Research Article

The Influence of Executive Functions on Phonemic Processing in Children Who Do and Do Not Stutter

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Purpose: The aim of the present study was to investigate dual-task performance in children who stutter (CWS) and those who do not to investigate if the groups differed in the ability to attend and allocate cognitive resources effectively during task performance.

Method: Participants were 24 children (12 CWS) in both groups matched for age and sex. For the primary task, participants performed a phoneme monitoring in a picture-written word interference task. For the secondary task, participants made pitch judgments on tones presented at varying (short, long) stimulus onset asynchrony (SOA) from the onset of the picture.

Results: The CWS were comparable to the children who do not stutter in performing the monitoring task although the SOA-based performance differences in this task were more variable in the CWS. The CWS were also significantly slower in making tone decisions at the short SOA and showed a trend for making more errors in this task.

Conclusions: The findings are interpreted to suggest higher dual-task cost effects in CWS. A potential explanation for this finding requiring further testing and confirmation is that the CWS show reduced efficiency in attending to the tone stimuli while simultaneously prioritizing attention to the phoneme-monitoring task.

Speech production requires the concerted coordination of processes at the multiple levels of language and speech motor planning and execution. The multifactorial model (Smith, 1999) described stuttering as an external speech motor event that happens due to nonlinear interactions on the basis of moment-to-moment variations in underlying factors, including neurophysiological, constitutional, motoric, linguistic, environmental, and cognitive. The role of cognitive or executive functions, such as attention and working memory processes, in stuttering causation has been the focus of several investigations since the 1980s. Webster (1990) suggested that stuttering is the result of a general deficit in motor and cognitive organization. Walden et al. (2012) postulated that high linguistic and cognitive demands influence stuttering causation and maintenance. Although there is indirect support for the argument that cognitive variables interact with language planning and processes (e.g., Anderson & Wagovich, 2010),

experimental data to support this claim are limited, particularly in children who stutter (CWS). The aim of this study was to investigate the effects of performing a dual task on response speed and accuracy of both tasks in a homogeneous group of CWS compared with age-matched children who do not stutter (CNS). Dual-task studies offer the opportunity to investigate the ability to manage cognitive resources effectively, resulting in individual task performances and dual-task cost effects appropriate for age.

Dual-Task Performance: Theoretical Considerations

Dual-task interference occurs when two tasks (Tasks 1 and 2) requiring independent responses are performed simultaneously such that speed and accuracy of one or both tasks are affected relative to task performance in isolation (Ferreira & Pashler, 2002). In a typical dual-task paradigm, the onset of Task 2 (secondary task) follows the onset of Task 1 (primary task) by a fixed interval called stimulus onset asynchrony (SOA). The psychological refractory period (PRP; Telford, 1931) is the varying effect of SOAs on the response latencies of the two tasks and is described further here within. According to the central capacity sharing account (e.g., Kahneman, 1973), limitations in cognitive resources due to a central processing bottleneck created by the response selection processes associated with both the

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primary and secondary tasks result in the PRP effect. Because the primary task is attended to first, the effects of SOA on the primary task are hypothesized to be limited. In contrast, the secondary task is influenced by the SOA manipulation to a greater extent. At longer SOAs, central bottleneck processing of the primary task is completed well before the time the stimulus for the secondary task is presented, and therefore, processing of the secondary task does not get postponed. The ability to flexibly allocate sufficient attention to the introduction of a secondary task at the short and the long SOAs and to update this information in working memory until processing of the primary task is completed is a crucial factor in determining successful performance in both the primary and secondary tasks.

Baddeley's (1996) model of working memory serves as a theoretical framework for dual-task studies. This model has several components, including the central executive system and two subsystems, namely the phonological loop and the visuospatial sketchpad. Of these, the central executive system is domain-general, applicable to all of the subsystems, and is thought to be actively involved in updating relevant information in working memory during task performance (Kane & Engle, 2003). Tasks involving speech and language processes use the phonological loop to hold and manipulate the stimuli and to perform articulatory rehearsal. In addition, contemporary models of working memory (e.g., Miyake et al., 2000) attribute critical roles to cognitive processes, including attention shifting, inhibition, and working memory update, in language processing and speech production. All of these processes are referred by the term *executive control processes*, or skills that enable a person to select and provide appropriate responses to a task, and are the focus of the current investigation.

Dual-Task Performance in Persons Who Stutter

Although there are several studies that have investigated dual-task effects, in this section we review studies that have contributed to the understanding of cognitive skills in persons who stutter. A summary review showed that early dual-task studies involved minimally one motor task and investigated hemispheric laterality differences. Webster (1986) reported larger dual-task interference effects in bimanual finger-tapping and finger-sequencing tasks in adults who stutter (AWS) and suggested that the findings may be reflective of greater susceptibility of the motor system in AWS to ongoing activities due to poor attention regulation. Since then, the focus of dual-task studies has shifted to include both language and speech motor tasks. The central premise of such studies has been that persons who stutter are susceptible to ongoing activity at the different levels of speech and language planning and production, partly due to the less encapsulated planning and production systems that share a finite set of attentional and other cognitive resources.

Appendix A summarizes the dual-task studies that, in a similar manner to the current study, have used language tasks as primary or secondary tasks or have discussed implications of the findings to cognitive processes. Arends, Povel,

and Kolk (1988) tested the association between speech motor and attentional processes in a dual-task study involving a speech and a visual tracking task. They tested if performing the dual task distracted the AWS from stuttering, thereby shifting them from a highly controlled speech strategy to automated speech production, or if it resulted in overreliance on attentional resources and therefore more stuttering. Their findings largely supported the overreliance hypothesis; although prior to introducing the dual task the AWS did show a reduction, there was a significant increase in disfluencies during dual-task performance.

In a series of studies, Bosshardt and colleagues (Bosshardt, 1999, 2002; Bosshardt, Ballmer, & De Nil, 2002; Bosshardt & Franssen, 1996; Metten et al., 2011) tested the hypothesis that the language and speech production systems in AWS draw on similar cognitive processing systems. They reported significant dual-task interference effects in four of the five studies. Bosshardt (1999) reported higher variability in AWS in a word repetition–mental calculation dual task; Bosshardt (2002) reported significant dual-task interference effects in AWS compared with those who do not stutter (ANS) when performing word repetition concurrently with reading and memorization. Bosshardt argued that when performed concurrently, the linguistic, particularly the phonological, and articulatory subsystems in AWS are more vulnerable to attention-demanding processes. Extending this work further, Bosshardt et al. (2002) tested dual-task interference effects in sentence generation and production, processes that are less controlled or automated than word repetition and therefore likely to exhibit larger interference effects. They reported reduced propositional units and a trade-off with fluency in a sentence-generation task in AWS in the single- and dual-task conditions when performed concurrently with a semantic/phonemic category decision task. The ANS showed a clear distinction between the single- and the dual-task conditions. In a functional imaging study, De Nil and Bosshardt (cited in Bosshardt, 2006, p. 379) reported overactivation of the speech motor centers in AWS during both the planning and production stages of a dual task involving sentence generation and delayed production. They attributed the shared neural resources for planning and production and the less modular linguistic and articulatory subsystems to the greater sensitivity of AWS to dual-task interference effects.

More recent behavioral studies have tested further dual-task interference effects using task combinations that involve similar language processes and working memory subsystems. Jones, Fox, and Jacewicz (2012) tested AWS and matched ANS in a dual-task combination of rhyme judgment and letter recall and did not find group differences in dual-task interference effects. Tsai and Bernstein Ratner (2016) tested AWS and ANS in a picture–written word interference (PWI) task while performing a tone-decision task. The authors varied the task order and the SOA such that participants performed a dual task with either the picture-naming or the tone-decision task as the first task at the short or the long SOA. The AWS were highly variable in performing this task combination. Although Tsai and

Bernstein Ratner reported nonsignificant effects, using a similar task combination, Maxfield et al. (2016) in an event-related potential study reported significant group differences in both accuracy and P3 values. The P3 was reduced or attenuated in the short SOA condition for the secondary tone task, thereby suggesting limited availability of attentional resources.

In summary, seven of the 13 dual-task studies included in the review reported significant results. Of these, one study reported on grade-school CWS, and all others reported dual-task performance in AWS. Although all of the studies reported behavioral data, two studies also provided neural correlates of dual-task performance. Although the nonsignificant dual-task interaction effects can be attributed to the lack of group differences in dual-task interference effects, they can also be attributed to the dual-task combination itself with tasks that are less automated (e.g., sentence generation) and involving similar processes showing larger dual-task effects. Last, two of the studies that reported nonsignificant findings reported more variable dual-task performance in the stuttering group.

Present Study: Rationale and Significance

The aim of the present study is to use phoneme monitoring in a dual task involving a PWI task performed at short or long SOA to investigate the interactions of cognitive- and phonemic-level processes at the word level in school-age CWS. The PWI task is a well-known task in the psycholinguistic literature that involves presenting an interfering word along with a picture to be named. Unlike priming, which facilitates responses at the phonemic level (prime and target word pairs that share phonemes enable faster lexical access), the written word in the PWI task interferes with responses on the basis of the extent of overlap between the picture-word pair. Tsai and Bernstein Ratner (2016) and Sasisekaran and Donohue (2016) reported phonemic inhibitory effects on picture naming and phoneme monitoring in a PWI task in both disfluent and fluent speakers, respectively. In the present study, the rationale for using phoneme monitoring, a task that lends itself well to a PWI task, are (a) task performance can be attributed to a certain theoretical stage of speech production (Levelt, 1989; Levelt, Roelofs, & Meyer, 1999), and (b) studies in the psycholinguistic literature (e.g., Wheeldon & Lahiri, 2002; Wheeldon & Levelt, 1995) have attributed the time course of task performance to processes at the output of the phonological encoding level of language planning. Therefore, performing phoneme monitoring minimally requires monitoring of a completed phonological speech plan.

The focus of the current study was to investigate dual-task cost effects in performing a task requiring implementation of phonemic processes. Several sources of evidence suggest that CWS experience difficulties in performing phonemic-level processes. First, epidemiological studies have reported higher incidence of phonological and articulation disorders in CWS (e.g., Arndt & Healey, 2001). Second, differences have been reported between CWS and CNS in

performing tasks, such as nonword repetition, phonological priming, and phoneme and rhyme monitoring/judgment (e.g., Berman Hakim & Bernstein Ratner, 2004; Byrd, Conture, & Ohde, 2007; Sasisekaran, Brady, & Stein, 2013; Weber-Fox, Spencer, Spruill, & Smith, 2008); more recent studies have reported differences between children who persist or recover from stuttering in such tasks (Mohan & Weber-Fox, 2015). This evidence suggests that CWS exhibit weaker phonemic knowledge and/or difficulties implementing phonemic processes in speech production, and such processes may be prone to interference from other ongoing processes. Last, evidence from a subset of the dual-task studies summarized above suggest that AWS differ from ANS in allocating cognitive resources to dual tasks involving phonemic processes. Furthermore, indirect evidence suggests that CWS differ from CNS in cognitive abilities that are crucial for speech production and for dual tasking. Survey studies have reported that young CWS lag age-matched peers in cognitive skills, including attending to a task, inhibitory control, and flexibly shifting attention from one task to another (e.g., Anderson, Pellowski, Conture, & Kelly, 2003; Eggers, De Nil, & Van den Bergh, 2010, 2012; Karrass et al., 2006). Anderson and Wagovich (2010) reported higher correlation between attentional skills measured using parental survey responses and performance in nonword repetition in CWS.

On the basis of these findings, we hypothesized that performing phoneme monitoring in a dual task would have adverse effects on cognitive resource allocation in school-age CWS and, in particular, the ability to flexibly attend and perform both tasks equally well compared with CNS. Although dual-task performance has been investigated in AWS, such investigations are negligible in CWS, except for Brutten and Trotter (1986). Furthermore, very few experimental studies have investigated the ability to manage cognitive resources during speech and language planning and production in CWS although the findings from survey studies suggest that CWS differ from CNS in such abilities.

In the present study, two variables were used to create resource constraints in task performance. First, a hierarchy of processing complexity was created in the phoneme-monitoring task by varying the extent of overlap between the picture and the written distractor word such that these were the same (e.g., *cat-cat*; replica condition), related phonemically (shared onset consonant or consonant and vowel (e.g., *cat-cap*; related condition), or unrelated (e.g., *cat-book*; unrelated condition). On the basis of previous findings (Cook & Meyer, 2008; Mädebach, Jescheniak, Oppermann, & Schriefers, 2011) and because the participants were required to perform phoneme monitoring while silently naming pictures, we hypothesized that: (a) response times in the replica condition would be the fastest; (b) compared with the replica condition, the competing written word in the related condition would create a phonological interference effect despite the shared set of phonemes, thus requiring additional time and resources in finalizing the monitoring decision; and (c) interference in the related condition would make the monitoring responses in this

condition comparable in speed to the responses in the unrelated condition. This latter condition is the most complex as it requires participants to encode and monitor all of the phonemes individually. On the basis of the studies reviewed, we also hypothesized that CWS would show a larger phonological interference effect in the related condition evident as slower phoneme-monitoring responses and/or a speech–accuracy trade-off effect.

Second, a tone-decision task was introduced at short or long SOA from picture onset in the phoneme-monitoring task. We argue that auditory tasks rely on the same working memory substrate as other speech and language tasks, and therefore, performing the two tasks in a dual-task combination will likely constrain the domain-specific resources applicable to sharing the phonological loop space and the domain-general attention demands on the central processor. Furthermore, the tone task was selected to match the PWI task in complexity. If CWS have difficulties in flexibly attending to the tone stimuli when it is presented and in retaining this information in working memory while performing the phoneme-monitoring task, this would result in larger dual-task cost effects evidenced as either slower or more erroneous responses to the tone task at the short more than the long SOA. However, if group differences are evident in the phoneme and the tone tasks, then such effects may be relevant to task-specific processes, such as phonemic encoding and working memory limitations.

The study was designed to address the following research questions:

1. Do CWS differ from CNS in performing a phoneme-monitoring task as the primary task in a dual task? Do the groups differ in the three conditions varying in cognitive demands (unrelated, related, replica) of this task?
2. Do CWS differ from CNS in performing a tone-decision task as the secondary task in a dual task? Do the groups differ in the tone task at the short versus the long SOA?
3. Do CWS and CNS show a similar pattern of dual-task response to the primary and secondary tasks used in this study?

Method

Participants

A total of 32 participants, including 16 CWS and 16 age- and sex-matched CNS, in the age range of 7 to 16 years of age were tested. We tested school-age CWS because a permanent diagnosis of stuttering is acquired during this age, and the underlying mechanisms precipitating and maintaining stuttering should be consistently evident at this age. Data from three quarters of participants in the CNS group from this study are also presented in a larger study reporting on normative data for this dual-task combination in fluent children and adults (Sasisekaran & Donohue, 2016). All participants were native English speakers

recruited through school boards from Minneapolis and surrounding suburbs and the Julia M. Davis Speech-Language-Hearing Center at the Department of Speech-Language-Hearing Sciences, University of Minnesota. The protocol was approved by the Institutional Review Board, University of Minnesota. Parents completed a questionnaire to verify that their child had a negative history of neurological deficits; developmental delays; or language, speech, or hearing difficulties (other than stuttering in the CWS group). Parents also provided information about their child's current usage of medications likely to affect the outcome of the experiment (e.g., for attention-deficit/hyperactivity disorder [ADHD]) and reading level. Data from four participants in the CWS group were excluded due to the presence of other co-occurring conditions. Two participants were below grade level in reading and were enrolled in reading remediation as reported by parents; one participant was on ADHD medication, and one participant had both ADHD and reading difficulties. The remaining 12 participants in both groups were comparable in mean age (CWS, M age = 11;9 [years;months], SD = 3.1; CNS, M age = 11;9, SD = 2.9), $t(22) = 0.02$, $p = .98$.

All participants passed a binaural hearing screening comprising 20 dB HL pure tones presented at 500, 1000, 2000, 4000, and 8000 Hz. All participants in the CWS group had received a diagnosis of developmental stuttering from a school-based speech-language pathologist or a speech-language pathologist from the Julia Davis Center. In addition, stuttering severity ratings on a 7-point scale (1 = *mild*, 7 = *severe*) obtained from parents at the time of testing revealed that ratings were in the range of 1 to 4 (rating of 1–2, N = 6; rating of 2–3, N = 3; rating of 4, N = 3). All except one participant were attending treatment sessions at school, through private practice, or through the stuttering camp organized at the Julia Davis Center at the time of participation in the study.

Initial Assessments

Vocabulary, Memory, and Phoneme Awareness

Participants' expressive vocabulary skills were tested using the Expressive Vocabulary Test–Second Edition (Williams, 2007); short-term memory and working memory skills were tested using the forward and backward digit span subtests of the Wechsler Adult Intelligence Scale–Third Edition (Wechsler, 1997). Participants also completed the Lindamood Auditory Conceptualization Test–Third Edition (Lindamood & Lindamood, 2004), used to evaluate phoneme awareness skills, including segmentation and syllable counting. Independent t tests revealed the groups to be comparable in all three tests: Expressive Vocabulary Test–Second Edition, M (SD), CWS = 115.7 (15.2), CNS = 116 (12), $t(22) = -0.04$, $p = .48$; raw scores forward digit span, M (SD), CWS = 11.2 (2.5), CNS = 11.0 (2.9), $t(22) = 0.22$, $p = .41$; raw scores backward digit span, M (SD), CWS = 5.8 (1.9), CNS = 5.7 (2.1), $t(22) = 0.20$, $p = .42$; phoneme awareness converted scores, Lindamood Auditory

Conceptualization Test–Third Edition, $M(SD)$, CWS = 109.1 (9.4), CNS = 112.7 (15.5), $t(22) = -0.69$, $p = .24$.

Disfluency Assessment

Conversational samples were obtained from all participants. A trained research assistant transcribed each 5-min sample and coded them for typical (interjections, revisions, word and phrase repetitions, false starts) and atypical (sound, syllable repetitions, word repetitions, prolongations, and blocks) disfluencies. The percentage of total disfluencies was computed for all participants in both groups and correlated with performance in the dual tasks. Interrater agreement was obtained between the research assistant and the second author by verifying agreement on each of the disfluencies coded in three CWS (CWS 1, Rater 1 = 6.7%, Rater 2 = 7%; CWS 2, 11.9%, 12.58%; CWS 3 = 5.5%, 6.19%; Pearson $r = .99$).

Experimental Stimuli

Primary Task

A detailed description of the stimuli for the PWI task is presented in Appendix B. The stimuli included 32 monosyllabic and bisyllabic nouns from Cook and Meyer (2008). Black-and-white line drawings selected from Snodgrass and Vanderwart (1980) and Gilhooly and Logie (1980) were used to elicit picture-naming responses. Appendix B presents the values for image agreement, familiarity, age of acquisition, Brown's spoken word frequency, and Kucera–Francis written frequency for the pictures. For words that did not have corresponding pictures in Snodgrass and Vanderwart, we selected representative line drawings using the Google search engine. Identical to Cook and Meyer, the target words represented by the pictures were paired with competing written words to create the three types of written word–picture pairings, namely, unrelated, related, and replica.

Secondary Task

Using MATLAB, auditory tokens of the phonemes to be monitored in each trial of the PWI paradigm were appended to a low (0.18 KHz), medium (0.5 KHz), or high (8.0 KHz) pure tone. The appended pure tone (100 ms) was heard either at the short (100 ms) or the long (900 ms) SOA from the offset of the phoneme (note that the SOA values are based on Cook & Meyer, 2008, who used the PWI paradigm to investigate dual-task costs on language planning in adults). Four adult participants and one CWS, whose data were eventually included in the data set, were tested to determine data trends and to investigate if the SOA and trial durations were sufficient to perform the phoneme monitoring–tone decision dual task. SOA is defined as the time lapse between the onset of the phoneme and one of three tones to be monitored to provide a tone decision.

Experimental Tasks

Two trained research assistants administered the entire protocol requiring approximately 2.5 hr. There were

three experimental tasks: (a) picture familiarization, (b) a phoneme-monitoring dual task, and (c) a rhyme-monitoring dual task. The dual tasks and the block order within each task were counterbalanced across participants. The picture-familiarization task was presented prior to the dual task. The rhyme task and findings are not reported in this manuscript.

Picture Familiarization

Prior to the dual task, participants viewed target pictures individually on a computer screen and named them. Errors in picture naming were corrected at the end of the task. A majority of the participants had about five to six errors during the first naming attempt. Following a round of naming and error correction, participants were presented a second time with those pictures that they named incorrectly at first attempt. All participants were able to name all pictures correctly before proceeding to the phoneme–tone dual task.

Phoneme Monitoring–Tone Decision Dual Task

The purpose of this task was to investigate group differences in the ability to allocate cognitive resources while performing a dual task. The groups were compared in verbal response times and percentage of errors in the monitoring task while simultaneously providing button-press responses to pure tones presented at the short or the long SOA.

Task Design

Participants were seated comfortably in front of a computer screen. Prior to the experiment, participants were told that at the beginning of each trial they would hear and see a speech sound and a picture, respectively. They were also told that a written word would appear above each picture that may sometimes help with their responses. After the onset of each picture, either at 100 ms or 900 ms, a low-, medium-, or high-pitched tone was presented. Participants were asked to respond first to the phoneme-monitoring task with a verbal yes/no response and then to provide a button-press response indicating the pitch of the pure tone in the tone task. On the basis of recent work reporting normative data from children ($N = 20$) and adults ($N = 10$) in this dual-task combination (Sasisekaran & Donohue, 2016), we hypothesized that this approach would ensure a specific response pattern: (a) response times to the phoneme-monitoring task would be slower at the long SOA because presentation of the tone has a larger disruptive effect on the cognitively demanding final stages of the monitoring task, and (b) at the short SOA, response times to the tone task would be delayed because the monitoring task has to be completed first, and this would require delaying processing of the tone task until the cognitively demanding stages of the phoneme-monitoring task are performed.

Participants were specifically instructed to look at both the picture and the written word on the screen although just presenting the picture–word pair would have implicitly

created the same interference. Following instructions, all participants were familiarized with the three tones from the tone-decision task. Next, in a set of five to six trials, the tones were presented in random order, and participants had to press the correct button corresponding to the tone. This was to ensure that participants were able to perform the tone task. Then, a few practice trials were used to familiarize participants with the dual task. A trial in each block consisted of the following series of events: (a) an orienting screen for 500 ms and (b) auditory presentation of a pre-recorded target phoneme coinciding with the onset of a target picture–written word pair. Participants were required to provide a verbal response to the phoneme-monitoring task while silently naming the picture, followed by (c) a pure tone of 100 ms presented at the short or the long SOA post–phoneme onset. Response to the tone task initiated the presentation of the same picture again, and participants were instructed to name each picture aloud to verify each picture’s name. This last step was undertaken to ensure that participants were naming the pictures correctly during the monitoring task. Presentation of the next trial in the sequence was instigated by the experimenter after the participant named the picture or automatically after 10 s. This duration was chosen on the basis of pilot testing, which revealed that CWS required sufficient time to name the pictures at the end of every trial, particularly the stuttered trials.

Studies that have used phoneme monitoring during silent picture naming in fluent speakers (Wheeldon & Lahiri, 2002; Wheeldon & Levelt, 1995) and those that have adapted this task to test persons who stutter (Sasisekaran & Byrd, 2013; Sasisekaran & De Nil, 2006; Sasisekaran, De Nil, Smyth, & Johnson, 2006) have used a similar protocol of testing picture naming after the participant provides a motor phoneme-monitoring response. In the present study, this protocol was modified to elicit a yes/no verbal response for the monitoring task on the basis of the argument that monosyllabic verbal responses (particularly a two-choice yes/no response involving speech sounds acquired early in development) are comparable between those who do and do not stutter (e.g., van Lieshout, Hulstijn, & Peters, 1996). Furthermore, we used a verbal response for the phoneme task and a nonverbal response for the tone task to keep the output systems separate and to limit the extent to which the two tasks shared similar resources for motor output.

Primary Task

Participants were presented the picture–written word stimuli in four blocks. Each target picture occurred four times in one block, once in the related and replica conditions and twice in the unrelated condition. The phonemes to be monitored occurred in word middle or final positions (e.g., the sound /t/ in the picture–written word pair /cat/–/cap/). Each block consisted of 15–16 trials from the unrelated, seven to eight from the related, and seven to eight from the replica conditions, respectively, resulting in a comparable number of trials in the three conditions across all four blocks.

Secondary Task

In each block and in each of the conditions, an equal number of tone stimuli were presented at the short or the long SOA. Short SOA trials consisted of a 100-ms lapse between the offset of the phoneme to be monitored and the tone. Long SOA trials consisted of a 900-ms lapse between the offset of the phoneme and the tone. In each block, the frequency of occurrence of the three tones was distributed evenly.

Instrumentation

The experimental stimuli were programmed and presented using SuperLab software (Cedrus Corporation, 2016) installed on a Dell desktop. Verbal and manual responses from the monitoring and tone tasks as well as spoken responses from the overt naming trials were recorded using a Marantz digital recorder. The manual responses from the Cedrus response box resulted in a clear audio recording as illustrated in Figure 1. In addition, errors from the tone task were recorded using the Cedrus response box. Response times and errors from the phoneme and the tone tasks were measured using PRAAT software (Boersma & Weenink, 2013). Figure 1 illustrates the events in each trial of the dual task and the response time computation for the monitoring and tone tasks. Monitoring time in milliseconds, the time between the offset of the audio token of each phoneme in the phoneme task and the participant’s verbal response, was measured. Tone decision times in milliseconds, the time between the onset of the tone and the participant’s button-press response, were also measured.

Data Coding and Analysis

The data were analyzed by the principal investigator (PI), and reliability testing of the entire data set was performed by a trained research assistant. Disagreements in data coding between the two raters were revisited and recoded such that there were no disagreements between the two raters. Trials in both tasks were categorized as correct or incorrect. All correct responses were included in the response time analysis, and all incorrect trials were included in the error analysis.

Response Time

For the phoneme task, correct responses included trials in which participants identified correctly the presence or absence of a phoneme match. For the tone task, correct responses included trials in which participants identified correctly the pitch of the tone as being low, medium, or high. Correct trials in both tasks were further coded for outlier responses. Outlier responses included trials in which the response times for the phoneme and tone tasks were 2 *SD* above or below (Ratcliff, 1993) the individual’s mean response time specific to condition and SOA. A total of 3.6% (*SD* 0.70), 4.3% (*SD* 0.58) trials from the phoneme task and 2.8% (*SD* 1.2), 4.7% (*SD* 1.1) trials from the tone task were excluded from the CWS and CNS groups, respectively. In

Figure 1. Events in a single trial of the dual task used in this study identified using PRAAT.

addition to the correct responses, trials in which the tone decision or the picture-naming responses occurred prior to the monitoring responses, in which the monitoring and tone decision responses overlapped at onset, and in which the pictures were named incorrectly were excluded from the response time analysis. The response time data were analyzed by the PI, and data from two participants were analyzed by the second author and verified by the PI for agreement on placement of the cursors (see Figure 1).

Error Responses

For the phoneme task, incorrect responses and lack of responses were coded as errors. Incorrect responses included trials in which participants responded with a false positive or a false negative response to the monitoring task. For the tone-decision task, all incorrect responses and lack of responses were coded as errors. Because these two types of errors correspond directly to errors in the dual task, these were the only types of errors included in the error analysis. In addition, several types of errors were coded, including: (a) trials in which participants responded to the tone task before the phoneme task, (b) trials in which a distinct onset was not discernable for each task type due to a response overlap, and (c) trials in which the picture was named overtly instead of a yes/no monitoring response. Because these errors are attributable to the inability to attend to a given task while inhibiting other responses, the two groups were compared in an aggregate measure (arcsine transformed sum of percentage values) of these error types.

Statistical Analysis

Response times and percentage errors from both tasks were obtained for both groups. The Kolmogorov–Smirnov test of normality revealed that the average response time data across the conditions and the SOAs for the two tasks fit the normal distribution curve ($p > .05$) for both the CWS and the CNS groups. The percentage error

data from both the tasks were arcsine transformed to reduce the effect of extreme values on mean. Statistical analyses were performed on the arcsine-transformed percentage error data.

The response time data from the phoneme and tone tasks were analyzed in a mixed analysis of variance (ANOVA). This analysis involved group (CWS, CNS) as the categorical between-subjects variable and task (phoneme, tone), condition (unrelated, related, replica), and SOA (short, long) as the within-subject variables. The error data from the phoneme and tone task were analyzed in a separate mixed ANOVA. Group was the between-subjects variable, and task, condition, and SOA were the within-subject variables. Errors in the sequencing of responses (yes/no response first, then tone-decision response, and picture naming last) were compared between the groups for the three conditions (averaged between SOAs due to the lack of a significant SOA effect) using the t test. The purposes of these analyses were to determine dual-task costs in performing a secondary task while simultaneously performing phoneme monitoring and to investigate the effects of SOA on dual-task performance in CWS and CNS. All post hoc comparisons were performed using Fisher least significant difference, and p values for all effects are provided.

Results

In the following subsections, we describe first the results from the response time analysis and then report the results from the error data analysis of performance in the dual task. Table 1 presents the results from the mixed ANOVA of the response time data from the phoneme-monitoring and the tone-decision tasks.

Response Time (ms)

It was hypothesized that: (a) CWS would show difficulties in the monitoring task, evident as slower responses to the phoneme-monitoring task, and in the related compared

Table 1. Results from mixed analyses of variance of response time data from phoneme-monitoring and tone-decision tasks.

Effect	df	F	p	Partial eta-squared	Observed power
Group	1, 21	2.89	.104	.12	0.37
Task	1, 21	8.12	.010	.28	0.78
Condition	2, 42	30.29	.000	.59	1.00
SOA	2, 42	74.90	.000	.78	1.00
Task × Group ^a	1, 21	3.68	.069	.15	0.45
Condition × Group	2, 42	0.23	.797	.01	0.08
SOA × Group	2, 42	5.11	.035	.20	0.58
Task × Condition	2, 42	0.09	.918	.00	0.06
Task × SOA	1, 21	84.73	.000	.80	1.00
Condition × SOA	2, 42	0.21	.808	.01	0.08
Task × Condition × Group	2, 42	0.21	.807	.01	0.08
Task × SOA × Group ^a	1, 21	3.95	.060	.16	0.47
Condition × SOA × Group	2, 42	0.63	.536	.03	0.15
Task × Condition × SOA	2, 42	1.77	.183	.08	0.35
Task × Condition × SOA × Group	2, 42	1.12	.336	.05	0.23

^aEffects are indicated as marginal trends in the text.

with the replica condition of the PWI paradigm, and (b) CWS would show larger dual-task costs in performing the tone task—that is, significantly slower tone-decision responses, particularly at the short SOA compared with the long SOA condition. No differences were expected between groups in the PRP pattern of response to the dual-task combination used in this study. Due to the number of main and interaction effects, only significant main and interaction effects and effects with a trend toward significance are discussed here.

Mixed ANOVA revealed that the main effects of task, category, and SOA were significant. Participants were slower in: (a) the tone compared with the phoneme task ($p = .007$), (b) the related ($p < .0001$) and unrelated ($p < .0001$) conditions compared with the replica condition, and (c) the short compared with the long SOA ($p < .0001$). The main effect of group was not significant although the CWS group was slower than the CNS.

A significant SOA × Group interaction was obtained, $F(2, 42) = 5.11$, $p = .035$. Both groups were significantly slower in responses at the short SOA when the stimuli for the phoneme and the tone tasks were presented in quick succession; this difference in response time between the short and the long SOAs was larger in the CWS group ($p < .00001$). A trend toward significance was observed in the Task × Group effect, $F(1, 21) = 3.68$, $p = .069$, with larger group differences in the tone task. The CWS were significantly slower than the CNS at this task ($p = .03$). Furthermore, the interaction of Task × SOA × Group (see Figure 2) showed a trend toward significance, $F(1, 21) = 3.95$, $p = .06$, suggesting that the SOA effect differences were mostly due to slower responses to the tone task at the short SOA in the CWS group. We ran post hoc comparisons to identify the source of this trend. The larger response time difference between the short and the long SOA in the CWS group was primarily from the tone task. Thus, the second hypothesis (Hypothesis 2) that CWS would show larger dual-task cost effects at the short SOA in the tone task was confirmed in this analysis.

All other effects were nonsignificant. Although both groups showed slower responses in the related and unrelated conditions compared with the replica condition, no significant group differences were evident in the different conditions of phoneme monitoring (Hypothesis 1).

Positive Predictive Value of the Current Findings

Due to the low power of the only significant interaction in the response time analysis, we evaluated the positive predictive value (PPV) or the probability that the positive finding in this dual-task study reflects a true effect. According to Button et al. (2013), PPV depends on the prior probability of a dual-task interference effect being true on the basis of the findings from past studies, the statistical power reported from the previous studies, and the statistical significance. It is computed using the formula $([1 - \beta] \times R) / (1 - \beta \times R + \alpha)$, where R refers to the prestudy odds of non-null as computed from Appendix A (seven in 13 odds of a non-null finding), $1 - \beta$ or the power is based on the values reported in previous studies (ranging from 0.2 to 0.8) and is set at an estimate of 0.2 considering the range of values reported previously, and α is set at 0.05. This computation yielded a 68% chance that the significant finding reported in this study is reflective of a real effect.

Errors (Percentage)

It was hypothesized that difficulties in encoding and/or monitoring would result in more errors in the phoneme task in the CWS group, particularly in the related condition, due to the interference created by the written word sharing onset or rhyme with the picture (Hypothesis 1). In a similar manner, we hypothesized that larger dual-task cost effects in CWS would result in more errors in the tone task and larger group differences in the short SOA condition (Hypothesis 2).

Figure 2. Phoneme monitoring and tone decision response times (ms; 95% CI) by stimulus onset asynchrony (SOA) in children who stutter (CWS) and children who do not stutter (CNS).

Table 2 presents the results from the mixed ANOVA of the error data from the phoneme-monitoring and the tone-decision tasks. Results revealed significant main effects of task and condition with more errors in: (a) the tone compared with the phoneme task ($p = .001$) and (b) the related compared with the unrelated ($p = .0001$) and replica conditions ($p < .0001$). The main effects of group and SOA were nonsignificant. A significant Task $\times$ Condition effect was obtained, $F(2, 44) = 7.30$, $p = .002$; more errors were observed in the related condition of the monitoring task compared with the unrelated ($p < .0001$) and replica ($p < .0001$) conditions in both groups. A carryover of this

difference between categories was not evident in the tone task. Furthermore, a marginal trend toward significance was observed in the Task $\times$ Condition $\times$ Group effect, $F(2, 44) = 2.88$, $p = .067$ (see Figure 3). Post hoc comparisons to identify the source of this trend revealed the group differences to be most evident in the tone task. The CWS group made more tone-decision errors in the related and replica conditions.

Independent t test comparisons did not reveal significant differences between the two groups in the percentage of errors in the sequencing of the phoneme, tone, and picture-naming responses. However, the CWS group had

Table 2. Results from mixed analyses of variance of error data from phoneme-monitoring and tone-decision tasks.

Effect	df	F	p	Partial eta-squared	Observed power
Group	1, 22	1.02	.323	.04	0.16
Task	1, 22	6.50	.018	.23	0.68
Task $\times$ Group	1, 22	1.02	.323	.04	0.16
Category	2, 44	14.81	.000	.40	1.00
Category $\times$ Group	2, 44	0.80	.454	.04	0.18
SOA	1, 22	0.05	.819	.00	0.06
SOA $\times$ Group	1, 22	0.59	.449	.03	0.11
Task $\times$ Category	2, 44	7.30	.002	.25	0.92
Task $\times$ SOA	1, 22	1.12	.301	.05	0.17
Task $\times$ Category $\times$ Group ^a	2, 44	2.88	.067	.12	0.53
Task $\times$ SOA $\times$ Group	1, 22	0.10	.760	.00	0.06
Category $\times$ SOA	2, 44	0.15	.862	.01	0.07
Category $\times$ SOA $\times$ Group	2, 44	0.12	.887	.01	0.07
Task $\times$ Category $\times$ SOA	2, 44	1.07	.353	.05	0.22
Task $\times$ Category $\times$ SOA $\times$ Group	2, 44	0.39	.676	.02	0.11

^aEffects are indicated as marginal trends in the text.

Figure 3. Phoneme monitoring and tone decision errors (%; 95% CI) by category in children who stutter (CWS) and children who do not stutter (CNS).

more response-sequencing errors in all of the categories: unrelated condition, CWS: $M = 7.8$, $SD = 6.6$, CNS: $M = 3.3$, $SD = 4.3$, $t(22) = 1.9$, $p = .06$; related condition, CWS: $M = 9.4$, $SD = 5.3$, CNS: $M = 5.4$, $SD = 6.2$, $t(22) = 1.7$, $p = .10$; replica condition, CWS: $M = 7.8$, $SD = 10.8$, CNS: $M = 6.9$, $SD = 6.3$, $t(22) = 0.25$, $p = .79$.

Correlations Between Dual-Task Performance and Total Disfluencies

No significant correlations were evident between percentage of total disfluencies (both CWS and CNS) and response time differences between the short versus the long SOA for the phoneme or the tone task in the CWS or the CNS groups. A positive correlation was evident only for the CNS group between total disfluencies and percentage of monitoring errors in the relative condition at the short SOA ($r = .85$, $p = .001$). A scatterplot (see Figure 4) of the individual percentage of disfluencies and errors are provided. Excluding one participant with extreme values in the error data resulted in a nonsignificant correlation ($r = .4$).

Discussion

The aim of the present study was to investigate the effects of a dual task on response times and errors in CWS and matched controls. Participants performed a phoneme-monitoring task; the complexity of this task was varied in a PWI paradigm to investigate if CWS differ from CNS in this task. Dual-task cost effects were studied by presenting a pure tone at either short or long SOA from the monitoring task.

Performance in the Phoneme Monitoring–Tone Decision Task

Phoneme Monitoring Task

We created a hierarchy of processing complexity in encoding and monitoring by manipulating the extent of overlap between the picture and written distractor word in the PWI task such that these were the same (replica), related phonemically (related, shared onset or rhyme), or unrelated. It was hypothesized that the competing written word in the related condition (e.g., *cap-cat*, both start with the same consonant and vowel; the written word diverges from the word to be monitored in the final phoneme) would create phonological interference, thus requiring additional time to resolve before finalizing the monitoring decision (e.g., Cook & Meyer, 2008; Mädebach et al., 2011). Our findings revealed the predicted effect of condition such that responses to the related condition were comparable to the unrelated condition and slower than the replica condition. However, although CWS were slower than the CNS in response times to the phoneme-monitoring task, the predicted Group $\times$ Condition interaction was absent—that is, the groups were comparable in response times to the monitoring task in all conditions. The findings suggested that CWS are not different from CNS in the encoding and monitoring of speech sounds in a silent naming task. Similar lack of difference was reported by Sasisekaran and Byrd (2013) in a study involving phoneme and rhyme monitoring of monosyllabic words in school-age CWS. The lack of group differences, although suggestive of comparable encoding and monitoring abilities in CWS and CNS, should be considered with caution. First, although 16 participants were tested in the CWS group, only 12 without

Figure 4. Scatterplots of percent disfluencies and monitoring errors in children who stutter (CWS) and children who do not stutter (CNS).

any associated co-occurring conditions were eventually included in the data set. Considering that the prevalence of co-occurring conditions is higher in CWS (e.g., Arndt & Healey, 2001), the current findings indicate the necessity to consider further the compounding effects of associated conditions and task complexity on dual-task performance in CWS (when all 16 participants were included in the analysis, significant group differences and an interaction effect were obtained). Second, although dual-tasking occurs frequently in everyday speech situations, much of this is at the conversation/sentence level. Last, slower responses and more errors have been reported in both single and dual tasks involving phonemic-level processes at the word level in both CWS and AWS (e.g., Jones et al., 2012; Weber-Fox, Spencer, Spruill, & Smith, 2005; Weber-Fox et al., 2008). The present study is limited to naming of words acquired early, and the findings are not reflective of dual-task performance at other levels of speech and language planning and production in CWS and CNS.

Monitoring Errors

It was hypothesized that the written word in the related condition of the PWI paradigm would interfere with the monitoring task. This was confirmed in both the CWS and the CNS such that more errors were evident in the related compared with the unrelated and replica conditions. A speed-accuracy trade-off was not evident because slower responses were seen in both the unrelated and related conditions, and a higher percentage of monitoring errors was evident only in the related condition. Contrary to expectations, the groups were comparable in the percentage of monitoring errors in all three conditions. It could be argued that this finding does not support the assertion that prolonged competing activation of similar elements in the phonemic lexicon contributes to stuttering (e.g., the covert repair hypothesis; Postma & Kolk, 1993). However, this conclusion is not warranted as the stimuli used in this study

were at the word level and involved word retrieval and encoding as it relates to picture naming; therefore, the findings are not generalizable to other levels of language planning. Lack of between-group differences in error rates, particularly in the related condition, can also be interpreted to suggest that CWS do not differ from CNS in sublexical inhibitory processes at the word level considering that both groups were able to overcome the phonological inhibitory effects of the interfering written distractor word within a comparable time frame although this claim requires further testing.

Tone-Decision Task

We hypothesized slower response times to the secondary tone-decision task. Our findings confirmed that the CWS were slower at this task, significantly at the short SOA. Furthermore, the marginal Group $\times$ Task $\times$ SOA effect revealed this difference to be due to slower response times to the tone-decision task in CWS compared with CNS. It can be argued that auditory and speech/language tasks access the same working memory system—that is, the phonological loop—and resources, and this finding suggests that performing a relatively simple task, such as the tone-decision task, concurrently, with limited time separation between the tasks, can interfere with language and speech processing in CWS. Tsai and Bernstein Ratner (2016) reported greater variability, and Maxfield et al. (2016) reported significant differences in behavioral and electrophysiological data for this dual-task combination in AWS compared with ANS. Although we used a covert speech task, the findings are comparable to dual-tasks involving overt speech to the extent overt and covert speech access similar neural networks (Riecker, Ackermann, Wildgruber, Dogil, & Grodd, 2000).

In the absence of group differences in response times to the phoneme task, this finding suggests that prioritizing

attention to the monitoring task may have resulted in the CWS attending less effectively to the tone task, particularly at the short SOA when the presentation of the stimuli from the two tasks in quick succession necessitated attending and updating working memory of the tone information until responding to this task. A trend for more tone-decision errors in the CWS further supports this conclusion and rules out a speed–accuracy trade-off—that is, slower tone decisions resulting in fewer errors. Although preliminary in nature, this is the first study to have demonstrated dual-task cost effects in a secondary task in CWS. Although other types of errors, those thought to indicate difficulties in sequencing responses, did not reveal significant group differences, it is likely that such trials involved processes beyond those tested in this study (e.g., boredom or selective inattention to some of the trials, resulting in response sequencing errors). Last, although heightened anxiety may have resulted in slower responses in the CWS group, the fact that trials within each block were randomized for SOA makes this a less plausible explanation for the significantly slower responses at the long SOA condition.

Implications of Findings to Dual-Task Performance in CWS

We hypothesized slower responses to phoneme monitoring at the long SOA and slower responses to tone monitoring at the short SOA. Our findings are similar to those reported by Sasisekaran and Donohue (2016) in fluent children and adults with the exception that in this study we did not find a statistical effect of SOA on phoneme-monitoring performance. Caution is warranted in comparing these studies directly due to the fact that age contributes significantly to dual-task performance as evidenced in Sasisekaran and Donohue; the current study differs from the other study in the number of children tested in the age groups included. Preliminary analysis of the data with age as a covariate failed to show a significant effect (response time, $p = .065$; accuracy, $p = .110$) of this variable. The non-significant age effect in this study may have been due to the uneven and small number of participants in the age range tested (other than a 7-year-old and a 16-year-old, the participants were between 9 and 15 years old). We found that both the CWS and the CNS groups were comparable in the response pattern to the primary and the secondary tasks although the control group did show descriptively slower monitoring responses at the long compared with the short SOA. Analysis of the individual monitoring times in all three conditions of the phoneme task revealed that, although a majority of the CNS showed either comparable response times or slower responses at the long SOA, half of the participants in the CWS group were slower in monitoring responses at the short SOA, and this was not limited to any particular age. To the contrary, all participants in both groups showed slower responses to the tone task at the short SOA condition. Thus, the SOA-based performance differences were more variable in the CWS.

On the basis of Baddeley's (1996, 1997) model of working memory and the inherent processing stages involved in the phoneme-monitoring and the tone-decision tasks, we speculate that the cognitive demands required for performing this dual task may have been higher on the central processor. Because this system has been attributed a crucial role in allocating attention, which in turn is responsible for holding and updating working memory, we speculate that ineffective allocation of attentional resources is a contributing factor to the difficulties experienced by CWS in performing this dual-task combination. Difficulties in attending to or orienting to new stimuli in CWS have been reported in other studies (e.g., Eggers et al., 2012). Larger dual-task cost effects on the secondary task or higher variability in performing dual tasks involving phonological processing have been reported in other studies in AWS (e.g., Bosshardt, 1999, 2002; De Nil & Bosshardt, 2000; Maxfield et al., 2016; Tsai & Bernstein Ratner, 2016). Furthermore, neuroimaging studies have reported gray matter volume differences of the cingulate in CWS (Chang, Erickson, Ambrose, Hasegawa-Johnson, & Ludlow, 2008) and heightened activity of the cingulate cortex and cerebellum in AWS (e.g., Braun et al., 1997; De Nil, Kroll, Kapur, & Houle, 2000), structures thought to be involved in attending and monitoring ongoing speech and in response decisions (e.g., Barch, Braver, Sabb, & Noll, 2000). Therefore, we interpret the present findings to suggest that the use of cognitive resources to simultaneously plan, produce, and monitor speech while performing a secondary task that is also reliant on the same cognitive mechanisms may prove detrimental to dual-task performance in CWS.

Conclusions, Limitations, and Future Directions

We tested a small group of CWS and CNS on the effects of performing phonemic encoding and monitoring in a PWI paradigm concurrently with a secondary tone-decision task presented at short or long SOA from picture onset to investigate the dual-task costs involved. The present study is a novel contribution to understanding dual-task interference effects in school-age CWS. Our results showed that, although the groups were comparable in response speed and accuracy in the monitoring task, presenting a tone at the short SOA did influence performance of the secondary tone task in CWS. This trade-off was evident as higher dual-task costs—that is, significantly slower responses and a trend for more tone-decision errors. We attribute this finding in CWS to reduced ability to attend to the tone stimuli because attentional resources were being prioritized to performing covert speech and monitoring. However, cautious interpretation and further confirmation of the finding is necessary considering the results from the PPV analysis.

The present study has a few limitations and future directions to consider. First, the age range tested in this study was 7–16 years, and due to the uneven distribution of ages in this range, we were unable to identify if the developmental trajectory of dual-task performance in school-age CWS is different compared with CNS. Second, present

findings revealed that both the CWS and the CNS did not differ significantly in the PRP pattern of dual-task performance for the tasks used in this study although the CWS group was more variable in performing this dual task. Because the stimuli were words, this could suggest a comparable approach to performing this dual-task combination in CWS and CNS while necessitating testing at other levels of language planning and production. Third, we did not compare performance in the dual task to performing the two tasks as single tasks; instead, the term *dual-task costs* in this study refers to the varying effects of SOA. This decision is based on the assumption that at the long SOA, considering the time separation, the two tasks will be performed with limited interference. Last, because the verbal responses elicited from participants were monosyllabic yes/no responses with limited stuttering, we were unable to correlate either the response time or the percentage of errors in the tone task to speech disfluencies during task performance.

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Appendix A

Summary of dual-task studies

Study	Participant groups	Number of subjects	Primary task	Secondary task	Significant (S)/not significant (NS) dual-task effect
1. Webster (1986) 2. Brutten and Trotter (1986)	AWS versus ANS CWS versus CNS	18 versus 18 20 versus 20	Finger tapping Hand tapping	Foot tapping Speech task (three conditions with increasing task demands)	S; ipsilateral dual-task interference effect NS dual-task interaction effect; only omnibus group effect
3. Arends, Povel, and Kolk (1988)	AWS versus ANS	11 versus 11	Three speech tasks	Visual tracking task	S; increase in fluency when performing the dual task
4. Bosshardt and Fransen (1996)	AWS versus ANS	14 versus 14	Prose reading	Semantic, rhyme decision task	NS; AWS were slower in the semantic decision task than the rhyme decision task
5. Bosshardt (1999)	AWS versus ANS	9 versus 10	Word repetition	Mental calculation	NS; variable influence of dual task on disfluencies in the stuttering group
6. De Nil and Bosshardt (2000)	AWS versus ANS	11 versus 11	Delayed sentence production	Semantic/rhyme judgment	S; reduced accuracy in the judgment tasks; the groups were comparable in the number of propositional units in the sentence task
7. Bosshardt (2002)	AWS versus ANS	14 versus 16	Silent reading	Word memorization	S; stuttering rate increased beyond the single-task level
8. Bosshardt, Ballmer, and De Nil (2002)	AWS versus ANS	14 versus 16	Sentence generation	Semantic/rhyme category decision	S; less proposition units in the dual-task condition in AWS; groups comparable in accuracy in the secondary category decision tasks
9. Smits-Bandstra and De Nil (2009)	AWS versus ANS	9 versus 8	Syllable sequence reading	Color recognition	S; reduced accuracy in the primary task in the dual-task condition
10. Jones, Fox, and Jacewicz (2012)	AWS versus ANS	9 versus 9	Rhyme judgment	Letter recall	NS dual-task interaction effect; group differences reported within the different conditions of the primary and the secondary tasks
11. Eichorn, Marton, Schwartz, Melara, and Pirutinsky (2016)	AWS versus ANS	19 versus 20	Spontaneous speech	Working memory task	NS; both groups showed reduced performance in the working memory task in the dual-task condition; benefits to fluency in the dual task were evident in both groups
12. Tsai and Bernstein Ratner (2016)	AWS versus ANS	20 versus 20	Picture naming	Tone identification	NS; variability was higher in the AWS group. Both groups exhibited semantic facilitation and phonological interference in the picture-naming task
13. Maxfield et al. (2016)	AWS versus ANS	15 versus 15	Picture naming	Tone identification	S; AWS showed reduced P3 and less accurate responses to the tone task at the short SOA condition

Appendix B

Phoneme stimuli for the picture–written word interference task

Words	Image agreement		Familiarity		Age of acquisition	Brown spoken frequency	Kucera–Francis written frequency
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>			
bed	3.65	0.99	4.72	0.77	1.69	18	127
bell	2.92	0.94	2.20	0.93	2.36	6	18
bucket	Not illustrated in S and V						7
button	4.48	0.92	3.85	1.26	1.92	2	10
camel	3.92	0.99	2.08	1.06			1
candle	3.85	0.76	3.08	1.15			18
cap	3.52	0.97	1.52	0.63		1	27
car	3.10	1.22	4.70	0.60	1.97	29	274
card	Not illustrated in S and V					3	26
cat	3.78	0.91	4.22	0.88			23
chain	4.46	0.84	2.82	1.00	3.11	2	50
chair	3.22	1.28	4.58	0.86		10	66
doctor	Not illustrated in S and V					32	100
dog	3.05	1.26	4.60	0.70	1.55	8	75
doll	2.28	1.07	2.92	1.14	1.55		10
dolphin	Not illustrated in S and V					1	1
hammer	4.10	1.02	3.48	1.16	3.55	2	9
hamster	Not illustrated in S and V						
hand	4.30	0.90	4.82	0.67		42	431
harp	4.29	1.06	1.88	1.08			1
hat	3.65	1.22	3.18	1.00		3	56
heart	4.49	0.98	3.72	1.16	2.81	14	173
lemon	4.35	0.94	3.25	1.22	3.06	5	18
letter	Not illustrated in S and V				2.56	46	145
nun	Not illustrated in S and V						2
nut	3.62	1.65	2.55	1.28		1	15
pencil	4.40	0.80	4.42	1.00	2.25	1	34
pepper	3.64	1.28	2.92	1.29	2.69		13
pig	3.62	1.04	2.18	0.97	2.94	1	8
pin	Not illustrated in S and V				2.61	1	16
rabbit	4.20	0.81	2.95	1.07	2.61		11
radish	Not illustrated in S and V						8

Note. S and V refers to Snodgrass and Vanderwart (1980) norms.