Predictors of verbal working memory in children with cerebral palsy

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ARTICLE INFO

1. Introduction

Working memory is used in situations in which small amounts of material are held actively and then reproduced in a sequential or unchanging form. Baddeley and Hitch (1974) proposed a model of working memory (WM) that consists of three aspects: a visuospatial sketchpad that is assumed to be capable of temporarily maintaining and manipulating visuospatial information (Baddeley, 2000), a central executive responsible for the coordination of the visuospatial sketchpad and the phonological loop and their connection to the long-term memory. The phonological loop consists of a phonological store, specialized in the storage of verbal material or recoding of nonverbal materials, and a...

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phonological rehearsal component. In this rehearsal component, materials are represented in a phonological code and rehearsed in order to prevent the traces from decaying (Baddeley, Gathercole, & Papagno, 1998). This phonological or articulatory loop is considered to play an important role in learning to read and write (Card & Dodd, 2006) as it might facilitate long-term phonological learning (Baddeley, Papagno, & Vallar, 1988). For instance, the phonological loop plays an important role in learning phoneme–grapheme conversion rules necessary for word decoding and ultimately text-comprehension (Baddeley, 2003).

Previous studies to the precursors of verbal WM have indicated four skills that play an important role in its development. First of all, previous studies indicate a strong relationship between general intelligence and verbal WM (cf. Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004). In a study of Henry and MacLean (2002), it was shown that children with intellectual disabilities scored below a mental-age matched control group on different memory tasks.

Secondly, articulatory coding is considered to play a role in the size of memory spans. Studies suggested that the memory span is equivalent to the number of items that can be pronounced in about 2 s (White, Craft, Hale, & Park, 1994). Both the word-length effect, i.e., the memory span for long words is less than for short words as it takes more time to pronounce long words (Bishop, 1988), and the phonological similarity effect, i.e., immediate serial recall is impaired when items are similar in sounds or articulatory characteristics, is abolished by normal subjects when a visual presentation is used and subjects are required to articulate concurrently (Bishop & Robson, 1989). These results gave rise to the view that articulatory coding, i.e., “coding of information as a set of motor commands to articulators” (Bishop, 1985, p. 245) is involved in verbal WM. However, it is not just the motor ability to articulate but also speech output that is associated with verbal WM capacity. Previous studies have shown that there is a relationship between articulation speed, or speech rate, and the memory span. For example, Kail (1997) conducted a study focusing on the memory span of 120, 6- to 10-year-old children and found their memory span, i.e., the longest sequence of words that can be correctly repeated in a serial order, was related to their speech rate. The faster the children could articulate, the more words they could rehearse within a fixed time, and therefore the longer their memory spans. Other studies have also indicated a significant relationship between speech rate and memory span (Hulme, Thomson, Muir, & Lawrence, 1984; Roodenrys, Hulme, & Brown, 1993; White et al., 1994). Another aspect of speech that has shown relationships with verbal WM is articulation quality. Rapala and Brady (1990) studied the relationship between the quality of articulation, measured with tongue-twister word pairs such as [si] and [shi], and verbal STM. They found that the better the children could articulate, the longer their memory spans. Locke and Kutz (1975) showed that children with a speech disorder were worse in indicating the right series of pictures of spoken words compared to a control group. They proposed that the inability to articulate could influence the efficiency of storing words in the phonological loop.

A third precursor of verbal WM is auditory perception. Studies have indicated that it is necessary for children to be able to hear and process incoming speech sounds correctly in order to have access to and retrieve the phonological representations from the long-term memory (Foy & Mann, 2001) and prevent the memory traces from decaying (cf. Brady, Shrankweiler, & Mann, 1983; Rapala & Brady, 1990).

Finally, studies have shown a relationship between verbal WM and phonological awareness. Alloway et al. (2005) have shown that phonological skills, such as phonological awareness, are related to memory span.

Taking into account the importance of these precursors for verbal WM, the question can be asked how the verbal WM skills of children with cerebral palsy (CP) are developed and what role these precursors play in the verbal WM spans of these children. According to Bax et al. (2005, p. 572), cerebral palsy can be described as “a group of disorders of the development of movement and posture, causing activity limitation that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of CP are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behaviour, and/or by seizure disorders”. In addition, children with CP often have dysarthria, a speech production problem that may be a direct result of the motor impairment (Pirila et al., 2007). Kent (2000, p. 399) described dysarthrias as “speech disorders that result from neurologic impairments associated with weakness, slowness, or
incoordination of the musculature used to produce speech”. The disturbed neuromotor control of the speech mechanisms may in a minority of the children result in such severe speech impairments that these children are unable to speak and are therefore called nonspeaking children. This may have consequences for the development of the verbal WM skills of these children.

From previous studies, it is known that children with CP lag behind in their verbal WM skills (Dahlgren Sandberg, 2002; Peeters, Verhoeven, van Balkom, & de Moor, 2008) what might have consequences for their reading development as working memory skills are important for the consolidation of phoneme–grapheme conversion rules and the development of a large vocabulary (Baddeley & Hitch, 1974; Baddeley et al., 1998). However, till now it is not clear if and how the additional speech and intellectual impairments play a role in the development of verbal WM of children with CP. Previous studies towards the precursors of verbal WM in children with CP are scarce. Experimental studies that have been conducted are mainly focused on the role of speech abilities in verbal WM. For instance, it is speculated that if articulatory coding is necessary for subvocal rehearsal then subjects who have never been able to articulate words, such as children with anarthria, would show no or a reduced effect of word-length and phonological similarity (cf. Bishop & Robson, 1989). Bishop and Robson (1989) studied the memory spans of 12 adolescents with dysarthria and 12 adolescent with anarthria with 24 adolescents matched for chronological age and nonverbal ability. Both the control and the speech-impaired group showed evidence of phonological similarity and word-length effects. In a similar vein, Foley and Pollatsek (1999) compared six adults with dysarthria and six adults with anarthria on memory processes. Phonological similarity effects were significantly greater for the individuals with dysarthria. However, also two adults with anarthria demonstrated significantly phonological similarity effects. Similarly, word-length effects were apparent in the group of adults with dysarthria, while also one individual with anarthria showed significant word-length effects.

The results of previous studies make it clear that articulatory coding is not essential for subvocal rehearsal (Bishop & Robson, 1989; Vallar & Cappa, 1987). Therefore, researchers have suggested that processes such as rehearsal involve a more abstract central phonological code (Bishop, 1985; Bishop, 1988; Bishop & Robson, 1989). Regarding the role of speech rate in verbal WM, Raine, Hulme, Chadderton, and Bailey (1991) investigated the verbal STM spans of speech-disordered children and suggested that speech rate may be a causal determinant of verbal STM capacity. The faster the children could articulate, the more words could be rehearsed and the less will be faced in the phonological loop.

Conclusively, the role of diverse precursors in the verbal WM capacity of children is far from conclusive from previous studies. Bearing in mind the often interrelated additional impairments of children with CP, it is necessary to study all the precursors simultaneously in one-design. The present study is a nationwide study of the verbal STM skills of children with CP in Grade 1. In the present study, an attempt has been made to overcome previous limitations by investigating the verbal WM skills and its precursors such as intelligence, speech, auditory perception, and phonological awareness by a large group of children with CP with varying intellectual and speech abilities. The main research question of this study was: To what extent can the variation in verbal WM in Grade 1 be explained from its precursors?

It is expected that, first of all, intelligence will play an important role in the memory spans of children with CP as working memory is a cognitive process. Taken into account the role of IQ for the capacity of the verbal memory spans, it is expected that other precursors would still be related to verbal WM. First of all, speech abilities will play a major role in the verbal WM spans of these children when controlling for intellectual skills. In addition, a major role is ascribed to auditory perception in the process of remembering words.

2. Method

All 32 schools for children with physical and multiple disabilities in the Netherlands were asked to participate and obtain written consent from the parents of children with CP who fit the following inclusion criteria: Dutch had to be their native language, the intellectual level must range from a mild intellectual disability to average intelligence or above, hearing and vision must be within the normal range, with the ability to respond intentionally, either through speaking or by means of alternative
communication (e.g., looking, pointing or gesturing), and they must be 5-years-old at the beginning of the longitudinal study. Although the present study is conducted in Grade 1, the children of the present study were all participating in a larger longitudinal study to the emergent literacy development of children with cerebral palsy (cf. Peeters, Verhoeven, de Moor, & van Balkom, 2009). Fifty-two children with CP participated in the present study; 33 boys (63.5%) and 19 (36.5%) girls. Fifty children (96.1%) had spastic CP and 2 children had ataxia (3.8%). Of the children with spastic CP, 13 children (26.0%) had quadriplegia, 22 children (44%) had diplegia, 8 children (16%) had hemiplegia, 5 children (10%) had a combination of spastic-ataxic CP, 1 child (2%) had spastic-hypotonia CP, and 1 child (2%) had spastic-dyskinetic CP. Nine of the 52 children (17.3%) had seizures. The speech-language therapists of the children reported that 24 children (46.2%) had no speech difficulties, 10 children (19.2%) had mild dysarthria, 6 children (11.5%) had moderate dysarthria, 9 children (17.3%) had severe dysarthria and were unable to speak, 1 child (1.9%) had moderate dyspraxia, and 2 children (3.8%) had a combination of severe dysarthria and dyspraxia. The speech-language therapists of the children reported that 24 children (46.2%) had no speech difficulties, 10 children (19.2%) had mild dysarthria, 6 children (11.5%) had moderate dysarthria, 9 children (17.3%) had severe dysarthria and were unable to speak, 1 child (1.9%) had moderate dyspraxia, and 2 children (3.8%) had a combination of severe dysarthria and dyspraxia. The speech-language therapists of the children reported that 24 children (46.2%) had no speech difficulties, 10 children (19.2%) had mild dysarthria, 6 children (11.5%) had moderate dysarthria, 9 children (17.3%) had severe dysarthria and were unable to speak, 1 child (1.9%) had moderate dyspraxia, and 2 children (3.8%) had a combination of severe dysarthria and dyspraxia. The average age of the children in Grade 1 was 84 months ($SD$ = 6.1). Twelve children (23.1%) use some sort of Augmentative and Alternative Communication (AAC) to communicate. All children with CP attended special schools for children with physical and multiple disabilities across the Netherlands. The average score of the fine motor function as measured by the Dutch version of the Manual Ability Classification System (Eliasson et al., 2006), which ranges from one (low impairment) to five (high impairment), was 2.52 ($SD$ = .94). The average gross motor skills as measured by the Dutch version of the Gross Motor Function Classification System (Palisano et al., 2000), which also ranges from one to five, was 2.71 ($SD$ = 1.26). All parents of the children in the present study had given written consent for their children to participate.

2.1. Materials

2.1.1. Speech intelligibility

In order to assess children’s articulation quality or speech intelligibility, the standardized Word Articulation task of the SLI Screening test was administrated (Verhoeven, 2006). In the Word Articulation task the child was asked to repeat real words. Words were presented one-by-one by a computer with recorded voice, whereby the task started with words containing only one syllable and increased to words containing up to five syllables. When a child made five successive errors, the task was ended. Eighty-four percent of the children with CP were able to do this task since they had some level of understandable speech; the other children who were given a score of zero. The maximum score was 40. The test manual reported a good internal consistency with a Cronbach’s alpha of .94.

2.1.2. Speech rate

To measure the speed of articulation, a task was constructed in which children had to pronounce a given word within a given time frame. The children saw a picture of a familiar word that consisted of three syllables and they had to pronounce that word as frequently as possible within 10 s, after the test leader said ‘start’ and pushed the stopwatch. During those 10 s the children could look at the picture, in order to relive their memory as much as possible. All words consisted of three syllables. The practice item was a picture of a telephone [te-le-foon]. The test items were pictures of peanut butter [pin-da-kaas], sugar bowl [sui-ker-pot], and farm [boer-de-rij]. The amount of fully pronounced words of the three items was counted up to create a total score. The internal consistency of this task was very high with a Cronbach’s alpha of .96.

2.1.3. Auditory perception

To assess auditory perception abilities, the Auditory Discrimination Task of the standardized Dutch Language Proficiency Test was administrated (Verhoeven & Vermeer, 2001). In this task, the child was presented with minimally differing word pairs and had to indicate whether the words in a pair sounded alike. Response adaptations for children with speech difficulties consisted of nodding or pointing to left or right to indicate if the words sounded the same or different. All items were tested and the maximum score was 50. The task was highly reliable with a Cronbach’s alpha of .97 (Verhoeven & Vermeer, 1999).

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2.1.4. Phonological awareness

To test phonological awareness skills, the first-phoneme recognition task was used (de Jong, van Otterloo, & Regtvoort, 2006). This task consists of 10 items with CVC words. Each item consists of five pictures, one stimulus picture and four response pictures. During the exercise items, the test assistant pointed at the stimulus picture and named that picture (e.g., roof). Subsequently, the test assistant explained that the stimulus word could be split up in two parts, the first-phoneme of that word versus the rest of the word (e.g., rrrrr-oof). The test assistant subsequently named all four response pictures with explicitly emphasis on the first-phoneme of the words. The child had to point at one of the four response pictures that started with the same first-phoneme as the stimulus word (i.e., r). During the test items, the test assistant named the stimulus picture and the response pictures without explicitly emphasizing the first-phoneme of the word. The internal consistency of this task in this study was good with a Cronbach’s alpha of .83.

2.1.5. Intelligence

Nonverbal reasoning was measured with the Raven Coloured Progressive Matrices (Raven, 1956). This task was used as it correlated highly with general intelligence (Duncan et al., 2000). The task measures nonverbal reasoning with a minimal interference of language and is a commonly used instrument to assess intelligence, or general reasoning ability, in the nonspeaking population (Pueyo, Junqué, Vendrell, Narberhaus, & Segarra, 2008). Children were asked to point, aided or unaided, to one of the six pictures that completed the presented figure. The task consisted of 36 items. Raw score were converted to standard scores ranging from .5 to 9.5 using Dutch norms (van Bon, 1986).

2.1.6. Verbal working memory (WM)

To be able to assess the verbal WM abilities of both speaking and nonspeaking children, a forced-choice recognition task was developed based on a serial-recognition experiment of Gathercole, Pickering, Hall, and Peaker (2001) that did not require physical or speech production abilities. In the newly constructed task, the child heard a string of words and after 2s the child heard another string of words (e.g., [boat], [knife], [cap], versus [boat], [window], [cap]). The child had to decide whether the two successive strings of words were identical or not. The task consisted of strings of words that increased in length, starting with a length of one word and increasing to a length of eight words. For this task, a set of 10 highly frequent monosyllabic consonant–vowel–consonant (CVC) words were used which occurred in a list of words used in the context of kindergarten education (Schaerlaekens et al., 1999) and differed phonologically and semantically as much as possible from each other. There were a total 48 items; 6 items of each string length. If the child had only three or less items of a string length correct, the task was ended. The internal consistency of this task in this study was very high with a Cronbach’s alpha of .95.

2.2. Procedure

All tasks were administrated at the end of Grade 1. All children were individually tested in a quiet room in their schools by a trained test assistant; an assistant teacher was present as well. Prior to each task, there was a training phase, to make sure the children understood the test. The test order was the same for all children and the tests were divided over two or three sessions. Response adaptations for children with speech difficulties were nodding or pointing, aided or unaided. This study was proposed to the Dutch Association of Rehabilitation Physicians [Vereniging van Revalidatieartsen] and the Dutch Association of Schools for Children with Physical Disabilities [Vereniging van Mytyl- en Tyltylscholen] who gave their full official cooperation. This study did not need permission of the medical ethical committee because only behavioral data and existing medical information was collected.

2.3. Statistical methods

Statistical analyses were performed to provide answers to the research questions. First, descriptive statistics (means, standard deviations, skewness, kurtosis, minimal and maximal value) were computed for intelligence, speech intelligibility, speech rate, auditory perception, phonological
awareness, and verbal WM. To examine the variation in verbal WM and to inspect the data for possible
co-linearity, Pearson correlations were computed between all measures. Subsequently, a Multiple
Regression Analysis was conducted by means by using AMOS 5 for Structural Equation Modeling
(SEM) (Raykov & Marcoulides, 2006). SEM not only affords to account for measurement errors while
examining the influence of the predictor variables on verbal WM (Baron & Kenny, 1986; Wagner,
Torgesen, & Rashotte, 1994) but also to look at the independent contribution made by each predictor,
and the interrelationships among the predictor variables (Arbuckle & Wothke, 1999). The Goodness of
Fit of the estimated model was assessed by seven fit indices: $\chi^2$, with degrees of freedom and $p$-value,
Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Normed Fit Index (NFI),
Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and Standardized
Root Mean square Residual (SRMR). A model fits well if the ratio of the Chi-square value to the degrees
of freedom is smaller than two (Ullman, 2001), GFI, NFI, and CFI are between .90 and 1.00, and close to
1.00 (Bentler, 1990; Hu & Bentler, 1999; Jaccard & Wan, 1996), and AGFI is greater than .85 (Kline,
1998). In addition, Hu and Bentler (1999) advised a cutoff value of .06 for RMSEA and .08 for SRMR.

3. Results

3.1. Descriptive statistics of verbal WM and its predictor variables

Table 1 shows the descriptive statistics of verbal WM and its predictor variables. As can be seen, the
skewness and kurtosis values show a good normal distribution of each variable.

Table 2 shows the correlations between all variables. As is shown in Table 2, verbal WM and its
predictor variables are highly significant correlated. Table 2 shows that all predictor variables were
significant correlated with verbal WM and therefore should all be included into the Multiple
Regression Analysis to uncover what predictor variable or variables could best predict verbal WM
skills in Grade 1. However, the predictor variables show also highly significant intercorrelations.
Pearson correlation shows that speech intelligibility and speech rate were highly correlated ($r = .86,
p < .001$). As these two variables are highly correlated and tap into the same pool of variance, putting
these variables together in a regression analysis results in an unstable regression model (see for details
Belsey, Kuh, & Welsch, 1980). Therefore, it was decided not to enter these variables separately into the
model to predict verbal WM but to examine if these variables could be entered into the model by
means of a latent factor called speech.

Table 1

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<th></th>
<th>M</th>
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<td>Speech rate</td>
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<td>-.26</td>
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<td>50</td>
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<td>10</td>
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Table 2

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<td>.73</td>
<td>.63</td>
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</table>

* $p < .05$.  
** $p < .01$.  
*** $p < .001$.  

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3.2. Regression analysis

In order to predict verbal WM skills by its predictor variables, a SEM analysis was conducted with one latent variable, the factor called speech consisting of speech rate and speech intelligibility, and three observed predictor variables, i.e., intelligence, auditory perception, and phonological awareness. The correlations between the variables are presented in Appendix A. First of all, the latent variable speech turned out to be a good factor of speech intelligibility and speech rate as it explained 91.8% of the variation in speech rate and 81.0% of the variation in speech intelligibility. The beta coefficients were .90 (p < .001) for speech intelligibility and .96 (p < .001) for speech rate.

The results show that the SEM model has a good fit, $\chi^2(3) = .603$, $p = .896$, GFI = 1.00, AGFI = .97, NFI = 1.00, CFI = 1.00, RMSEA = .00, and SRMR = .01, indicating that the data fits very well with the tested model. Fig. 1 shows the model. As can be seen in Fig. 1, three out of four predictor variables turned out to be significantly related to verbal WM when taken into account the other predictor variables, indicating that these variables were all explaining unique variance in verbal WM skills. The best predictor of verbal WM turned out to be auditory perception ($\beta = .43$, $p < .001$), followed by the latent factor speech ($\beta = .29$, $p < .05$), intelligence ($\beta = .21$, $p < .05$), and finally, phonological awareness ($\beta = .12$, $p > .05$). In this model, 68.2% of the variance in verbal WM is explained by its predictor variables.

4. Discussion and conclusions

From the present study several conclusions can be drawn. First of all, correlation analyses have indicated a highly significant correlation between speech intelligibility and speech rate. Considering the fact that a lot of children with cerebral palsy have dysarthrias coming from neurologic impairment, it is no surprise that speech intelligibility and speech rate are strongly related as the speech impairments of these children have a physical or motor origin. When children have problems with the oral motor coordination to produce speech this will negatively affect their speech intelligibility as well as the speed at which they are able to articulate.

Regarding the prediction of verbal WM, auditory perception turned out to be the best predictor when taken into account other predictor variables. The fact that besides intelligence, auditory perception still predicts performance of the verbal WM capacity indicates that the ability to process incoming auditory speech signals and having access to the phonological representations of the words in long-term memory is highly predictive of the verbal WM span. The better children with CP are in processing these incoming speech signals and match them with existing phonological representations in the brain, the better these signals will be rehearsed and ultimately remembered. These results are in accordance with previous studies of Brady et al. (1983) and Rapala and Brady (1990) conducted with normally developing children.
The fact that the latent factor speech turned out to be a predictor of verbal WM, indicates that speaking is not an all-or-nothing phenomenon as previous research has suggested. For example, previous experimental studies indicate that the ability to speak and articulatory coding is not necessary for subvocal rehearsal. The fact that there is a linear relationship between speaking and verbal WM skills indicates that the better the speech abilities are of the children with CP, the better they are in remembering words. Tentatively, it can be concluded that the ability to speak facilitates children’s ability to remember words.

Of course some limitations apply to the present study. One limitation deals with the nature of the verbal WM task. As a lot of children with CP were having speech impairments, it was not possible to develop a task that requires a verbal response as most verbal WM tasks do. Therefore, we decided to construct a forced-choice task where the child had to indicate, by means of looking, talking or pointing, if two strings of words were identical or not. This made the task a bit different from the well known digit span tasks. Besides, the child had to do more than just remembering the strings of words as he or she had to compare the strings in order to decide if they were identical or not. Another possibility could have been to construct a task in which children had to point to the pictures they just heard, but taken into account the physical impairments of these children, using this task had more to do with motor speed than verbal memory.

The results of the present study have clinical implications. To begin with, the fact that auditory perception is strongly related to verbal WM capacity indicates that children with low levels of auditory perception skills are at risk for memory problems. Therefore, early intervention is needed in order to prevent memory difficulties and ultimately reading impairments. A possibility of stimulating the auditory perception skills of children is using education software such as LinguaBytes in which auditory discrimination skills are trained (Hengeveld et al., 2008; Voort et al., 2008). Another way of improving auditory perception skills is slowing down or stretching the entire speech signal of words (Segers & Verhoeven, 2005) a method used in the remediation program called Fast ForWord (Tallal et al., 1996). An intervention based on this principle could improve the auditory perception skills of these children.

The fact that speech abilities are strongly predictive of verbal memory skills shows that it is necessary for children with speech impairments to improve their speech abilities in order to prevent them for memory problems and ultimately reading difficulties. One way of improving the speech abilities for nonspeaking children is by providing them with AAC devices with a speech-output component (cf. Millar, Light, & Schlosser, 2006). Speech-language therapists as well as parents play an important role in improving the speech abilities of these children. Although their physical impairments limit them for being able to speak, the more frequently they hear the sounds the better they will be able to use these sounds in speech output or subvocal rehearsal.

Acknowledgements

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Appendix A

Input correlation matrix for Structural Equation Modeling analyses.

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<tbody>
<tr>
<td>1</td>
<td>Phonological awareness</td>
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<tr>
<td>2</td>
<td>Auditory perception</td>
<td>0.57</td>
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<tr>
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<td>Intelligence</td>
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<td>1.00</td>
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<td></td>
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</tr>
<tr>
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<td>5</td>
<td>Verbal WM</td>
<td>0.63</td>
<td>0.73</td>
<td>0.48</td>
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<tr>
<td>6</td>
<td>Speech rate</td>
<td>0.65</td>
<td>0.50</td>
<td>0.23</td>
<td>0.96</td>
<td>0.63</td>
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<td>7</td>
<td>Speech intelligibility</td>
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<td>0.47</td>
<td>0.22</td>
<td>0.90</td>
<td>0.58</td>
<td>0.86</td>
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References


Verhoeven, L., & Vermeir, A. (2001). *Taaltoets Alle Kinderen (TAK) [Language Proficiency Test for All Children]*. Arnhem: CITO.

