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Verbal Working Memory Skills of Children Who Stutter: A Preliminary Investigation

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Working memory comprises the system of human memory that is dedicated to both temporary storage of phonological detail and allocation of cognitive resources necessary for forming lasting memories (Baddeley, 2000; Cowan, 1997; Sternberg, 2003). It is believed that this combination of storage and processing is crucial for language comprehension. Cognitive-linguistic abilities that are particularly reliant on the support of verbal working memory include sentence comprehension, problem solving, mental arithmetic, reading, and word learning (Engle, 2002; Gathercole & Baddeley, 1993; Logie, Gilhooly, & Wynn, 1994).

As theoretical foundations and empirical models of working memory have become more refined, their application to language disorders has become more commonplace. Working memory impairments have since been identified across a range of populations with communication disorders, including children with Down syndrome (Jarrold, Baddeley, & Hewes, 2000), specific language impairment (Montgomery, 1995), adults with aphasia (Caspari, Parkinson, LaPointe, & Katz, 1998; Martin & Saffran, 1990), and dementia (Reilly, Martin, & Grossman, 2004). However, children who stutter (CWS) represent a population whose working memory skills remain uninvestigated. Here we report a pilot study aimed at exploring this relationship. AQ1

ABSTRACT: In the field of speech-language pathology, recent attention has focused on the role of verbal working memory in language processing. The current study examined the verbal working memory skills of children who stutter (CWS) via a digit and letter span experiment. The CWS showed significantly reduced recall when compared to an age-matched group of children who do not stutter (CWDS). This effect was apparent across both written and oral response modalities. Implications for the relationship between verbal working memory, phonological development, and stuttering are discussed. Furthermore, we call for more extensive investigation of these associated phenomena among CWS.

KEY WORDS: stuttering, working memory, rehearsal, fluency, memory

Working memory theorists have argued that individual differences in the span of immediate memory are predicted by a small number of factors. Strong correlational evidence supports a linear relationship between speech rate, processing speed, and word list recall (Baddeley, Thomson, & Buchanan, 1975; Case, Kurland, & Goldberg, 1982; Kail & Park, 1990). The following equation illustrates this relationship, where S is the maximum number of words an individual can immediately recall, r is the individual's speech rate, and τ is the individual's maximum capacity of phonological storage (Baddeley, 2000; Baddeley, Lewis, & Vellar, 1984; Burgess & Hitch, 1992; Mueller, Seymour, & Kieras, 2003).

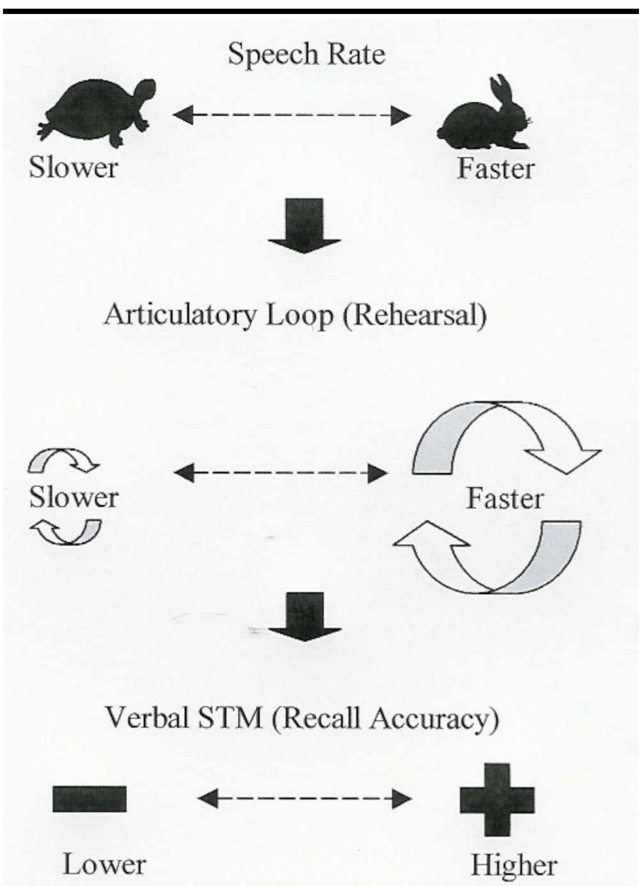
$$S = r + \tau$$

1092-5171/05/3201-0038

A research paradigm has subsequently emerged that suggests that a faster overt speech rate results in more rapid covert rehearsal and that more rapid rehearsal translates to an increased memory span (Hulme, Thomson, Muir, & Lawrence, 1984). If this paradigm holds true, a person with a slower overt speech rate should perform poorly on memory tasks that require verbal rehearsal (see Figure 1). Caplan, Rochon, and Waters (1992) tested this hypothesis in patients with apraxia of speech (AOS), demonstrating that people with AOS did, indeed, experience reduced recall. The authors attributed this deficit to the effect of impaired motor planning on articulatory rehearsal.

In similar studies, Bosshardt (1990, 1993) questioned whether the reduced speech rate of adults who stutter (AWS) was associated with inefficient articulatory rehearsal. Bosshardt examined German AWS, citing a theoretical basis that was consistent with the prevailing speech rate and working memory paradigm. Bosshardt noted that the overt speech rate of people who stutter is, by definition, slowed, and that slowed speech rate may translate to poor performance on memory span tasks. Bosshardt showed that AWS did indeed exhibit inferior short-term recall of consonant–vowel–consonant (CVC) syllables. However, the primary measure of recall was *not* significantly correlated with speech rate. Bosshardt interpreted this finding such that an interaction was likely responsible for differences in recall between AWS and fluent adults. This interaction included factors such as slow phonological encoding, slow rehearsal time, and a deficit in elaborative memory processes of AWS. Bosshardt suggested that people who are fluent encode verbal detail using more visual imagery, more associations, and more language mediators (Bosshardt, 1993). A consequence of this deeper, more elaborative level of encoding in fluent adults is a richer conceptual representation of words that ultimately facilitates recall.

Figure 1. Speech rate, articulatory rehearsal, and the verbal working memory relationship.



Changes in memory span during development are associated with increased speed of articulation (Baddeley, 2000). As children mature, they produce sounds faster and more accurately. The speech rate and working memory paradigm predicts that as the speed of articulation increases, so too does memory span (Hulme et al., 1984; Siegler, 1998). Although research has shown that AWS show reduced speech rate, there is little evidence to support the same claim among CWS (Kelly & Conture, 1991; Yaruss, 1997; Yaruss & Conture, 1995). Therefore, if CWS do show reduced working memory skills, speech rate alone may not provide a comprehensive explanation of the difference.

The current study represents an initial exploration of working memory skills of CWS. We questioned whether CWS and children who do not stutter (CWDS) would show group differences on a digit and letter span task. This preliminary question may aid in directing further research initiatives on the relationship between verbal fluency, speech rate, and working memory.

METHOD

Participants

Participants included 5 CWS (mean age = 7;9 [years;months]) and 5 age-matched CWDS (mean age = 8;5). The group of CWS included 5 males, and the group of CWDS included 4 males and 1 female. CWS were recruited from stuttering support groups in Pennsylvania and a private clinic on Long Island, New York. All CWS demonstrated at least moderate or greater stuttering severity as assessed by the Stuttering Severity Instrument—3 (Riley, 1994). Participants were monolingual English speakers with no documented history of hearing loss or language impairment.

Materials

Final Cut Pro-3® (http://www.apple.com/finalcutpro/) presentation software was used to record auditory stimuli. Sound clips were converted to .wav format for use in a standard Windows operating system. Twenty separate audio clips were created as test stimuli, with three audio files recorded as a familiarization sequence. All children were tested using the same laptop computer equipped with a Microsoft Powerpoint 2000 presentation that advanced stimulus and cue slides at preset intervals. Two versions of the same program were created with alterations in response order (written or oral response) but no difference in the audio stimuli. An adult, male speaker recorded the stimuli.

Test Procedure

Participants were tested in their own homes in a private setting (e.g., home office). Two CWS were tested in a private clinic after closing hours in a quiet room. Participants were seated at a laptop computer; after completing a familiarization sequence and consent, parents were asked to wait outside the testing room for the duration of the session.

Participants were instructed to follow the directions announced by the computer program, which explained that the child was going to play a memory game where it was important to remember as many numbers and letters as he or she could. Participants then heard a familiarization sequence consisting of three randomly mixed digits and letters (e.g., 7…X…1). After a 20-s delay, a cartoon cue slide (i.e., a roaring lion) appeared on the computer monitor requesting that the child repeat the numbers and letters he or she had just heard. The next familiarization sequence contained four mixed digits and letters followed by another familiarization sequence of five randomly mixed digits and letters. The identical cue slide prompted the child to recall each digit and number sequence. If a child was unable to accurately recall the familiarization sequence, that child was permitted to replay the stimulus until correct recall was achieved. Formal testing was initiated upon successful completion of the familiarization sequence.

Stimuli included 20 trials of seven randomly mixed digits and letters (e.g., 7…X…G…3…4…A…8). The computer program presented each digit and letter sequence twice and automatically advanced after a 20-s delay to the cue slide used in the familiarization sequence (i.e., lion). The cue slide prompted the child to either write or announce his or her response. Participants were cued for written responses for blocks of five slides followed by oral responses for the next block of five slides. Participants were instructed to write their responses for half of the items and repeat their responses for the other half. This measure was included to assess whether response modality (i.e., oral or written) influenced recall accuracy.

The adult examiner recorded the child's oral responses, and the child recorded his or her written responses on a form provided by the examiner. Test duration ranged from 25 to 35 min. Testing was terminated if a child failed to recall *any* digits or letters upon two successive trials. Responses were converted to proportion correct for statistical analyses.

RESULTS AND DISCUSSION

CWDS showed significantly higher recall than CWS, $F(1, 8) = 12.44$, $p = .01$. These differences were apparent across both oral and written recall modalities: Oral $F(1, 8) = 35.64$, $p = <.01$; Written $F(1, 8) = 31.81$, $p = .01$. Interestingly, within the sample of CWS, similar recall accuracy was observed regardless of whether the children wrote or announced their responses, $t(8) = 1.88$, $p = .09$. These results suggest that response modality alone cannot be responsible for the reduced memory capacity observed in the CWS. Table 1 reflects individual recall performance, and Figure 2 reflects group differences.

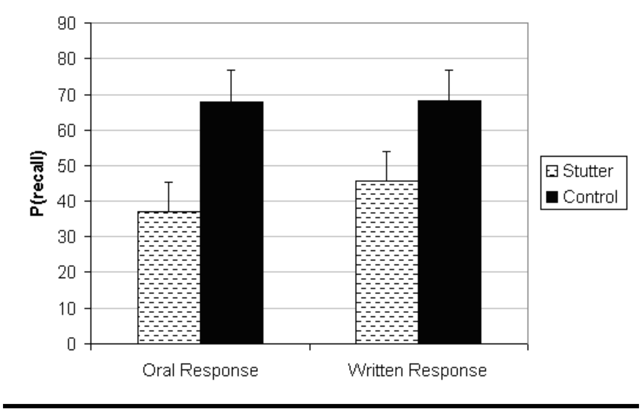
If the speech rate and working memory paradigm holds true, discrepancies in recall that are observed between CWS and CWDS may result from the reduced speech rate of CWS. However, this account relies on two fundamental assumptions: (a) CWS exhibit a slower overt speech rate than CWDS; and (b) slower *overt* speech is indicative of slower *covert* rehearsal. There are fundamental problems with both assumptions; however, the assumption of slowed speech rate among CWS is perhaps most problematic. Researchers have reported inconsistent differences between the speech rates of CWS and those of CWDS. Furthermore, many studies have found no significant differences at all between the speech rates of these groups (Kelly & Conture,

Table 1. Participants' stuttering severity, age, and recall accuracy by response modality.

	Stuttering severity	*Age*	*Response modality* *Oral*	*Written*
CWS_1	Severe	87	51.40%	48.57%
CWS_2	Moderate	84	47.61%	25.71%
CWS_3	Severe	107	37.14%	77.12%
CWS_4	Severe	98	20.00%	17.14%
CWS_5	Moderate	95	28.57%	31.42%
$CWDS_1$		128	74.28%	81.42%
$CWDS_2$		99	64.29%	58.57%
$CWDS_3$		95	67.86%	76.78%
$CWDS_4$		84	62.50%	42.86%
$CWDS_5$		99	71.42%	82.14%

Note. CWDS = child who does not stutter; age is in months.

Figure 2. Recall accuracy by response modality.



1991; Yaruss, 1997; Yaruss & Conture, 1995).

An alternative hypothesis to impaired rehearsal is that verbal working memory is impacted by phonological processing difficulties among CWS. An estimated 33% to 45% of CWS exhibit concomitant phonological disorders (Arndt & Healey, 2001). It has also been demonstrated that CWS experience a rapid catch-up of phonological abilities during early adolescence (Paden, Yairi, & Ambrose, 1999). The effects of phonological processing delays on working memory may arise during phonological encoding or at an earlier stage of word processing, as has been suggested of children with specific language impairment (Gillam, Cowan, & Marler, 1998; Montgomery, 1995; Weismer, 1996). Similar to the findings of Bosshardt (1990, 1993), the reduced recall abilities of CWS may be related to an interaction of factors including phonological encoding, rehearsal time, and the development of more elaborate memory strategies. Further research is necessary to better understand whether a relationship exists between these factors.

Methodological issues such as sample size and task diversity do not permit generalizations of the current findings. However, these preliminary results warrant further investigation. Such analyses are likely to be informative on both practical and theoretical grounds by elucidating relationships between rehearsal, verbal fluency, and working memory.

ACKNOWLEDGMENT

We acknowledge the contributions of Lee Caggiano, Shamus McDermott, Nora Newcombe, and Lila Chrysikou.

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