Storytelling, like language production in general, relies on the ability to maintain and actively integrate linguistic information in WM (Dodwell & Bavin, 2008; Swanson & Berninger, 1996). This is achieved thanks to two components of the WM system (Acheson & MacDonald, 2009; Baddeley, 2003): (a) a temporary storage component for verbal-acoustic information, the *phonological loop*, that maintains the relevant linguistic information active in memory for the time necessary to perform the verbal task and (b) an attentional component, the *central executive* system, responsible for regulating attention and distributing memory resources when task demands increase or when attentional and memory resources must be distributed among different tasks (e.g., rehearsing words and organizing words in sentences or transcribing a sentence while holding its elements in memory). The phonological loop employs *subvocal rehearsal* mechanisms for refreshing relevant information, and these can be measured by forward digit span or word span tasks (Acheson & MacDonald, 2009; Baddeley, 2003; Gathercole, Pickering, Ambridge, & Wearing, 2004). The central executive component of verbal WM employs attentional and executive functions and is typically assessed by more complex verbal WM tasks, such as listening or reading span tasks. These require the simultaneous processing of sentences as well as the temporary storage of single words (Conway et al., 2005).

Deaf children's difficulties with verbal tasks have been mainly associated with problems in the first of these two components: the phonological loop (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003). Specifically, deaf children appear to have slow subvocal rehearsal or inefficient refreshing mechanisms (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003), which substantially limit their ability to maintain active verbal information in WM (Geers, Strube, Tobey, Pisoni, & Moog, 2011; Pisoni & Cleary, 2003). This verbal WM deficit is associated with deaf children's poor speech perception (Pisoni & Cleary, 2003), reduced articulation speed (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003), poor expressive and receptive syntactic skills (Harris et al., 2013), and poor reading skills (Geers, 2003).

Compared with their rehearsal skills, however, the executive component of deaf children's WM appears in some studies to be preserved more (e.g., Harris et al., 2011; Pisoni & Cleary, 2003). This component is more involved in deaf children's higher order language skills, such as reading and language comprehension (Pisoni, Kronenberger, Roman, & Geers, 2011). Thus, it could have an important role in discourse production.

Recent research has mostly focused on the WM skills of children with cochlear implants (Geers et al., 2011; Pisoni & Cleary, 2003). Yet, verbal short-term memory and WM also explain the linguistic and literacy performances of deaf children without a cochlear implant (Colombo et al., 2012; Hamilton, 2011; Harris & Moreno, 2004; Garrison, Long, & Dowaliby, 1997). This study involves this population.

The Contribution of Verbal WM to Deaf Children's Oral and Written Discourse

Given the role of verbal WM in deaf children's verbal language performances (Hamilton, 2011; Harris et al., 2013; Pisoni & Cleary, 2003; Pisoni et al., 2011), it is surprising that so little work has been done investigating the relationship between verbal WM skills and deaf children's oral and written discourse production.

To our knowledge, the contribution of verbal WM to deaf children's discourse production has been explored in only two studies to date—both of which focus on writing (Alamargot et al., 2007; Arfé et al., 2014). Both studies reported a significant association between deaf children's verbal WM and their written texts. Specifically, Alamargot et al. (2007) found that the executive component of verbal WM (measured by a written version of the speaking span task) explained writing fluency in the texts produced by 11- to 17-year-old deaf signers. Arfé et al. (2014) showed that forward digit span—that is, verbal rehearsal skills—contributed to explaining the microstructure of the written texts produced by 9- to 15-year-old deaf children, in particular the proportion of spelling errors and correct clauses they produced. Interestingly, the contribution of forward digit span remained significant even when age and oral language skills (phonological skills and receptive grammar) were controlled.

No studies, to our knowledge, have investigated the role of deaf children's verbal WM skills in oral discourse production. However, written and oral language may tax the deaf child's WM system in different ways. The purpose of this study is to explore this possibility.

In hearing children, oral and written storytelling seems to load on different components of the verbal WM system: Verbal rehearsal skills—and short-term storage—appear to contribute more to oral storytelling, whereas executive memory skills impact on written narration more significantly (Dodwell & Bavin, 2008; Duinmeijer et al., 2012; Swanson & Berninger, 1996). For example, Dodwell and Bavin (2008) found that phonological memory tasks (i.e., word span), but not central executive tasks (sentence span), correlated with SLI (specific language impairment) hearing children's ability to generate or reproduce the macrostructure of a story, although the SLI children differed from age-matched controls for both of these measures. Likewise, Duinmeijer et al. (2012) found that SLI children's word span correlated with their ability to reproduce the plot of a story in a retelling task, and their digit span scores correlated with the microstructural organization (i.e., mean length of utterance) of a story generated from a picture sequence.

By contrast, in written storytelling, text generation has been found to be associated mainly with executive WM skills (e.g., sentence span) (Swanson & Berninger, 1994, 1996). Swanson and Berninger (1994) found that sentence span scores were associated with the ability to generate sentences and combine sentences in the text and with the macrostructural quality of written stories. On the other hand, phonological memory and verbal rehearsal skills were mainly related to children's low-level writing processes, that is, spelling (Swanson & Berninger, 1996). This significant involvement of executive WM skills in writing has been typically explained as an effect of the cognitive control that is necessary in the writing task (Hooper, Swartz, Wakely, de Kruif, & Montgomery, 2002).

Written language draws on the development of oral language skills (e.g., Babayigit & Stainthorp, 2011; Mackie, Dockrell, & Lindsay, 2013). However, oral and written expressions have different functional and structural characteristics (Halliday, 1989; Olson, 1977), which may pose different constraints on the children's cognitive system. Written language, for example, requires greater precision and explicitness than oral language production (Olson, 1977), forcing the writer to provide more information (nouns, adjectives, and verbs) within each single unit of meaning (i.e., clause) (Halliday, 1989). These differences have been found to be associated with a greater planning and monitoring typical of written production, which thus requires greater executive control (Bereiter & Scardamalia, 1987; Ravid & Berman, 2006). Moreover, writing involves transcription (i.e., spelling and handwriting), in addition to oral language skills, and this poses extra demands on the child's WM system, especially in less expert writers (Berninger & Swanson, 1994). Hence, for young hearing children with and without language problems, writing typically requires more effort than spoken language production (Fey et al., 2004).

Several studies suggest that written might be more demanding than oral production for deaf students as well (Kelly & Whitehead, 1983; McAfee et al., 1990; Tur-Kaspa & Dromi, 2001). For example, deaf students have been found to make more grammatical and clause construction errors in their written compared with their oral productions (Kelly & Whitehead, 1983; McAfee et al., 1990; Tur-Kaspa & Dromi, 2001). The translation of ideas into written sentences is hindered by deaf children's limited oral vocabulary and grammatical skills (Arfé et al., 2014; McAfee et al., 1990; Tur-Kaspa & Dromi, 2001; Yoshinaga-Itano & Downey, 1996), and their difficulties with spelling (Colombo et al., 2012; Geers & Hayes, 2011) can further challenge their WM during translation. Therefore, despite deaf students demonstrating abilities in the (top down) planning processes (Antia et al., 2005; Marschark, Mouradian, & Halas, 1994; Musselman & Szanto, 1998), they find it difficult to convert their plans into written texts (Arfé & Perondi, 2008; Yoshinaga-Itano & Downey, 1992). Oral discourse production may challenge their verbal WM less.

Current Study

The present study examines the cognitive costs of oral and written story production for a group of deaf children, with severe to profound hearing loss. The study intended to answer the following research questions: Do deaf children's verbal rehearsal and executive WM skills contribute to explain their problems with oral and written story production? Do deaf children's oral and written story productions involve the same verbal rehearsal and executive WM resources?

To address these research questions, the oral and written stories of a picture storybook, *Frog, where are you?*, produced by 29 Italian severely to profoundly deaf children, aged 8–13, were examined and compared with those of school-aged-matched hearing controls. In addition, the reading comprehension, verbal rehearsal, and executive WM skills of the deaf and hearing children were also examined. Reading skills were assessed by a standardized reading comprehension task (Cornoldi et al., 1998), whereas verbal rehearsal and executive WM skills were assessed by a forward digit span task and a reading span task, respectively. The unique contribution of verbal rehearsal and executive memory skills to the children's oral and written narration was investigated, controlling for their age and reading comprehension skills.

Based on prior research (Arfé & Boscolo, 2006; Kyle & Harris, 2010; Pisoni & Cleary, 2003; Tur-Kaspa & Dromi, 2001), we expected that hearing children would display greater reading comprehension, verbal rehearsal, and executive WM skills than deaf children. They would also produce better stories at micro- and macrostructural levels.

We made the following hypotheses about the role of verbal WM in oral and written discourse production: Given the role of verbal WM in deaf children's spoken and written language performance (Alamargot et al., 2007; Arfé et al., 2014; Geers, 2003; Harris et al., 2013), it was predicted that deaf children's verbal rehearsal and executive WM skills would contribute to their oral and written story production, over and above age and reading comprehension skills. Past research has also shown that inefficient verbal rehearsal mechanisms explain most of the verbal language problems of deaf children (Geers et al., 2011). Thus, we expected that deaf children's verbal rehearsal skills would also account for the variance in their oral and written story productions. Considered the cognitive costs of writing (Hooper et al., 2002; Swanson & Berninger, 1996), written story production was hypothesized to be more demanding and require greater verbal WM resources than oral story production.

Method

Participants

Fifty-eight 8- to 13-year-old Italian children participated in this study: 29 deaf children with severe to profound prelingual hearing loss (18 boys and 11 girls) and 29 controls with normal hearing (22 boys and 7 girls), matched for school grade. The mean age of the deaf children was 10.9 years (standard deviation [*SD*] = 2.1), whereas the mean age of the hearing children was 10.3 years (*SD* =1.6). Hearing children were, on average, younger than their deaf peers. However, an analysis of variance (ANOVA) confirmed that the two groups did not differ significantly for age $F(1, 56) = 1.91$, p = ns.

Deaf children

The group comprised only children with severe to profound binaural and congenital hearing loss (i.e., hearing threshold ≥ 70 dB), with no documented comorbidities. Their nonverbal intelligence was within normal limits, as reported by their clinical files. Six children presented severe hearing loss (with a hearing threshold ≥ 70 dB) and 23 presented profound hearing loss (hearing threshold ≥ 90 dB). Their hearing loss was compensated by hearing aids, and the mean age at compensation was 2.6 years (*SD* = 2.0). At the time of the study, the children had received speech-therapy interventions for 4–12 years.

Children were selected by two speech-language pathology units and two special schools for the deaf in northern Italy. Oral language was the main mode of communication for all children and all, at the time of the study, were receiving speech-language interventions. Italian was their first language (L1). Twenty-four children had two hearing parents and five had one deaf and one hearing parent. The latter were also exposed to Italian Sign Language. The reading comprehension, forward digit span, and reading span scores of this bilingual (oral/sign language) group of students did not differ from those of the other deaf participants [$t(27) = -1.27$, p = ns; $t(27) = 0.04$, p = ns; $t(27) = -0.03$, p = ns, respectively].

Although all students were reported to have IQ scores within the normal range (i.e., greater than 80), the children's standard scores in the visual-motor integration (VMI; Beery, 1997) test were also used to estimate their nonverbal skills. VMI requires children to copy a sequence of geometric forms of increasing complexity. The scores are reported to correlate significantly with nonverbal intelligence, $r = .66$ and scholastic performance, $r = .58$ (Beery, 1997). Standard scores in VMI have a mean of 100 and SD of 15. The mean VMI score for deaf children was 95.2 ($SD = 9.88$, range: 80–122). Four children had a standard VMI score between 80 and 85. A cutoff of 80 has also been used in other studies to exclude cognitive impairment (e.g., Boons et al., 2013b).

Hearing children

The control group comprised 29 hearing children, with no known history of language or learning problems. Their L1 was Italian. Their teachers rated them as having an average academic performance, and their VMI scores were within normal limits ($M = 108$, $SD = 12$, range: 91–141). The mean forward digit span scores of the hearing children were similar to those found by Colombo et al. (2012), who used a bimodal[1] digit span procedure to assess verbal WM in hearing and deaf children.

The VMI scores of the deaf and hearing participants differed significantly, $F(1,56) = 22.43$, $p = .001$, $\eta_p^2 = .29$. Other authors (Schlumberger, Narbona, & Manrique, 2004) have reported similar differences between deaf and hearing children in copying tasks similar to the VMI, despite normal intelligence and the lack of neurological disorders.

Procedure

Each child was tested individually on two subsequent days. In the first session, the children performed a standardized reading comprehension task, the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) forward digit span task (Wechsler, 2003), and an experimental reading span task designed for this study. In the second session, they were asked to tell a picture story twice: orally and in written form.

Standardized Tasks

Reading comprehension

A standardized reading comprehension task (MT test, Cornoldi et al., 1998) was administered to all children. Reading comprehension can be considered a higher order language skill, which requires the integrated use of vocabulary, syntactic, and discourse knowledge (Cain, 2003; Catts, Adlof, & Weismer, 2006). It may account for variance in narrative skills due to the ability to use discourse structures and to link the meanings of a sequence of sentences, components that are also typical of narrative production (Cain, 2003; Carretti et al., 2013; Yoshinaga-Itano & Downey, 1992). The MT reading comprehension battery used in this study comprises a set of narrative texts, each appropriate for a different grade level—from Grade 1 to Grade 8. The battery is widely used in Italy in educational and clinical assessment and has proved to be sensitive to individual differences in reading abilities (Carretti et al., 2013; Desimoni, Scalisi, & Orsolini, 2012).

After reading a text, the child answers a set of multiple-choice questions about the story. Because of deaf children's language difficulties, and to prevent floor effects in their performance, the text for intermediate third grade was selected to be administered to all participants. This choice was based on both the last assessment of the children's reading skills and on estimations of their reading levels provided by teachers and speech-language pathologists. The test comprised 10 multiple-choice questions. Thus, scores could range from 0 (*no correct answers*) to 10 (*all answers correct*).

Forward digit span, WISC-IV

This was employed to assess verbal rehearsal skills (Burkholder & Pisoni, 2003; Gathercole et al., 2004; Pisoni & Cleary, 2003; Wechsler, 2003). In its standard form, this task is administered orally and consists of repeating sequences of digits of increasing length in the same order as they are produced by the examiner. The sequences are presented in two parallel trials of the same length (e.g., two sequences of three digits, two of four digits, etc.). A score of 2 is attributed when the child correctly repeats both trials; a score of 1 if s/he correctly repeats only one of the two trials. The final score can be considered as an indicator of the child's verbal rehearsal skills (WISC-IV, Italian standardization by Orsini, Pezzuti, & Picone, 2012).

In this study, an adaptation of the WISC-IV, forward digit task (standard procedure) was employed (Colombo et al., 2012) to minimize problems due to deaf participants' imperfect access to the oral input. The task was administered bimodally, wherein the examiner produced the conventional signs of digits while also speaking them. The child was asked to repeat the digits in the same order in which the examiner had produced them. The score was attributed if the child repeated the digits orally only or bimodally (orally plus signing), but not if only signing was used.

Experimental Tasks

Reading span

This task is an adaptation of the original Daneman and Carpenter's (1980) task. Reading span tasks are complex verbal WM tasks that are typically used to assess the central executive component of WM (Conway et al., 2005). Children were presented with series of individual sentences on a computer screen and were asked to read each sentence at their own pace and respond to a comprehension question while remembering the last word of the sentence for later recall. The comprehension questions required the child to judge whether the sentence was true or false. The series comprised 2 to 5 sentences each (Conway et al., 2005, recommends from two to five elements per set). There were eight sets, two for each set size (of two, three, four, and five sentences), for a total of 28 sentences, which varied in length from five to eight words. The sentences were constructed to be syntactically and semantically simple. Half of the sentences were false and half true. Examples include *Il leone mette sempre il cappello in testa* (The lion always puts a hat on his head; False) or *I bambini disegnano con le matite* (Children draw with pencils; True). The comprehension scores (true/false) of the reading span task confirmed that the deaf children processed the sentences with a success rate of 76%.

After each set of sentences, the children recalled and wrote down the last words of the sentences read in the order in which they had been presented. The sets of sentences were presented in ascending order, from the shortest to the longest, until the child failed to recall two subsequent items. Four training sentences were presented before starting the task. The Cronbach alpha was .77.

Following Friedman and Miyake (2005), the children's performance was scored by counting the total number of words recalled. Moreover, as deaf children typically have problems with sequential memory (Conway, Pisoni, Anaya, Karpicke, & Henning, 2011), we decided to take this aspect into account in our scoring. If an element was recalled in the correct serial order, it was scored 2. A score of 1 was given instead to elements in a set that were recalled correctly, but not recalled in the correct serial order (e.g., the elements' position in recall was inverted). The first author and an independent rater, blind to the hypotheses of the study, scored all reading span tests. Interrater agreement in Pearson correlations was .94.

Oral and Written Narration

The children were asked to tell a picture story orally and, subsequently, to retell it in writing. The procedure has been used in prior research with deaf students (Asker-Arnason et al., 2012). With this retelling procedure, children have to write a story that they have already planned and generated orally. Thus, the costs of planning are reduced in written production. However, written narration can present other demands related to ideas translation and to the costs of transcription processes (Berninger & Swanson, 1994), which may be challenging for the memory system of deaf children (Arfé et al., 2014; Colombo et al., 2012).

A wordless picture book, *Frog, where are you?* (Mayer, 1969), was used to elicit the oral and written narratives. This book consists of 24 pages of pictures depicting the story of a boy and his dog in search of their lost pet frog. Children were asked to look carefully at the pictures to see first how the story unfolded and then to tell the story orally. After having told the story aloud, they were invited to write the story down. Before starting to tell the story and before starting to write it, the children were reminded to be as clear and complete as possible. The children could use the picture book during retell and, thus, were free to look at the pictures again while producing their stories. They were also free to revise their written texts although no specific instruction to revise was given. No time limits were given. Oral storytelling lasted from 2 to 4 min, whereas written narrations generally took from 10 to 20 min total. The oral stories were videotaped and subsequently transcribed by a trained speech-language pathologist.

Analysis

The microstructure and macrostructure of the oral and written stories was analyzed.

Microstructure

The main unit of analysis for the story microstructure was the clause (see Halliday, 1989; Tur-Kaspa & Dromi, 2001).

Total number of clauses

The total number of recognizable finite and infinitive clauses produced was considered an index of the facility to translate ideas in the story.

Correct clauses

The proportion of grammatically correct clauses over the total number of clauses produced tapped accuracy at microstructural level. Each clause was scored independently from the previous one, so this measure did not account for the logical or linguistic links between clauses.

Words per clause (clause complexity)

The total number of recognizable words over the total number of clauses produced is a measure of clause complexity (see Mackie et al., 2013). It can correlate with the production of grammatically complete clauses. However, it does not overlap with it, as errors in clause production result not only from the omission of words but also from substitutions or insertions of incorrect word forms (Tur-Kaspa & Dromi, 2001).

Misspellings

For written stories, the proportion of misspelled words over the total number of words written tapped deaf children's transcription difficulties (Alamargot et al., 2007; Arfé et al., 2014).

Macrostructure

A macrostructure score was attributed to each oral and written narration considering the degree to which the narration presented the typical goal-plan story structure (Trabasso & Nickels, 1992) and provided the necessary information for the reader to understand the plot. This included the *who*, *when*, *where*, and *why* of the narration and the existence of logical links between the parts.

Five minimal story components were identified for the narration of *Frog, where are you?*, based on prior research (Trabasso & Nickels, 1992): the setting (i.e., the boy has a pet frog); the initial event (i.e., the frog is missing), which motivates the main goal of the protagonist(s) (i.e., to find the frog); at least two episodes that logically and hierarchically relate to the protagonist(s)' goal(s) and in which the protagonist(s) perform(s) actions to resolve the problem (i.e., search for the frog in the room, in the wood, or everywhere); and a solution or final outcome (i.e., the/a frog is finally found). A score from 0 to 5 was assigned to each story by attributing one point for the inclusion of each of these elements (setting, initial event, first and second episodes, and solution) in the narration. The score was only given if the elements were presented in the correct logical order, that is, if the setting opened the story or if a logical relation between the story elements could be inferred: that is, an episode was clearly related to the main goal of the protagonist. Four further scores were assigned to the story when it included sufficient information about the *who*, *when*, *where*, and *why* of the narrated events. An additional point was assigned if the story presented logical links between the parts. Therefore, the story macrostructure score ranged from 0 to 10, where 10 points indicated that the plot was complete in all aspects and coherent to the reader.

Interrater reliability between the first author and a trained independent rater was computed for all the oral and written stories. Pearson correlations ranged from .88 for story macrostructure to .99 for clause correctness.

Results

ANOVAs with age covariate were run first to explore differences between the reading comprehension scores and forward digit and reading span scores of the deaf and hearing participants. Table 1 summarizes the results of these analyses.

Hearing children showed greater reading comprehension than deaf children. The forward digit span scores also differed significantly between the groups, whereas the difference was not significant for reading span scores (p = .08), indicating a

Table 1. Comparison between hearing children and deaf children: reading comprehension, forward digit, and reading span scores

	Hearing (n = 29)		Deaf (n = 29)				
	M	*SD*	*M*	*SD*	F	*p*	η^2
Reading comprehension scores	9.2	0.78	5.9	2.0	60.82	.001	.53
Forward digit span scores	6.4	1.6	3.8	1.6	37.02	.001	.40
Reading span scores	27.27	8.9	23.48	9.7	3.17	.08	.06

Note. Age covariate. Effect sizes (η^2) express the magnitude of the difference between groups.

larger gap between the groups in verbal rehearsal than in executive WM skills (see also Pisoni & Cleary, 2003; Table 1).

The next analysis compared the oral and written stories produced by the two groups of children.

Oral and Written Production in Deaf and Hearing Children

It was expected that deaf children would show greater difficulties than their hearing controls in oral and in written story productions. To test this hypothesis, two multivariate analyses of variance were performed with group as between factor, one for oral story production and one for written story production. Age was the covariate. The number of clauses produced, the proportion of correct clauses and spelling errors (for written stories), the number of total words per clause, and the macrostructure scores of the oral and written stories were the dependent measures. Bonferroni corrections were applied to control for Type 1 errors, and the level of significance was adjusted to .01. Within-group comparisons between modalities (oral and written production) were not explored in this study due to the lack of counterbalancing in task order.

Analyses were run on transformed scores. Proportional scores were arcsine transformed and square root transformations were applied to the number of clauses in the stories (Howell, 2007). The results are summarized in Table 2.

Oral storytelling

At the microstructural level, hearing and deaf children produced stories of similar length in terms of the number of clauses. However, hearing children's stories included proportionally more correct clauses, $F(1,55) = 73.09$, $p < .001$, $\eta_p^2 = .57$, and a greater number of words per clause, $F(1,55) = 32.61$, $p < .001$, $\eta_p^2 = .37$, indicating greater accuracy and complexity than deaf children's oral stories in microstructure. At the macrostructural level, the hearing group produced more complete and coherent stories, $F(1,55) = 28.22$, $p < .001$, $\eta_p^2 = .34$. The magnitude of the effect, expressed by η^2 values, was greater for clause accuracy (i.e., correct clauses) than for clause complexity and story macrostructure.

Written storytelling

Also in the written stories the two groups produced approximately the same number of clauses. Yet, hearing children's stories included proportionally more correct clauses than the deaf children's stories, $F(1,55) = 61.42$, $p < .001$, $\eta_p^2 = .53$, fewer spelling errors, $F(1,55) = 7.85$, $p < .01$, $\eta_p^2 = .13$, and more complex clauses (i.e., more words per clause), $F(1,55) = 17.75$, $p < .001$, $\eta_p^2 = .24$. The hearing children also produced better stories at the macrostructural level, $F(1,55) = 52.07$, $p < .001$, $\eta_p^2 = .49$. The effect size was large for clause accuracy and story macrostructure. It was smaller for spelling errors. In fact, there were very few spelling errors in both groups: 2% in the hearing group and 6% in the group of deaf children (Table 2).

To check whether these results could be determined by group differences in VMI scores, we ran a second set of analyses, adding VMI scores to age as covariate. These analyses replicated the original findings and the covariate was not significant.

Overall, the results showed that the deaf children in this study significantly lagged behind their hearing peers in reading skills and verbal rehearsal skills, that is, forward digit span, and in both oral and written story productions.

The Contribution of Verbal Rehearsal and Executive WM Skills to Oral and Written Narration

The main research question of this study concerned the contribution of verbal rehearsal and executive WM skills to the oral and written story production of the deaf children. To address this research question, we first explored the association between reading comprehension, forward digit span, and reading span scores; VMI scores; and oral and written story production. Forward digit span scores and reading span scores were measures of children's verbal rehearsal and executive WM skills. Partial correlations were run, controlling for age. Next, multiple hierarchical regressions were run to explore the unique contribution of forward digit span scores and reading span scores to oral and written story production.

Tables 3 and 4 present the results of the correlational analyses. Hearing children made very few errors and omitted little information in their oral and written stories, resulting in a performance that showed ceiling effects and little variance. Therefore, the analysis did not reveal any significant correlation between verbal WM skills and oral and written story production for this group. We thus performed hierarchical regression analyses for the group of deaf children only. VMI scores were not included in the regression models because they did not show any significant association with the measures of the study. Separate hierarchical regressions were run for oral and written story production. The models are summarized in Table 5.

Our prediction was that deaf children's verbal rehearsal and executive WM skills would contribute to explaining variance in oral and written story production over and above age and reading comprehension skills. Thus, variance in story production due to age and reading skills was controlled first by entering age and reading comprehension scores at Step 1. The unique contribution of forward digit span and reading span scores to oral and written story production was then analyzed. Forward digit span scores were entered at Step 2, as a measure of verbal rehearsal skills, and reading span scores were entered last, to test the unique contribution of the executive component of verbal WM, after verbal rehearsal was controlled.

Previous studies (Arfé et al., 2014; Dodwell & Bavin, 2008; Duinmeijer et al., 2012; Swanson & Berninger, 1996) showed an association between hearing and deaf children's verbal WM skills and the number of correct clauses they produce in oral or written narratives, the complexity of the clauses (i.e., number

Table 2. Comparison between hearing children and deaf children in oral and written story production

	Oral stories				Written stories			
	Hearing (n = 29)	Deaf (n = 29)			Hearing (n = 29)	Deaf (n = 29)		
	M (SD)	M (SD)	p	η_p^2	M (SD)	M (SD)	p	η_p^2
Story microstructure								
Number of clauses	30.4 (12.3)	39.2 (17.8)	.08	.06	24.1 (9.36)	23.9 (11.9)	.68	.00
Correct clauses (proportion)	0.87 (.13)	.38 (.27)	<.001	.57	0.94 (0.07)	0.40 (0.32)	<.001	.53
Words per clause	5.8 (.51)	4.4 (1.2)	<.001	.37	5.8 (0.70)	4.8 (1.1)	<.001	.24
Spelling errors (proportion)					0.02 (0.02)	0.06 (0.06)	.007	.13
Story macrostructure	8.4 (1.5)	4.8 (2.9)	<.001	.34	9.1 (1.1)	4.4 (2.9)	<.001	.49

Note. Effect sizes (η_p^2) express the magnitude of the difference between groups.

Table 3. Partial correlations between forward digit span, reading span, reading comprehension, and oral narrative production

	1	2	3	4	5	6	7	8
1. Forward digit span	1	−.07	−.06	.23	−.18	−.36[#]	.28	−.23
2. Reading span	.35[#]	1	−.08	.07	.20	.04	−.20	.05
3. Read comp.	−.01	.40*	1	−.32	−.07	−.16	.24	−.18
4. VMI standard scores	.01	.19	−.16	1	−.21	.01	−.06	−.12
5. Number of clauses	.01	.28	.35[#]	−.05	1	.34	−.10	.41*
6. Correct clauses	.45*	.37[#]	.27	−.07	.12	1	−.48**	.61***
7. Words per clause	.54**	.55**	.27	−.04	.40*	.71***	1	−.35[#]
8. Macrostructure	.34	.59***	.25	.12	.51**	.57***	.66***	1

Note. The table presents correlations for deaf children below the diagonal and correlations for hearing children above the diagonal. Age has been partialled out. Read comp. = reading comprehension.
[#]p = .06; *$p \le .05$; **$p \le .01$; ***$p \le .001$.

of words per clause), and the macrostructure of the story produced. These measures were thus used as dependent variables. In addition to these variables, the number of clauses produced in oral and written stories was considered as a measure of productivity at clause level. Misspellings were not considered in the regressions due to their low frequency in the deaf children's written texts. Bonferroni corrections were applied and the level of significance was adjusted to .01. In the following section, the results are summarized considering this level of significance.

Microstructure in Oral and Written Stories

Total number of clauses

Only age, at Step 1, marginally accounted for the number of clauses produced in the oral stories. Reading span scores, that is, executive WM skills, at Step 3, marginally accounted for the number of clauses produced in the written stories. The full model did not explain variance in the oral story production, $F(4,28) = 2.01$, p = ns, or in the written story production, $F(4,28) = 2.13$, p = ns.

Correct clauses

Deaf children's forward digit span scores, that is, verbal rehearsal skills, at Step 2, explained 18% of unique variance in the proportion of correct clauses produced orally and 20% of unique variance in the proportion of correct clauses produced in written stories. The full model was marginally significant for oral story production, $F(4,28) = 3.46$, $p = .03$, and was significant for written story production, $F(4,28) = 5.02$, $p < .005$.

Words per clause

Forward span scores, (verbal rehearsal), explained 28% of unique variance in clause complexity in oral stories. In contrast, none of the variables contributed uniquely to clause complexity in writing. The full model was significant for oral story production, $F(4,28) = 5.38$, $p < .005$, and only marginally significant for written story production, $F(4,28) = 2.71$, $p = .05$.

Macrostructure in oral and written stories

Only executive WM skills, that is, reading span scores, at Step 3, accounted for a significant portion of variance in the macrostructure of the oral stories (19%). In the written stories, forward digit span scores, (verbal rehearsal skills) contributed to explaining 26% of unique variance in the story macrostructure. Reading span scores, at Step 3, accounted for a further 19% of variance. The full model was marginally significant for oral story production, $F(4,28) = 3.56$, $p = .02$, and significant for written story production, $F(4,28) = 6.61$, $p = .001$.

In synthesis, verbal rehearsal and executive WM skills contributed uniquely to deaf children's oral and written narrative production. At the microstructural level, verbal rehearsal skills (forward digit span scores) contributed most, explaining variance in the microstructural accuracy (i.e., number of correct clauses produced) of the oral and written stories and in the microstructural complexity (i.e., clause length) of the oral narration. At the macrostructural level, executive WM skill, that is, reading span scores, was the only factor that contributed to the macrostructural quality of the oral stories. In contrast, in written story production, also verbal rehearsal skills, that is, forward digit span, contributed to macrostructural quality.

Discussion

In the present study, we asked deaf and hearing children to reproduce a picture story orally and then in writing. The students' performance in the two tasks was analyzed, and the

Table 4. Partial correlations between forward digit span, reading span, reading comprehension, and written narrative production

	1	2	3	4	5	6	7	8	9
1. Forward digit span	1	−.07	−.06	.23	−.22	−.14	.06	−.01	−.11
2. Reading span	.35#	1	−.08	.07	.23	−.35	−.11	−.36#	−.07
3. Read comp.	−.01	.40*	1	−.32	−.18	.24	−.00	.04	.02
4. VMI std scores	.01	.19	−.16	1	.10	−.03	−.00	−.42	.01
5. Number of clauses	.06	.45*	.17	.12	1	−.24	−.00	−.36#	.24
6. Correct clauses	.47**	.42*	.36#	−.23	.00	1	−.21	.10	.32
7. Words per clause	.26	.46**	.40*	−.17	.11	.62***	1	.32	−.30
8. Misspellings	−.31	−.29	−.30	.19	.21	−.55**	−.38*	1	−.27
9. Macrostructure	.51**	.66***	.27	.15	.49**	.51**	.36#	−.25	1

Note. The table presents correlations for deaf children below the diagonal and correlations for hearing children above the diagonal. Age has been partialled out. Read comp. = reading comprehension.
#$p = .06$; *$p \le .05$, **$p \le .01$, ***$p \le .001$.

Table 5. Hierarchical multiple regressions: unique contribution of forward digit and reading span scores to the oral and written story production of deaf children ($n = 29$)

	Regression step		Oral ΔR^2	Oral β	Written ΔR^2	Written β
Regression: The unique impact of verbal WM on *number of clauses*	1	Age_months	.23#	.43#	.09	.29
		Rea_comp.		.34		.17
	2	FDigit span	.00	.01	.00	.06
	3	Reading span	.02	.18	.17#	.49#
	Total R^2		.25		.26	
Regression: The unique impact of verbal WM on *correct clauses*	1	Age_months	.17	−.26	.25#	−.28
		Rea_comp.		.27		.35
	2	FDigit span	.18*	.43*	.20*	.45*
	3	Reading span	.01	.13	.01	.14
	Total R^2		.37#		.47**	
Regression: The unique impact of verbal WM on *words per clause*	1	Age_months	.11	−.11	.18	−.07
		Rea_comp.		.28		.40#
	2	FDigit span	.28**	.54**	.07	.26
	3	Reading span	.08	.34	.06	.30
	Total R^2		.47**		.31#	
Regression: The unique impact of verbal WM on *macrostructure*	1	Age_months	.06	.08	.08	.00
		Rea_comp.		.26		.27
	2	FDigit span	.12	.35	.26**	.52**
	3	Reading span	.19*	.52*	.19**	.52**
	Total R^2		.37#		.52***	

Note. Age_months = age in months; Rea_comp. = reading comprehension scores; FDigit span = forward digit span.
#$p \le .05$; *$p \le .01$, **$p \le .005$, ***$p \le .001$.

contribution of verbal rehearsal (forward digit span scores) and executive WM skills (reading span scores) to deaf children's oral and written story production was examined.

Deaf and Hearing Children's Oral and Written Storytelling Skills

The deaf children in this study presented reading comprehension and verbal rehearsal problems when compared with their hearing peers, as also observed in previous studies (e.g., Crosson & Geers, 2001; Kyle & Harris, 2010; Pisoni & Cleary, 2003; Yoshinaga-Itano & Snyder, 1985). However, only their verbal rehearsal (forward digit span) and executive WM skills (reading span) contributed to explaining their performance in oral and written narration. This is an important finding of this study, which will be commented next.

The hearing controls also outperformed the deaf children in both the oral and written story production, at the micro- and macrostructural levels. Overall, the deaf children's production appeared to be more delayed at the microstructural, that is, clause, level than at the macrostructural level (with effect sizes of .57 and .54, respectively, for clause accuracy in oral and in written story production). This result is in line with previous studies (Antia et al., 2005; Arfé et al., 2014; McAfee et al., 1990; Spencer et al., 2003). Only in the written narration were the micro- and macrostructural organization of the story equally compromised. (The effect size was .53 for clause accuracy and .49 for story macrostructure.) The results of the regression analyses may explain why.

The Contribution of Verbal Rehearsal and Executive WM Skills to Oral and Written Story Production

Deaf children's oral and written story production relied largely on the same verbal WM resources: mainly their verbal rehearsal skills, assessed by forward digit span scores. This finding explains why the deaf children showed similar difficulties in these two tasks compared with their hearing peers.

Verbal rehearsal skills have been shown to be significantly compromised in deaf children (Harris et al., 2013; Pisoni & Cleary, 2003), and the results of the present study confirm deaf children's significant delay in verbal rehearsal. However, these skills contributed significantly to explain deaf children's ability to structure the oral and written stories at the microstructural level (i.e., in clauses) and were also associated with the generation of the written story macrostructure (i.e., complete and coherent narrations). The significant involvement of verbal rehearsal skills (forward digit span) in the macrostructural organization of the written, but not the oral, stories may explain why the micro- and macrostructural organization of the story were equally compromised in written production only.

As Table 5 shows, forward digit span scores contributed mainly to deaf children's clause construction. Thus, it is plausible that when deaf children's verbal rehearsal skills are more efficient, they are better able to control local text generation processes (i.e., clause construction) in writing and better able to focus their attention—and executive WM skills—on the macrostructure of their written texts. This may be particularly important in a task where the speed of language production is relatively slow, such as in writing. Pisoni and Cleary (2003) have shown that there is a significant relationship between deaf children's articulation rate in speech and their verbal rehearsal skills. In writing, language production is slowed down by handwriting and spelling processes. Instead of being an advantage for deaf children, this reduced pace may pose additional demands on their poor verbal rehearsal skills, requiring them to refresh verbal information for a longer time. This is an aspect that future studies should explore more closely.

Central executive skills, assessed by the reading span task, were also involved in deaf children's narrations, though to a lesser extent. In line with Alamargot et al. (2007), we found that the executive component of deaf children's verbal WM was associated with their facility in translating ideas into writing (i.e., in written clauses). Deaf children's executive WM skills also contributed to explaining their ability to structure oral and written stories at the macrostructural level. These results are consistent with studies conducted with hearing children (Swanson & Berninger, 1996) and suggest that the ability to generate discourse structures partially relies on those WM resources that are apparently most preserved in deaf children (see the results of this study and also Harris et al., 2011; Pisoni & Cleary, 2003). A question for future studies is why these resources are apparently used less in linguistic processes at the local level (i.e., clause construction), as in hearing children, they also seem to be involved locally in written text production (see Swanson & Berninger, 1994).

In this study, we hypothesized that for deaf children, written story production would involve greater memory demands than oral. Two findings of the study seem to confirm this hypothesis. First, the number of clauses produced by the deaf children in the written stories, but not in the oral, was associated with their reading span scores. That is, the translation of ideas into clauses presumably required greater executive control in written than in oral production. Secondly, deaf children's verbal rehearsal plus executive WM skills (forward digit span plus reading span) explained a greater amount of variance in the written than in the oral narration at the macrostructural level (45% vs. 19%).

These results might be attributed to task order—written production always followed oral production. However, we consider this unlikely for two reasons. First, the macrostructural organization of the oral and written stories appeared to involve the same executive WM resources (reading span scores), that is, the same attentional control (19%). If the additional demands of written production were determined by the sustained effort and concentration necessary to perform the task second, we would have probably observed a greater involvement of executive WM skills in the written, compared with the oral, productions. By contrast, what varied between the oral and written story productions was the involvement of verbal rehearsal skills (forward digit span scores). Secondly, an opposite pattern of results was observed for clause complexity, which seemed to require fewer verbal rehearsal skills, that is, memory resources, in the written, compared with the oral production, although it increased in writing (Table 2).

A possible interpretation of this finding is that the visual feedback generated by writing could have supported the construction of longer clauses (more words per clause) without taxing deaf children's verbal WM. However, when the task involved processing linguistic relations (i.e., generating agreement between words in a clause), the visual support was probably no longer sufficient, and significant verbal rehearsal skills were required, both in written and oral language. In synthesis, written production presented greater memory demands than oral production, but not at all levels—only when considering productivity and the macrostructural quality of the story.

Limitations

A first limitation of this study is that no associations were found between verbal WM and discourse production in hearing children. This result may be attributed to the dependent variables considered in the study (e.g., number of words per clause, correct clauses produced, story completeness). These measures were selected because they are sensitive to individual differences in deaf children's language production (Asker-Arnason et al., 2012; Tur-Kaspa & Dromi, 2001). However, in this study, they did not capture the variance in the hearing children's narrations with the same level of sensitivity. In fact, the hearing children performed at ceiling levels: they produced 87% correct clauses in the oral and 94% correct clauses in the written narration, and their average macrostructural scores were very high in both oral and written narratives (8.4 and 9.1, respectively). Finding measures that are equally sensitive to variance in both hearing and deaf children's text production remains a challenge for future studies.

A second limitation of this study is that it did not provide direct evidence of modality (oral vs. written) effects in deaf children's language production. Although our results indicate that written and oral language may challenge the deaf child's cognitive system differently, a direct comparison between the quality of deaf children's oral and written production would be important to test the effects of these cognitive costs. In this study, this was not possible due to the lack of counterbalancing in task order (oral and written). Future studies should address this research question by exploring modality effects in deaf children's language production.

Conclusions

In general, further research is necessary to explore the cognitive costs of oral and written production for deaf children. In this study, we examined the oral and written production skills of children who had received an oral education. Therefore, the results of this study cannot be extended to deaf children in general and especially to deaf children using sign language as their primary communication mode.

The findings of this study could, however, offer new avenues to research as well as initial evidence for informing interventions. With other emerging findings (Arfé et al., 2014), this study suggests that poor spelling skills, and limited language or literacy knowledge, may not be the only barrier to the production of connected discourse for deaf children. Indeed, the use of verbal rehearsal and executive WM resources in discourse production should also be addressed in interventions, especially regarding writing, where the task demands might be greater. Facilitation procedures exist to overcome WM loads in poor writers (Bereiter & Scardamalia, 1987). These procedures could be effectively adapted in literacy activities addressed to deaf children (see e.g., Arfé, 2003). It is also possible that experience with language itself (Cleary, Pisoni, & Geers, 2001), and complex language tasks (i.e., discourse production), could foster the development of the child's WM system. This may happen if children are helped to focus on linguistic tasks that apply a cognitive load, such as relating sentences or discovering linguistic relations in discourse or text.

Conflicts of Interest

No conflicts of interest were reported.

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Note

1. The examiner produced the conventional signs of digits while pronouncing them. The child was asked to repeat the digits orally in the same order as produced by the examiner.

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