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Research Article

Developmental Associations Between Working Memory and Language in Children With Specific Language Impairment: A Longitudinal Study

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Purpose: This longitudinal study examined differences in the development of working memory (WM) between children with specific language impairment (SLI) and typically developing (TD) children. Further, it explored to what extent language at ages 7–8 years could be predicted by measures of language and/or WM at ages 4–5 years.
Method: Thirty children with SLI and 33 TD children who were previously examined on measures of WM and language at ages 4–5 years (T1) were reexamined at ages 7–8 years (T2).
Results: The developmental course of WM was mostly similar for the two groups; only the development of the verbal storage component differed. At T1, children with SLI performed significantly below their TD peers on all components of WM (verbal storage, verbal central executive [CE], visuospatial storage, and visuospatial CE), whereas at T2, the differences for the visuospatial components were no longer significant when age and intelligence were taken into account. Hierarchical regression showed language and verbal CE at T1 to be significant predictors of language at T2, with no differences in the developmental associations between language and WM for the two groups.
Conclusions: The results of this study suggest that particularly verbal CE is of importance for the acquisition of linguistic skills.

Over the past years, an increasing number of studies showed that children diagnosed with specific language impairment (SLI) demonstrate impairments not only in language but also in other cognitive domains. One factor that is often implicated is working memory (WM; Montgomery, Magimairaj, & Finney, 2010). Children with SLI at different ages demonstrate deficits in WM when compared with typically developing (TD) peers (Archibald, 2016; Henry & Botting, 2016; Montgomery et al., 2010). However, there are still many questions about the developmental associations between WM and language. To date, research on this topic is very limited. In the present study, we therefore addressed the developmental course of WM and its relation to language in children with SLI. Children with SLI and their TD peers at ages 4–5 years, who were examined on several measures of WM and language in a previous study, were reexamined in this follow-up study at ages 7–8 years (Vugs, Knoors, Cuperus, Hendriks, & Verhoeven, 2015).

WM in Children With SLI

Although the language of the majority of children develops apparently automatically, there are also children who show marked problems or delays. When these children encounter language problems that cannot be explained by other underlying impairments, such as hearing loss, intellectual problems, or marked neurological problems, a diagnosis of SLI is usually made (Bishop, 2002, 2006). Children with SLI form a heterogeneous group with different profiles of language deficits. SLI can affect various linguistic domains (i.e., phonological, morphological, lexical, and grammatical domains), and the language

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profile often changes with age and development (Bishop, 2006; Leonard, 1998).

WM refers to the structures and processes used to temporarily store and manipulate information. Although WM can be conceptualized somewhat differently (Courage & Cowan, 2009; Engle, Tuholski, Laughin, & Conway, 1999), the most frequently adopted account in research on children with SLI is the multicomponent WM model of Baddeley (Baddeley, 2003; Baddeley & Hitch, 1974). In this model, a central executive (CE) system is assumed to link three subsystems: the phonological loop, the visuospatial sketchpad, and the episodic buffer. The CE system coordinates and controls activities in WM. It has a limited attentional capacity and requires attentional control. The phonological loop and visuospatial sketchpad are so-called "slave" systems and responsible for the temporary storage of verbal and visuospatial information, respectively. The episodic buffer is a relatively recent addition to the model and responsible for the binding of information from multiple sources together into chunks (Baddeley, 2003).

The development of WM already starts during the first years of life and eventually peaks in young adulthood. Research in TD children has shown that the ability to keep simple information in mind is already present before the age of 6 months (Courage & Cowan, 2009; Garon, Bryson, & Smith, 2008). The development of WM is often associated with structural changes in the prefrontal cortex, which undergoes enormous neurodevelopmental changes between the ages of 3 and 6 years (Garon et al., 2008; Luciana & Nelson, 1998). A previous study on the underlying structure of WM in young children has shown a four-factor model with separate but interacting components of verbal storage, verbal CE, visuospatial storage, and visuospatial CE to provide the best account of WM in children with and without SLI at ages 4–5 years (Vugs et al., 2015).

In children with SLI, significant group differences have been reported compared with TD children on different components of WM. It is widely accepted that SLI is associated with problems in the verbal storage component of WM (i.e., the phonological loop). The so-called phonological storage deficit hypothesis assumes that a specific deficit in the temporary storage of novel phonological information underlies SLI (Archibald & Gathercole, 2007; Baddeley, 2003; Bishop, 1996; Coady & Evans, 2008; Gathercole & Baddeley, 1990). Impairments in verbal storage have been reported in children with SLI at different stages of development, varying from preschool until adolescence (Montgomery et al., 2010; Vugs, Hendriks, Cuperus, & Verhoeven, 2014). In addition to these deficits in verbal storage, substantial impairments have been reported for the verbal CE component of WM. Children with SLI are even more severely and consistently impaired on verbal complex memory span tasks that combine verbal storage with processing of information than on straightforward verbal storage tasks (Archibald & Gathercole, 2006a; Briscoe & Rankin, 2007). Impairments in the verbal CE component of WM have been found in children with SLI at different ages (Archibald & Gathercole, 2006b; Briscoe & Rankin, 2007; Ellis Weismer, Evans, & Hesketh, 1999; Henry, Messer, & Nash, 2011; Marton & Schwartz, 2003; Vugs et al., 2014).

Regarding the role of visuospatial WM in children with SLI, results are somewhat contradictory. Based on studies that showed children with SLI to perform similarly to their TD peers on visuospatial storage and CE tasks, several authors assume that the WM deficits of children with SLI are limited to verbal WM (Alloway & Archibald, 2008; Archibald & Gathercole, 2006a, 2006b). In contrast, the results of several other studies and a recent meta-analysis have yielded evidence suggesting that the WM deficit of children with SLI may extend to the visuospatial domain (Marton, 2008; Vugs, Cuperus, Hendriks, & Verhoeven, 2013). Although the results of the meta-analysis showed some impairments in visuospatial storage and visuospatial CE in children with SLI, it also revealed that the deficit for visuospatial WM is not as large as the deficit for verbal WM. The extent of the deficit in verbal WM was found to be two to three times larger than the extent of the deficit in visuospatial WM.

Associations Between WM and Language

Although many studies compared WM between children with SLI and TD children, much is still unknown about the exact associations between language and WM. Language is a complex system with different levels of processing, and it is well known that several of these language abilities can be affected in children with SLI. Recently, some studies more specifically addressed the possible associations between WM and language abilities in children with SLI.

The verbal storage component of WM has often been proposed to be linked to word learning or vocabulary acquisition (Montgomery et al., 2010). Gathercole and Baddeley (1989) were the first to demonstrate a strong association between the functioning of the phonological loop and the acquisition of new words in TD children between the ages of 4 and 5 years. In this longitudinal study, verbal storage at the age of 4 years was significantly linked with vocabulary knowledge one year later. Since then, other studies have documented a similar association for children with SLI (Gathercole & Baddeley, 1990; Horohov & Oetting, 2004; Montgomery, 2002). It is assumed that the storage of phonological information in WM and word learning are especially linked in the early stages of vocabulary acquisition (Archibald, 2016).

Children with SLI also tend to have problems in the understanding and production of complex syntactic sentences (Fortunato-Tavares et al., 2015; van der Lely, 1996). Accumulating evidence indicates that impairments in the verbal CE component of WM may account for these deficits in sentence processing (Archibald, 2016; Montgomery & Evans, 2009; Noonan, Redmond, & Archibald, 2014). In one study of sentence comprehension, for example, performance on a verbal CE task correlated significantly with the comprehension of complex sentences in school-aged children with SLI (Montgomery & Evans, 2009). Fortunato-Tavares et al. (2015) investigated the association between WM and sentence comprehension through direct manipulation of WM demands, showing an effect of WM on the syntactic assignment of predicates and reflexives in sentence comprehension in children with SLI. Recently, some authors have suggested that the role of verbal CE in sentence processing is influenced by the task requirements. Noonan et al. (2014) investigated the interrelations between WM deficits—measured using both verbal and visuospatial complex memory span tasks—and judgments of grammaticality. In this study, children with only language impairments and thus no WM deficits, children with deficits in both domains, and TD children completed a task in which grammatical markers occurred at different places in the sentence. Children with only language impairments performed significantly worse regardless of the location of the marker, whereas children with deficits in both WM and language were only impaired for sentences with late grammatical errors, which are supposed to impose a greater WM load. Frizelle and Fletcher (2015) found that the ability to process complex sentences involving greater syntactic development was related to the verbal CE component of WM in children with SLI, but not in TD children. Based on these findings, it is suggested that verbal WM skills are closely linked to sentence processing when language demands are high, which is often the case for children with SLI (Archibald, 2016).

Recently, we have examined how the different components of WM were related to linguistic skills in children with SLI at ages 4–5 years (Vugs et al., 2015). We found the verbal CE component to be moderately to strongly associated with several language abilities, including receptive vocabulary, expressive vocabulary, verbal comprehension, and syntactic development. In addition, the verbal storage component significantly correlated with receptive vocabulary and syntactic development. A clear and meaningful association between the visuospatial components of WM and any of the language abilities was not found.

Present Study

From the research conducted so far, there is clear evidence that WM and language are associated in children with SLI. However, most previous studies were cross-sectional and did not take into account developmental aspects. As it is well established that both WM and language significantly change cross-development, longitudinal research is needed to provide more information about the complex interplay between WM and language in children with SLI. Longitudinal studies taking into account language abilities and WM will shed some light on how these skills develop and how the relationship between them may change. Do children with SLI, for instance, just show a continuing delay or do the developmental trajectories differ for children with SLI compared with TD children? Furthermore, longitudinal research can be useful in addressing the issue of the directional relationship between WM and language (Kapa & Plante, 2015).

In the present longitudinal study, we investigated the developmental associations between WM and language in children with SLI. Since both WM and language abilities undergo significant changes in early childhood, we specifically focused on this stage of development. Children with SLI and TD children who were examined on several measures of WM and language at ages 4–5 years (T1) were reexamined at ages 7–8 years (T2). The specific questions we addressed were as follows:

1. Does the development of the different components of WM from T1 to T2 differ for children with SLI versus TD children?
2. To what extent can language at T2 be predicted from the language and/or WM measures at T1 in children with SLI and TD children?

In order to answer the first research question, we compared the performances of the children with SLI on the different components of WM with that of the TD children at T1 and T2 and examined differences in the development on the WM measures between the two groups. We expected the children with SLI to show a developmentally consistent pattern of WM impairments in this age range (Henry & Botting, 2016). With regard to the second research question, we expected the verbal components of WM and language abilities at T1 to predict language abilities of the SLI and TD groups at T2 (Archibald, 2016; Vugs et al., 2015).

Method

Participants

Children were recruited from a previous study population of children with SLI and age-matched TD peers at ages 4–5 years. In this study, all of the children had average intelligence (85 or more on the Snijder–Oomen Nonverbal Intelligence Test, SON-R 2½-7) and were native speakers of Dutch (Tellegen, Winkel, Wijnberg-Williams, & Laros, 1998). Any children with a diagnosed hearing impairment, neurological disorder, attention-deficit disorder or attention-deficit/hyperactivity disorder, or autism spectrum disorder were excluded. The children in the SLI group were recruited from special language units or from special education schools in the Netherlands. All of them were receiving daily support for their speech or language problems. Diagnosis was based on extensive clinical and psychometric assessment by speech-language pathologists; persistent difficulties specific to language were shown in all cases. For most of the children, recent results for measures of language and nonverbal intelligence were available via their personal files. These results were included in the study only when they were no more than 6 months old. Otherwise, assessment was repeated. Participants were included in the study when they performed 1.25 *SD*s or more below the mean on at least two language measures, following Tomblin (1996). The language measures included the Peabody Picture Vocabulary Test-III-NL (Dunn & Dunn, 1997; Schlichting, 2005), the Reynell Developmental Language

Scales (Reynell & Gruber, 1990; van Eldik, Schlichting, Lutje-Spelberg, van der Meulen, & van der Meulen, 2004), and tests of word and sentence development from the Schlichting Test for Language Production (Schlichting, van Eldik, Lutje-Spelberg, van der Meulen, & van der Meulen, 2003). The Dutch versions of these tests have all been normed. The children in the control group were recruited from three middle-class schools in the Netherlands. The language measures examined for the control group were the Peabody Picture Vocabulary Test-III-NL (Dunn & Dunn, 1997; Schlichting, 2005) and the Reynell Developmental Language Scales (Reynell & Gruber, 1990; van Eldik et al., 2004). All of the control children performed in the normal range on both of these tests. For a detailed description of the study population, see Vugs et al. (2014).

Three years after the initial study, all parents were contacted again and invited to participate in this follow-up study. A total of 67 children were available for follow-up: 33 children with SLI and 34 TD peers. First, we analyzed the profiles of language abilities and nonverbal intelligence of both groups at T2. At this time-point, nonverbal intelligence was measured by the subtests Categories and Patterns of the SON 6-40 (Tellegen & Laros, 2011). The scores on these two subtests were combined to form an estimated nonverbal IQ. For the SLI group, the language measures included tests of receptive vocabulary (Peabody Picture Vocabulary Test-III-NL; Dunn & Dunn, 1997; Schlichting, 2005), expressive vocabulary (Expressive Vocabulary subtest of the Clinical Evaluation of Language Fundamentals–Fourth Edition [CELF-4]), verbal comprehension (Concepts and Following Directions subtest CELF-4), and syntactic development (Formulated Sentences subtest CELF-4; Semel, Wiig, & Secord, 2003). The TD group was again examined with tests of receptive vocabulary and verbal comprehension. Three children in the SLI group and one child in the control group no longer met the mentioned inclusion and exclusion criteria. Data are reported for the remaining 63 children (30 children with SLI and 33 TD peers). The descriptive statistics for the SLI and TD groups at both time-points are presented in Table 1.

At T2, the mean age of the children SLI was 8;00 years; months (*SD* = 5.96 months, range = 7;02 to 8;09). The mean age of the TD peers was 8;04 (*SD* = 7.29 months, range = 7;03 to 8;11). One-way analyses of variance (ANOVAs) confirmed that, at this time-point, the SLI group had significantly lower scores on the language measures than the control group: PPVT-III-NL $F(1, 61) = 17.62, p < .001$; CELF-4 Concepts and Following Directions $F(1, 61) = 17.36, p < .001$. Additionally, the SLI and control groups significantly differed with regard to age, $F(1, 61) = 6.61, p = .013$, and nonverbal intelligence, $F(1, 61) = 7.58, p = .008$. The two groups did not differ significantly with regard to gender, $\chi^2(1, N = 63) = 0.610, p = .597$.

Procedure

Almost all children were tested individually in a quiet room at their school. Only three children were tested at home. Written consent was obtained for participation in the present follow-up study from the parents of the children. Assessment took about two hours, with a short break halfway through. In addition to the measures for nonverbal intelligence and language listed above, all of the children were administered four subtests of the Dutch translation of the Automated Working Memory Assessment (AWMA; Alloway, 2007). All children completed the test battery.

Measures of WM

The AWMA is an automated, computerized assessment battery suitable for use with respondents who are 4–22 years of age (Alloway, 2007). The AWMA has been validated and measures the different components of Baddeley's WM model, including verbal storage, verbal CE, visuospatial storage, and visuospatial CE (Gathercole & Pickering, 2000). The storage measures tap into the phonological loop or visuospatial sketchpad, depending on the nature of the information to be remembered. For the CE measures, the children must simultaneously store and process information. The processing activity is assumed to tap into the CE component of the WM model. In this study, we included four subtests: one for each component of WM.

Testing follows the same span procedure in all subtests. Following a practice session, a maximum of six sequences of increasing lengths are presented. The length of the sequences is increased by one after the child has correctly recalled four sequences of a particular length, with a maximum of seven items for the CE tasks and nine items for the storage tasks. Testing is stopped when three sequences of a particular length are not recalled correctly. The children respond by pointing to the answer of their choice on the screen or by saying it aloud. The experimenter then imports their choice into the computer program.

Verbal Storage

In the digit recall task, the child must recall a sequence of digits in the right order. The digits can range from one to nine and are spoken at a rate of one digit per second. The sequences are randomly generated, and no digits are repeated.

Verbal CE

In the listening recall task, the child is presented short sentences. The child must then judge whether the content of the sentence is correct (by saying "true" or "false") and remember the last word of the sentence. The number of sentences increases in length, and the child must then recall the last words of the sentences in the correct serial order. The sentences have a simple subject–verb–object order and contain early developing vocabulary.

Visuospatial Storage

In the dot matrix task, a sequence of red dots is presented on a 4 × 5 grid. All of the dots appear in the grid for 2 s. The dots then disappear, and the child must point to the position of each dot in the same serial order as presented.

Table 1. Descriptive statistics for age, gender, nonverbal intelligence, and language measures at ages 4–5 years (T1) and 7–8 years (T2).

	T1		T2	
	SLI (n = 30)	TD (n = 33)	SLI (n = 30)	TD (n = 33)
Measure	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Age	57.07 (7.19)	59.06 (7.00)	95.90 (5.96)	100.24 (7.29)
Gender (*n*)				
Male	21	20	21	20
Female	9	13	9	13
Nonverbal IQ				
SON-R 2½-7	107.50 (13.14)	116.61 (14.56)	—	—
SON-R 6-40	—	—	92.80 (15.57)	103.18 (14.35)
Receptive vocabulary				
PPVT-III-NL	94.43 (14.81)	107.24 (9.73)	90.23 (13.17)	102.61 (10.15)
Verbal comprehension				
Reynell	85.83 (14.36)	117.73 (10.87)	—	—
CELF-4, Concepts and Following Directions	—	—	6.73 (2.29)	9.61 (3.08)
Expressive vocabulary				
Schlichting WQ	81.83 (12.81)	—	—	—
CELF-4, Expressive Vocabulary	—	—	7.10 (2.58)	—
Syntactic development				
Schlichting ZQ	78.60 (9.48)	—	—	—
CELF-4, Formulated Sentences	—	—	6.40 (2.53)	—

Note. SLI = specific language impairment; TD = typically developing; SON-R 2½-7 = Snijders–Oomen Nonverbal Intelligence Test SON-R 2½-7; SON-R 6-40 = Snijders–Oomen Niet-verbale Intelligentietest SON-R 6-40; PPVT-III-NL = Peabody Picture Vocabulary Test–III; Reynell = Reynell Developmental Language Scales; CELF-4 = Clinical Evaluation of Language Fundamentals–Fourth Edition; Schlichting WQ = Schlichting Test for Language Production, Word Development; Schlichting ZQ = Schlichting Test for Language Production, Sentence Development.

Visuospatial CE

In the spatial span task, two identical shapes, with a red dot above the right shape, are presented to the child. The child must judge whether the two shapes are in normal or mirror image and remember the location of the dot. The position of the dot rotates to one of three positions of a triangle. After trials requiring the child to judge the similarity of the shapes, they disappear, and a triangle of three dots reflecting the possible positions of the previous dots appears. The child must point to the positions of the previous dots in the right order.

Statistical Analyses

First, differences between the SLI and TD groups at T1 and T2 were tested using multivariate ANOVAs and follow-up ANOVAs. Using the Bonferroni method, which divides the level of significance by the number of dependent variables, each ANOVA was tested at the .013 level. In addition, effect sizes were computed. The effect size (d) is the difference between the mean of the control group and the SLI group divided by the pooled sample standard deviation. Effect sizes are considered small for $d = 0.20$, medium for $d = 0.50$, and large for $d = 0.80$ (Cohen, 1988). To control that age and intelligence were not mediating performance on the WM measures, multivariate analyses of covariance (ANCOVAs) and follow-up ANCOVAs were next conducted for the four WM measures; nonverbal intelligence (IQ SON) and age were entered as covariates.

Then, 2 × 2 repeated-measures ANOVAs were conducted with time of assessment as the within factor (T1, T2) and group as the between factor (SLI, TD). Effect sizes (Cohen's η^2) were reported for all analyses. Following the criteria of Cohen (1988), effect sizes were considered small for $\eta^2 = .01$, medium for $\eta^2 = .06$, and large for $\eta^2 = .14$. To control that age and intelligence were not mediating possible time or interaction effects, repeated-measures ANCOVAs were next conducted for the four WM measures; nonverbal intelligence (IQ SON) and age were entered as covariates.

To examine the interrelations between the measures of WM and language at T1 and language at T2, first, principal component analyses with varimax rotation were conducted on the language tasks of the total group of children. Further, Pearson correlations were calculated, and a hierarchical regression analysis was conducted, with language at T2 as the criterion variable. The predictor variables and a Group variable (SLI = 1, TD = 0) were included in Step 1, and in Step 2, all corresponding interaction terms were included. To control for multicollinearity, we centered all predictor variables before conducting the regression analysis (Jewell, 2003).

Results

Development of WM

The descriptive statistics for the WM measures (AWMA) are shown in Table 2. First, performances of the SLI and TD groups were compared. Multivariate ANOVA investigating group differences on the four WM measures

Table 2. Descriptive statistics and group comparison at ages 4–5 years (T1) and 7–8 years (T2).

	SLI					TD					Time			Time × Group		
	T1	T2				T1	T2									
Variable	***M* (*SD*)**	***M* (*SD*)**	***t***	***p***	***d***	***M* (*SD*)**	***M* (*SD*)**	***t***	***p***	***d***	***F***	***p***	η^2	***F***	***p***	η^2
Verbal storage	71.40 (12.99)	81.50 (11.88)	3.045	.005	2.30	98.39 (10.86)	96.18 (13.56)	−1.367	.181	1.17	4.84	.032	.073	11.780	.001	.162
Verbal CE	99.60 (11.04)	98.43 (12.34)	−0.678	.678	2.14	123.36 (11.51)	116.61 (10.42)	−2.489	.018	1.63	4.15	.046	.064	2.066	.156	.033
Visuospatial Storage	91.93 (11.97)	100.73 (11.19)	3.017	.005	1.15	106.42 (13.52)	109.42 (14.67)	1.086	.286	0.68	8.63	.005	.124	2.085	.154	.033
Visuospatial CE	98.53 (12.30)	98.37 (9.70)	−0.063	.950	1.03	113.03 (16.73)	107.15 (15.92)	−2.056	.048	0.67	2.38	.128	.038	2.129	.150	.034

Note. SLI = specific language impairment; TD = typically developing; CE = central executive.

at T1 (i.e., verbal storage, verbal CE, visuospatial storage, and visuospatial CE) showed a significant overall group effect: Wilks's Λ = .33, $F(4, 58) = 29.93$, $p < .001$, $\eta^2 = .67$. Follow-up ANOVAs showed significant group effects for all four WM measures at a .013 level. The effect sizes ranged from 1.03 to 2.30. On all WM measures, the SLI group scored at a significantly lower level than the TD group.

At T2, there was also a significant overall group effect on the WM measures: Wilks's Λ = .56, $F(4, 58) = 11.60$, $p < .001$, $\eta^2 = .44$. Follow-up ANOVAs again revealed significant group differences for each of the individual WM measures, with effect sizes ranging from 0.67 to 1.63.

To control that age and intelligence were not mediating performance on the WM measures, multivariate ANCOVAs and follow-up ANCOVAs were conducted. At T1, the overall group effects on the WM measures remained significant: Wilks's Λ = .58, $F(4, 56) = 10.41$, $p < .001$, $\eta^2 = .42$. Once again, the univariate ANCOVAs showed significant group effects for the four WM measures: verbal storage $F(1, 59) = 60.92$, $p < .001$; verbal CE $F(1, 59) = 54.95$, $p < .001$; visuospatial storage $F(1, 59) = 10.87$, $p = .002$; and visuospatial CE $F(1, 59) = 7.59$, $p = .008$.

At T2, the overall group effect again was significant for the WM measures: Wilks's Λ = .58, $F(4, 56) = 10.41$, $p < .001$, $\eta^2 = .42$. Follow-up ANCOVAs showed significant group effects for verbal storage and verbal CE, but not for visuospatial storage and visuospatial CE: verbal storage $F(1, 59) = 12.99$, $p = .001$; verbal CE $F(1, 59) = 36.99$, $p < .001$; visuospatial storage $F(1, 59) = 3.26$, $p = .076$; and visuospatial CE $F(1, 59) = 1.71$, $p = .196$. Nonverbal intelligence was significantly related to visuospatial CE, $F(1, 59) = 15.09$, $p < .001$.

To investigate differences between the SLI and TD groups on the WM measures over time, repeated-measures ANOVAs were conducted (see Table 2). The results showed a significant effect of time for visuospatial storage, with a medium effect size. A significant Time × Group interaction effect was found for verbal storage, with a large effect size. Children in the SLI group showed an improvement in verbal storage over time, whereas the performances of the TD group remained stable. The other WM measures did not show significant effects.

When we controlled for possible mediating effects of age and nonverbal intelligence, repeated-measures ANCOVAs showed similar results as described above (data available from the first author).

Interactions Between WM and Language Abilities

To start, principal component analyses with varimax rotation on the language tasks revealed one language factor at T1 and T2. This factor explained 84.08% of the variance in language tasks at T1 and 82.99% at T2.

Pearson correlation coefficients were computed to explore how WM and language abilities are related over time for the total group of children. We correlated the predictor measures (i.e., verbal storage, verbal CE, visuospatial storage, visuospatial CE, and language at T1) and the criterion measure (i.e., language at T2). The resulting correlation matrix is shown in Table 3. Nearly all predictor measures at T1 were significantly correlated to language at T2. Only the visuospatial CE component of WM at T1 did not significantly correlate with language at T2.

To further explore the developmental associations between WM and language, we next conducted a hierarchical regression analysis, with language at T2 as the criterion variable. The predictor variables and a Group variable were included in Step 1. In Step 2, all corresponding interaction terms were included to explore differences between the SLI and TD groups. Table 4 summarizes the information of the regression analysis.

The results showed language and the verbal CE component of WM at T1 to be significant predictors of language at age T2: $\Delta R^2 = .536$, $F(6, 56) = 10.773$, $p < .001$. Step 2 of the regression analysis did not show significant interactions: $\Delta R^2 = .067$, $F(5, 51) = 1.731$, $p = .144$. These results indicate that the developmental associations between language and WM at T1 and language at T2 do not differ for the SLI versus TD children.

Discussion

The aim of this longitudinal study was to examine the developmental associations between WM and language from the ages of 4 and 5 years to 7 and 8 years in children with SLI and TD children. We first evaluated differences in the developmental course of WM between children with SLI and their TD peers. Furthermore, we examined whether language at T2 could be predicted from the language and/or WM measures at T1.

With regard to our first research question, namely, whether the development of the different components of WM from T1 to T2 differed for children with SLI versus TD children, we found the developmental course of WM to be mostly similar. No significant differences were found between the two groups with regard to the development of the verbal CE, visuospatial storage, and visuospatial CE components of WM. Only the development of the verbal storage component significantly differed for the children with SLI versus TD children. The children with SLI showed an improvement in verbal storage, whereas performances of

Table 3. Correlations between components of working memory and language at ages 4–5 years (T1) and language at ages 7–8 years (T2), *N* = 63.

Variable	1	2	3	4	5	6
1. Language T1	—					
2. Verbal storage T1	.601*	—				
3. Verbal CE T1	.669*	.640*	—			
4. Visuospatial storage T1	.542*	.541*	.590*	—		
5. Visuospatial CE T1	.386*	.448*	.506*	.552*	—	
6. Language T2	.671*	.501*	.622*	.445*	.211	—

Note. CE = central executive.

*$p < .001$.

Table 4. Results of hierarchical regression analysis on language at ages 7–8 years.

Variable	Total R^2	ΔR^2	β
Step 1			
	.536***	.536***	
Language T1			.459**
Verbal storage T1			.112
Verbal CE T1			.372*
Visuospatial storage T1			.078
Visuospatial CE T1			−.203
Group			.100
Step 2			
	.603	.067	
Language T1			.481**
Verbal storage T1			.158
Verbal CE T1			.362*
Visuospatial storage T1			.092
Visuospatial CE T1			−.228
Group			.119
Group × Language T1			−.038
Group × Verbal Storage T1			−.203
Group × Verbal CE T1			−.026
Group × Visuospatial Storage T1			.251
Group × Visuospatial CE T1			−.094

Note. T1 = 4–5 years; CE = central executive.

*p < .05. **p < .01. ***p < .01.

the TD children remained stable. Group comparison, however, revealed that the children with SLI still performed significantly worse on verbal storage compared with their TD peers at T2.

The children with SLI were found to perform significantly below their TD peers on all components of WM (i.e., verbal storage, verbal CE, visuospatial storage, and visuospatial CE) at both T1 and T2. At T1, the effect sizes for the different components were all large (range: $d = 1.03$ to $d = 2.30$). At T2, effect sizes were large for the verbal components of WM ($d = 1.17$ and $d = 1.63$) and medium for the visuospatial components ($d = 0.68$ and $d = 0.67$). These results are in line with previous findings showing clear impairments in verbal storage and verbal CE in children with SLI at different ages (Archibald & Gathercole, 2006b, 2007; Coady & Evans, 2008; Gray, 2003; Montgomery et al., 2010). Reduced performance on visuospatial storage and visuospatial CE tasks in young children with SLI has also been reported in most previous studies (Bavin, Wilson, Maruff, & Sleeman, 2005; Hick, Botting, & Conti-Ramsden, 2005; Marton 2008; Menezes, Takiuchi, & Befi-Lopes, 2007). At T2, we also found the children with SLI to perform below their TD peers on the visuospatial components of WM, but the magnitude of these deficits is not as large as the deficits in the verbal components of WM. This replicates findings of a recent meta-analysis of visuospatial WM, showing that the deficit in verbal WM of children with SLI is two to three times larger than the deficit in visuospatial WM (Vugs et al., 2013). Furthermore, the differences between the children with SLI and TD children in visuospatial storage and visuospatial CE at T2 were no longer significant when we took into account the mediating effects of age and nonverbal intelligence. In particular, nonverbal intelligence was significantly related to visuospatial CE. These results suggest that in children with SLI in the ages of 7–8 years, reduced performance on visuospatial storage and visuospatial CE might not be a specific problem in visuospatial WM, but rather an indirect effect of nonverbal intelligence. The relationship between WM, language, and intelligence in children with SLI is something that needs further investigation. Research in TD children has shown that executive functions (EFs), including WM, are correlated with crystallized and fluid intelligence (Arffa, 2007; Engle et al., 1999). A recent meta-analysis on nonverbal intelligence furthermore showed children with SLI to perform, on average, 0.69 *SD*s lower than their TD peers (Gallinat & Spaulding, 2014). It has to be determined in future research whether intelligence influences the associations between WM and language abilities in children with SLI.

Our second research question addressed to what extent language at T2 could be predicted from the language and/or WM measures at T1 in children with SLI and TD children. To answer this question, correlations were first calculated. Language, verbal storage, verbal CE, and visuospatial storage at T1 were all found to be significantly correlated to language at T2. Only the visuospatial CE component of WM did not show a significant correlation with language at T2. Hierarchical regression further showed language and the verbal CE component of WM at T1 to be significant predictors of language at T2. The verbal storage and visuospatial components of WM did not explain a significant amount of variance for language at T2. Moreover, it was found that these developmental associations between language and WM were similar for the children with SLI and TD children.

This study was one of the first to take into account the developmental associations between WM and language abilities in children with SLI in a longitudinal study. Taken together, the current results indicate a developmentally consistent pattern of WM impairment in children with SLI in early childhood. However, the verbal components of WM at ages 4–5 years are more strongly related to language abilities 3 years later than the visuospatial components in both children with SLI and TD children. Particularly, the verbal CE component of WM was found to be a significant predictor of language. These findings are in line with previous research, showing clear links between verbal CE and various language abilities in children with SLI (Archibald 2016; Montgomery & Evans, 2009; Noonan et al., 2014; Vugs et al., 2015). The current results suggest that verbal CE is important for the acquisition of linguistic skills. It seems plausible that the ability to simultaneously store and process verbal information (i.e., verbal CE) is involved in almost all everyday situations of learning new language abilities and that problems in verbal CE affect the processes of learning various linguistic skills. However, the present findings do not rule out that language abilities also affect WM. It is likely that WM and language develop in reciprocal interaction with changing effects on each other over time. More systematic research is needed to disentangle this complex interplay between WM and language in children with SLI. To gain more information about the directionality of the relationship between WM and language, it could be of interest to investigate whether linguistic training affects WM performance. Or, the other way around, whether WM training influences language abilities. Likewise, studies that identify groups of children whose WM and language skills dissociate may prove useful to draw more firm conclusions about the directional relationship between WM and language in children with SLI (Noonan et al., 2014).

Of course, several limitations apply to the present study. One possible limitation, for instance, is that no measures of other EFs such as inhibition and cognitive flexibility were included. Most recent models typically considered EFs a multifaceted concept with distinct subfunctions, and WM is one of the most frequently postulated components of EFs (Huizinga, Dolan, & van der Molen, 2006; Miyake et al., 2000). Recent studies showed impairments in other EFs, for instance, inhibition in children with SLI (Henry et al., 2011; Pauls & Archibald, 2016). How WM is related to other EFs in children with SLI is something to be determined in future research. Further, no measures of the functioning of the episodic buffer component of WM were included. The inclusion of such information might be of value for future research as impairments in this component of WM in children with SLI have been recently reported (Petrucelli, Bavin, & Bretherton, 2012). Another concern is the relative small sample size of the study, especially in relation to the hierarchical regression analyses that were conducted. Given the number of predictor variables and interaction terms, it is possible that some of the interactions would have reached statistical significance in a larger sample. A last limitation is the limited age range of the children included in this study. Based on this, no conclusions can be drawn with regard to the stability of the associations between WM and language abilities for children older than 8 years. Just how the associations between the components of WM and language abilities of the children develop—and possibly shift—as the children grow older is obviously something that has to be examined in future research. Continued research will provide greater insight in the role of WM in the language acquisition of children with SLI.

In closing, the present findings have some valuable implications for clinical practice. First, it seems important to include WM tasks in the assessment of children with SLI. Attention should be paid not only to the language problems of these children but also to possible WM impairments that can contribute to their language problems. It is specifically recommended to adopt a multimodal approach of WM given the current findings of impairments in both verbal and visuospatial WM. Although children with SLI show more substantial impairments in verbal WM, it is obviously important to know if the WM problems being experienced by a child are also visuospatial, for instance, for the use of visual support, which is a common intervention strategy adopted for children with SLI. Likewise, it seems sensible to pay attention to WM in treatment. Given the developmentally consistent WM impairments of children with SLI, it is important that WM demands be minimized during teaching and treatment in order to limit the adverse effects of the WM deficits. Further, interventions directed at improving WM and teaching children effective strategies to cope with their WM limitations (e.g., rehearsal, grouping, and visualization) may be valuable additions to more traditional linguistic interventions. Interventions focusing on both language and WM problems might result in more optimal results than those with attention to only linguistic abilities.

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