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Rhyming abilities in a dual-task in school-age children who stutter

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A R T I C L E I N F O

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A B S T R A C T

Purpose: We compared school-age children who stutter (CWS) and age and gender matched control participants (CWNS) in a dual-task involving a word-level rhyming task and a tone task involving pitch decisions.
Methods: Participants were 30 children (CWS, $n = 15$) between 7 and 16 years. Auditory word – picture stimuli pairs from the rhyme task were categorized into nonrhyme (e.g., *bear-cart)*, rhyme (e.g., *bear-pear*), and replica (e.g., *bear-bear*) categories. The effort associated with managing resources in the dual-task was varied through the manipulation of stimulus onset asynchrony (SOA) between the stimuli of the two tasks. Mixed methods analyses of the response time (RT, ms) and error (%) data were conducted with Group, Category, and SOA as the fixed effects and participants as the random effect. Age and phoneme awareness skills were included in the analyses.
Results: More rhyming errors and a significant positive correlation between rhyming errors and age was observed in the CWS compared to the CWNS. Compared to the CWNS, a higher percentage of rhyming errors was observed in the rhyme than the nonrhyme and replica categories in the CWS in both the SOA conditions, and this effect was influenced by age and phoneme awareness skills. Analysis of the tone task data indicated that a subgroup of CWNS with higher phoneme awareness skills showed reduced RT difference between the long and the short SOA conditions thereby suggesting higher efficiency with resource allocation for dual tasking. Task-specific differences between the CWS and CWNS are interpreted to suggest limitations in the encoding of the phonological aspects of covert speech in a dual-task.

1. Introduction

Stuttering has been described as a fluency disorder involving limited and modular neural resources for speech planning and production. Dual tasking has been used to test the hypothesis of limited neural resources and its effects on task performance in persons who stutter. There has been ongoing interest in understanding how children who stutter (CWS) and adults (AWS) perform in dual-task conditions resulting in interference between two competing tasks. The everyday nature of dual tasking involving speech production makes this an interesting and relevant question. When the interfering tasks share similar processes, cognitive resources and substrate, response time (RT) and accuracy for one or both tasks may be affected. In this study, we evaluated the effects of performing a primary word-level rhyme-monitoring task (hereafter, rhyme task) and a secondary tone decision task (hereafter, tone task) in school-age CWS

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compared to children who do not stutter (CWNS). Both rhyming and dual tasking are supported by executive control mechanisms, and rhyming has been identified as a relevant skill for the advancement of phonological abilities and speech fluency. Therefore, the aim of this study is to investigate rhyming in a dual-task to elucidate the mechanisms mediating rhyming performance in school-age CWS and the effects of cognitive demands on rhyming and dual tasking.

1.1. *Dual tasking and resource allocation: theoretical perspectives*

Performing two tasks concurrently relies on the use of working memory substrate and associated cognitive processes. Control mechanisms that coordinate the dynamics of cognition and action, including attention, contribute to dual-task performance (e.g., Baddeley, 1996). Within Baddeley's multicomponent working memory model, tasks involving verbal processes and tasks mediated by verbal processes (e.g., mathematical calculations) are conducted within the phonological working memory space while tasks involving visuo-spatial elements rely on the visuo-spatial sketchpad. Performing two tasks concurrently involves these mechanisms to a varying extent, and additionally, overlap between the two tasks in terms of response selection and output (motor) mechanisms result in task interference effects in RT and accuracy.

Several theoretical postulations propose varying accounts of an individual's capacity to efficiently allocate cognitive resources when performing multiple tasks concurrently. The *Capacity Sharing Account* (Kahneman, 1973) postulates that human resources are finite and individuals performing multiple tasks (dual tasking) share the processing resources and cognitive capacities supporting the tasks. Since there are limited resources available for each task and such resources are modularized based on the extent of task similarity, individual performances in the tasks deteriorate. The *Central Bottleneck Account* (Ferreira & Pashler, 2002; Pashler, 1994) is based on the premise that processes involving similar cognitive resources cannot be performed simultaneously and that these processes require sequential sharing of resources, where the resource-demanding stage of each task needs to be processed uniquely. If both tasks in the dual-task compete for the exact same cognitive resources, the outcome is a central "bottleneck" and a delay or inaccuracy in task performance. Research suggests that the findings from dual-task studies can be interpreted within both accounts of dual tasking. Finally, Kane and Engle (2002) postulated a central executive attentional network that is shared between tasks and attributed to individual differences in dual-task performance.

Dual-task studies have reported the effects of performing two tasks concurrently on both the primary (the task performed first in the sequence) and the secondary (the task performed second in the sequence) tasks. Additionally, in the absence of a single-task condition to compare dual-task performance, the overlapping task paradigm (OTP) involving varying stimulus onset asynchrony (SOA, defined as the difference in duration between the onsets of the primary and the secondary task stimuli) has been used to investigate dual-task effects. Within the OTP, investigating dual-task effects involves comparing the SOA conditions to determine the effects on the primary and the secondary task RT and errors (Strobach, Wendt, & Janczyk, 2018). With minimal temporal separation between the tasks, that is, at shorter SOA, more cognitive resources, in the form of working memory or attentional resources, are directed to the primary task. The resulting Psychological Refractory Period effect (PRP, Pashler, 1994; Telford, 1931) based on SOA is slower responses and/or more errors in the secondary task.

1.2. *Dual tasking and resource allocation in persons who stutter*

1.2.1. *Dual tasking in adults who stutter*

The central premise to testing dual tasking in persons who stutter is that with limitations in the neural substrate supporting cognitive resource allocation, persons who stutter might find it difficult to allocate cognitive resources efficiently, particularly for tasks involving speech production. Bosshardt (1999) tested the assumption that speech disfluencies can result from interference between overt speech movements and concurrently performed cognitive processes. The primary task involved repeating sequences of nouns and the secondary task involved mental calculation. The researchers found that the expectation of an impending mental calculation task temporarily reduced the stuttering rate, but the stuttering rate increased beyond the baseline single-task condition when the mental calculations were performed. Only for a subgroup of AWS, the secondary task interfered with fluent speaking to an extent that was not comparable to the matched adults who do not stutter (AWNS). Subsequently, Bosshardt and colleagues investigated varying dual-task combinations at the semantic, syntactic, and phonemic levels in AWS (Bosshardt, 2002; Bosshardt, Ballmer, & De Nil, 2002). Bosshardt (2002) investigated fluency in a word repetition task and a concurrent list memorization task involving similar (rhymed) or dissimilar words. They reported that memorization of similar words resulted in fluency inhibition in the repetition task. The findings from such studies supported less-modular speech planning and production systems with limited attentional and working memory resources for dual tasking in AWS.

Two dual-task studies in AWS involving word-level language tasks are of particular relevance to the current study. Jones, Fox, and Jacewicz (2012) tested AWS and AWNS in a dual-task involving rhyme and tone tasks. The stimuli for the rhyme task (Phonological, P) were either orthographically (O) similar or dissimilar resulting in four levels of complexity (O + P-, O + P+, O-P-, O-P+). The AWS showed more errors in the O + P- condition of the rhyme task in the dual-task condition, since this condition involved the most stimuli incongruence requiring additional processing demands. In the only behavioral study in adults to vary stimulus onset asynchrony (SOA) and cognitive resource constraints, Tsai and Bernstein Ratner (2016) compared AWS and matched AWNS in dual tasking in a picture-word interference paradigm. Participants performed picture naming in the presence of distractor words that were semantically and phonologically related or unrelated to the picture name. Stimuli for the secondary tone task were presented at short or long SOA from picture onset. Group differences in errors to the tone task were noted only in the short SOA condition when the stimuli from the two tasks were constrained to a narrow time window.

1.2.2. Dual tasking in children who stutter

Few studies have investigated dual-task effects in school-age CWS, although such effects have been reported in AWS. Brutten and Trotter (1986) evaluated hand tapping as the primary task in single- and dual-task conditions with speech production as the secondary task. There were four different speech production tasks with varying levels of complexity. The authors interpreted the decreased rate of hand tapping with increasing complexity of the secondary task in the CWS to suggest a "less robust" neuromotor system. Performances in the secondary tasks were not reported. In a more recent study, Sasisekaran and Basu (2017) evaluated dual-task performance in a primary phoneme-monitoring task and a secondary tone pitch decision task in school-age CWS and CWNS. Similar to the present study, participants performed the dual-task in short and long SOA conditions. The CWS showed variable performance in the primary task and were significantly slower and less accurate in the secondary task, particularly in the short SOA condition.

1.3. Purposes and aims

Behavioral studies involving word-level language tasks in AWS have been inconclusive in the effects of dual tasking in the primary task (e.g., Jones et al., 2012; Tsai & Bernstein Ratner, 2016). The aim of the present study is to investigate dual tasking at the word level in school-age CWS and CWNS in a rhyme – tone dual-task under conditions of varying cognitive demands to investigate the interactions between language and executive function skills. The use of the rhyme – tone task combination to study dual tasking in this age group of CWS is motivated by two reasons. First, there has been ongoing interest in investigating rhyming in CWS due to the relevance of this skill for the advancement of phonological abilities and speech fluency. Several studies have reported poor or reduced rhyming abilities in preschool CWS with diagnostic implications for persistence vs. recovery (e.g., Gerwin, Brosseau-Lapre, Brown, Christ, & Weber, 2019; Mohan & Weber, 2015) and in school-age CWS (Gerwin & Weber, 2020; Weber-Fox, Spruill, Spencer, & Smith, 2008). Interestingly, neuroimaging studies have established that rhyming abilities continue to develop in children between 9 and 15 years through the implementation of higher-order cognitive control strategies due to increased neural convergence between the neural centers involved in executive control and rhyming (e.g., Booth et al., 2004; Bitan, Cheon, Lu, Burman, & Booth, 2009; Coch, Grossi, Skendzel, & Neville, 2005). To this effect, the rhyme task stimuli used in this study varied in the extent of rhyme match (nonrhyme, rhyme, or replica categories) and the stimuli pairs in the categories were all congruent for orthography and phonology. For the nonrhyme condition this meant that the stimuli pairs did not match in orthography or phonology (e.g., bear – cart). For the replica condition this meant that the stimuli pairs were the exact same (e.g., bear – bear), thereby offering maximum match in orthography and phonology and a simpler condition to compare the nonrhyme and rhyme conditions. Because of the sensitivity of the rhyme task to poor performance in preschool and school-age CWS (e.g., Gerwin et al., 2019; Gerwin & Weber, 2020; Mohan & Weber, 2015; Weber-Fox et al., 2008), we expected that the rhyme task will result in group differences in the primary task and/or influence performance in the secondary task based on stimuli complexity. Second, in a previous dual-task study involving phoneme and tone decisions, Sasisekaran and Basu (2017) did not find an effect of dual tasking in the primary task performance, although higher performance variability in the primary task was noted in the CWS group. In contrast, Brutten and Trotter (1986) reported an effect of dual tasking in the primary task when responses involved the motor system. Therefore, in this study we tested if the rhyme task is a more sensitive word-level language task at detecting group differences in the primary and secondary tasks in a dual-task when the tasks are similar in complexity. With the present state of knowledge on dual tasking in CWS, further evaluation is required to understand if: (a) School-age CWS differ from CWNS in rhyming abilities in a word-level rhyme task within a dual-task, because such an effect is indicative of weaker mastery over the task; and (b) Resource demands associated with the SOA manipulation affect both the primary and secondary task performances in school-age CWS compared to CWNS. Several studies in the stuttering literature have reported limitations in the allocation of attention and working memory resources in CWS (e.g., Eggers & Jansson-Verkasalo, 2017; Eggers, De Nil, & Van den Bergh, 2010; Eichorn, Marton, & Pirutinsky, 2018; Sasisekaran & Basu, 2017). The findings from this study will contribute to understanding if such effects are evident in the simple dual-task combination used in this study.

The current study is also motivated by the findings on dual tasking in children reported in the developmental psychology literature. Dual-task effects in the primary and secondary tasks vary based on the age groups and the dual-task combinations investigated. Several studies have reported task interference resulting in poorer performance in the secondary task in children (e.g., Fatzer & Roebers, 2012; Strobach & Karbach, 2020). Such findings have suggested that school-age children are continuing to acquire the ability to allocate cognitive resources effectively while also developing the use of explicit cognitive strategies to facilitate dual tasking (e.g., Lejeune, Lise, Catale, & Meulemans, 2014; Sasisekaran & Donohue, 2016; Strobach & Karbach, 2020).

Sasisekaran and Lei (2021) reported normative data from the rhyme – tone dual-task used in this study in a larger group of children (7 to 11-year-olds, 12 to 15-year-olds) and young adults. These researchers investigated in a hypothesis-driven way the age-based task effects in dual tasking when the stimuli from the tone task were presented at short or long SOA from the rhyme task. They found significantly slower responses in the short compared to the long SOA condition for the tone task in both the children and the adults. Additionally, age-based SOA effects were most evident in the 7 to 11-year-olds in this task. The SOA effect in the tone task suggested concurrent processing of stimuli from the rhyme and tone tasks at the short SOA and higher demands on working memory and attentional resources. Contrary to the tone task, slower responses were obtained for the rhyme task in the long SOA condition. Age-based SOA effects in rhyming were most evident in the 12 to 15-year-olds compared to the 7 to 11-year-olds, while the young adults did not show an effect of SOA on rhyming. The latter finding was interpreted to suggest the recent acquisition and use of higher-order cognitive control strategies, including the automatic elicitation of orthography, to support rhyming in dual-tasking in the older children. Additionally, regression analysis identified age and phonemic awareness as significant contributing factors to dual-task performance. These findings offer several testable hypotheses in CWS.

1.3.1. Research questions (RQ) and hypotheses

RQ 1: Do CWS and CWNS show the expected PRP response for the rhyme – tone dual-task. Based on the findings from other similar dual-task studies (Sasisekaran & Donohue, 2016; Sasisekaran & Lei, 2021), we hypothesized that both the CWS and the CWNS will show opposing SOA effects in the rhyme (rhyme RT, long > short SOA) vs. tone tasks (tone RT, short > long SOA).

RQ 2: Do school-age CWS and matched CWNS differ in a primary rhyme task in a dual-task involving matching of rhymes between auditory word - picture name stimuli pairs that are congruent for orthography and phonology. We hypothesized that the school-age CWS in this study will differ in the primary rhyme task. Since age range was a significant predictor of dual-task performance in the previous studies (Sasisekaran & Donohue, 2016; Sasisekaran & Lei, 2021), we expected that age will be a significant contributor in this study. Because the dual-task based effects in the rhyme task were most evident in the older children in Sasisekaran and Lei (2021), we hypothesized that if rhyming difficulties persist in school-age CWS then older CWS will experience more difficulties in the task due to concurrent demands on explicit rhyming and dual tasking.

RQ 3: Do school-age CWS and matched CWNS differ in the secondary tone task under short vs. long SOA? We hypothesized that dual-task effects in RT and accuracy of the tone task, if present, will be influenced by SOA (short > long SOA) to a larger extent in the CWS compared to the CWNS. Additionally, based on Sasisekaran and Lei (2021), we hypothesized that performance in the tone task may be influenced by participant age such that the younger CWS will experience more difficulties in the secondary task.

2. Methods

2.1. Participants

2.1.1. Initial screening and recruitment

Twenty-three CWS (5 females; *Mean* Age = 12.23 years, *SD* = 2.35) and twenty-one CWNS (5 females; *Mean* Age = 12.3, *SD* = 2.25) in the age range of 7 and 16 years were recruited to participate in the study. The CWS had received a prior diagnosis of developmental stuttering by a speech-language pathologist (SLP). Participants in both the groups were native speakers of American English matched in gender and age. Participants from the CWNS group were recruited through fliers posted around the University campus and through a pre-established participant database. Participants in the CWS group were recruited primarily through the Julia Davis Speech-Language-Hearing Center, University of Minnesota. All participants passed a binaural hearing screening test at 0.25, 0.5, 1.0, 2.0, 4.0, and 8.0 kHz (20 dB) in a quiet room at the Speech Fluency lab, University of Minnesota. The study protocol was approved by the Institutional Review Board, University of Minnesota.

Three additional tasks were included in the initial recruitment process. Parents of all participants responded to an initial recruitment screening form and provided information on: (a) Neurological deficits, (b) Language/ speech/hearing difficulties, (c) Usage of medication that are likely to affect the outcome of the experiment (e.g., ADHD), and (d) Reading difficulties. Based on the information provided, three children in the CWS group were identified by the accompanying parent to exhibit symptoms of ADD/ ADHD, two CWS with reading/spelling difficulties, and one CWS with visuo-motor tracking difficulties. Data from these participants were excluded from the dataset. Additionally, conversation and reading samples obtained from the participants were used to screen for articulation errors. Two CWS with errors involving the consonant /r/ were identified through this screening process. Because the rhyme task in this study involved silent speech production in making a rhyme decision, data from these two participants were also excluded from the dataset. The final dataset consisted of 30 participants – Fifteen CWS participants (Males, $n = 12$) and an equal number of CWNS matched in age, $t(28) = 0.45$, $p = 0.63$), and gender to the CWS group.

2.1.2. Standardized and standard assessments

All participants were tested on two standardized assessments - Expressive vocabulary (*Expressive Vocabulary test,* EVT - 2; Williams, 1997), phonemic awareness (*Lindamood Auditory Conceptualization Test* – 3, LAC; Lindamood & Lindamood, 2004), and in the digit span test (forward and backward span) from the Weschler's intelligence scale (Wechsler, 1997). These tests were administered to determine vocabulary, phonemic skills, and working memory. Group means from these tests were compared using the Analysis of Covariance with Z transformed age as a covariate. The groups were comparable and showed only descriptive differences in the measures (EVT raw scores, CWS *Mean* = 141.2, *SE* = 3.7, CWNS *Mean* = 141.8, *SE* = 3.7, $F(1,26) = 0.02$, $p = 0.88$; LAC raw scores, CWS *Mean* = 50.2, *SE* = 2.52, CWNS *Mean* = 52.8, *SE* = *2.52*, $F(1,26) = -0.39$, $p = 0.53$; Digit span raw scores, CWS *Mean* = 15.6, *SE* = 1.03, CWNS *Mean* = 16.5, *SE* = 1.03, $F(1,26) = 0.11$, $p = 0.73$). For all three tests, age was a significant covariate (EVT, $F(1,26) = 23.9$, $p<0.001$, eta-squared = 0.47; LAC, $F(1,26) = 6.5$, $p=0.016$, eta-squared = 0.20; Digit span, $F(1,26) = 5.8$, $p=0.023$, eta-squared = 0.18), and the interaction of Group x Age was not significant.

2.1.3. Stuttering diagnosis and severity ratings

In addition to prior stuttering diagnosis from a speech-language pathologist, the accompanying parent provided a stuttering severity rating for each participant in the CWS group on a 7-point scale (1 - *mild*, 7 - *severe*). The severity distribution in the CWS group indicated 5 participants in each of the severity rating categories between 1 and 4; one participant received a severity rating of 6.

2.2. Stimuli

2.2.1. Primary rhyme task

Thirty-two monosyllabic words (Cook & Meyer, 2008) formed the stimuli. Line drawings representing the 32 words were selected from Snodgrass and Vanderwart (1980) and used to elicit rhyming responses during silent picture naming. For words that did not have corresponding pictures, the most representative line drawings were identified using the Google search engine. The picture stimuli were matched with auditory word tokens to establish three categories - nonrhyme (not matched in rhyme to the picture name, e.g., *bear - cart*), rhyme (matched in rhyme to the picture name, e.g., *bear - pear*), and replica (matched in rhyme and orthographically identical, e.g., *bear – bear*) (see Appendix A). The auditory word tokens spoken by an adult female native speaker of English were recorded using PRAAT (Boersma & Weenink, 2014) at a sampling rate of 11 kHz and normalized for intensity.

2.2.2. Secondary tone task

The auditory tokens of words from the rhyme task were appended to low (0.18 kHz), medium (0.5 kHz), or high (8.0 kHz) frequency pure tones of 230 ms at the short (100 ms) or long (900 ms) SOA. The pure tones were generated at 90 dB SPL and normalized for intensity. For the present study, SOA was operationally defined as the time lapse between the offset of the auditory word token to be matched in rhyme with the picture's name in the primary rhyme task and the onset of the tone to be monitored in the secondary tone task. The SOA values were based on Cook and Meyer (2008), who used these values in a dual-task involving a picture - written word interference paradigm and a tone task.

2.3. Design

The study involved a quasi-experimental repeated measures design with the participants in both groups responding first to the rhyme task and next to the tone task within each trial under both the SOA conditions (short vs. long). The 32 words from the rhyme task were categorized into four sets of 32 trials each. Stimuli pairing for the rhyme and the nonrhyme categories resulted in 16 pairs (e.g., *bear - cart* are two words resulting in one pairing in the nonrhyme condition, which created 16 pairs out of the 32 words for the nonrhyme condition). The remaining 16 pairs from these categories were created by switching the word and picture tokens (e.g., *bear - cart* vs. *cart - bear*). For the replica condition, each word was paired with its picture resulted in 32 pairs (e.g., *bear – bear*). Trials from each category per set were divided equally into the short and the long SOA conditions, which resulted in 16 trials per SOA per set.

2.4. Instrumentation

The experimental stimuli for the rhyme and tone tasks were programmed and presented using Super Lab v4.5 (Cedrus Corporation, 2014). A Dell desktop was used to present the stimuli for the tasks. Verbal and manual responses from the rhyme and tone tasks, as well as spoken responses from the overt naming trials were recorded using a Marantz digital recorder PMD620. In addition, errors from the tone task were recorded using a Cedrus response box. RT, errors, and disfluent overt naming trials from the dual-task were coded and measured using the PRAAT software.

2.5. Procedure

Two trained research assistants or the second author along with the PI administered the entire protocol. The experiment consisted of a picture familiarization task and the rhyme – tone dual-task (Data from a third task administered as part of this protocol and independent of the rhyme – tone dual-task are reported in Sasisekaran & Donohue, 2016). These tasks and the set order within the dual-task were counterbalanced in the order of occurrence across participants in both the groups. Fig. A1 illustrates the rhyme – tone decision dual-task in terms of the event sequence in each trial; the tasks are described in the following subsections.

2.5.1. Picture familiarization

The purpose of this task was to familiarize the participants with the names of the target pictures. Participants viewed the pictures and the corresponding names prior to the task. Subsequently, the pictures were presented individually on a computer screen and participants were asked to name each picture. The experimenter noted and corrected the errors at the end of the task. Additionally, participants were presented again with the pictures that they named incorrectly at first attempt. All participants were able to name all pictures correctly before proceeding to the dual-task.

2.5.2. Rhyme – tone dual-task

The purpose of this dual-task was to investigate differences between the CWS and the age-matched CWNS in the ability to allocate cognitive resources while performing a primary rhyme task and a secondary tone task. Participants were presented the four sets of auditory word - picture stimuli pairs. Additionally, in each set an equal number of low, medium, and high frequency tones from the secondary tasks were presented in the short and the long SOA conditions. Participants were familiarized with the tones and their ability to categorize the tones by frequency was also confirmed.

2.5.3. Task instructions and protocol

During the experiment, participants were seated comfortably in front of the computer screen. Prior to the experiment, participants were instructed to silently name each picture on the screen while matching the word they hear in rhyme to the picture's name. They were asked to respond with a "yes" or "no" to the rhyme task. For the concurrent secondary task, they were told that they would hear a tone after the picture and were asked to press one of three buttons on the response box corresponding to a low, medium, or high tone to indicate the tone pitch.

Following the instructions, practice trials were used to familiarize the participants to the tone task and the rhyme – tone dual-task. A trial in each experimental set consisted of the following series of events: (a) An orienting screen for 500 ms; (b) Auditory presentation of a word coinciding with the onset of a picture; the latter stayed on the screen until participants' responded to the secondary task. Participants were required to say 'yes' or 'no' as soon as possible to indicate the presence/absence of a rhyme match between the auditory word and the picture name; (c) A pure tone of 230 ms presented at the short (100 ms) or the long SOA (900 ms). Manual response to the tone task resulted in the presentation of the same picture again and participants were instructed thereafter to name each picture aloud to ensure that the picture in each trial was named correctly. The experimenter initiated the next trial in the sequence after the participant named the picture or automatically after 10 s.

2.6. Data coding and analysis

The data were analyzed by the first author, second author, and two trained research assistants. RT (ms) from the primary and the secondary tasks were measured using PRAAT. Rhyme RT was defined as the time lapse between the onset of the picture (and the auditory word) in the rhyme task and participants' verbal "yes/no" response. Tone decision RT was defined as the time lapse between the onset of the tone and participants' manual response from the tone task. Trials in each task were categorized into trials with correct and incorrect responses. Only trials with correct responses were included in the RT analysis. These trials in both the tasks were further coded for outlier responses. Outlier responses included trials where the RT for the rhyme and the tone tasks were 2 standard deviations (SD) above or below the individual's Mean RT specific to the task, stimuli category, and SOA. Less than 7% of the trials were excluded as outliers from both the rhyme and tone tasks in each group.

Trials where participants: (a) Named each picture before responding to the rhyme task; (b) Responded to the tone task first, but provided a correct rhyming response; or (c) Responded to both the rhyme and tone tasks simultaneously such that the onset of the responses were not independently determinable, were excluded from the RT analysis. In addition, error responses were coded for both the tasks - Incorrect responses (false positive and false negative) and the absence of a response were coded as errors. Additionally, sequence errors, defined as errors in the dual-task response sequence (rhyme – tone – overt picture naming), were coded and excluded from further analysis. Fewer than 5% of the error trials from both the groups were errors in sequencing.

2.6.1. Reliability

RT and error data from all participants were re-coded in PRAAT by two trained research assistants using the same coding conventions described previously. This analysis was conducted to confirm that the location of the onset and offset markers on PRAAT for the rhyme and the tone task responses were accurate. If discrepancies were noted, these were resolved through discussions between the first author and the research assistants.

2.7. Statistical analysis

Data from the tasks were analyzed separately due to the several categorical independent variables and levels within each variable. The RT data from each task were log transformed and analyzed in a mixed method analysis with Group (CWS, CWNS), Category (Nonrhyme, Rhyme, Replica), and SOA (Short, Long) as the fixed effects and participants as a random effect. A similar mixed method analysis was also conducted on the arcsine transformed error data. Since participants in the study were between 7 and 16 years, age was included in the analysis as a factor. Additionally, correlations computed between Z transformed age and EVT, LAC, digit span raw scores identified that EVT was most correlated with age (EVT, $r = 0.70$, $p < 0.001$; LAC, $r = 0.42$, $p = 0.019$, Digit span, $r = 0.43$, $p = 0.017$). Therefore, EVT was not included in the mixed method. Since digit span's contribution to the age-based differences observed in this task were limited (Sasisekaran & Lei, 2021), this variable was not included in the analysis. Therefore, Z transformed values for age and phoneme awareness skills (LAC scores) were included as relevant factors in the mixed method analyses involving RT and errors.

Statistical analyses were conducted using R (R Core Team, 2017). Mixed methods analyses of the RT and error data from the rhyme and tone tasks were conducted using the lmer package, and the model was fitted using the restricted maximum likelihood estimation method (Bates, Mächler, Bolker, & Walker, 2015). Bonferroni-corrected post-hoc comparisons were conducted using the emmeans package.

3. Results

3.1. Rhyme task: RT analysis

3.1.1. Main effects

Table A1 shows the significant effects from the mixed method analysis. The main effects of Category ($p < 0.001$), SOA ($p < 0.001$), and LAC scores ($p = 0.018$) as a covariate were significant. Averaged across the groups, RT to the rhyme and replica categories were significantly faster compared to the nonrhyme category ($p < 0.001$). RT to the long SOA condition was slower ($p < 0.001$).

3.1.2. Interaction effects

The Category x Age interaction was significant ($p = 0.031$) and showed a significant negative correlation [$p = 0.05/3 = 0.016$] between RT and age for the replica ($r = -0.34$, $p = 0.008$) and the non-rhyme ($r = -0.31$, $p = 0.016$) categories, compared to the rhyme category ($r = -0.32$, $p = 0.013$). The Category x Age x LAC interaction ($p = 0.057$) showed a weak trend for significance and indicated the most difference in RT between the rhyme task categories for the children with lower LAC scores than the group mean. Similarly, there was a trend for the older children with higher LAC scores from both groups to respond faster to all three categories in the rhyme task. None of the other effects were significant.

3.2. Rhyme task: error analysis

3.2.1. Main effects

Table A2 shows the significant effects from the mixed method analysis. Significant effects of Group ($p = 0.001$) and Category ($p = 0.000$) were obtained. The CWS group made significantly more rhyming errors ($p < 0.004$). The significant effect of Category showed that more errors were observed in the rhyme compared to the nonrhyme and replica categories ($p < 0.001$). Age as a covariate showed a trend for significance ($p = 0.056$). A significant Group x Age effect ($p = 0.006$) showed a positive correlation between age and rhyming errors in the CWS ($r = 0.28$, $p = 0.006$). A similar correlation between age and rhyming errors was not evident in the CWNS.

3.2.2. Interaction effects

A significant Group x Category effect was obtained ($p = 0.002$). In the CWS group, more error responses were observed in the rhyme compared to the nonrhyme and replica categories ($p < 0.001$; Fig. A2). In the CWNS, the categories were comparable in rhyming errors. The CWS made significantly more rhyming errors in the rhyme stimuli pairs compared to the CWNS ($p < 0.001$). This effect and the significant Category x Age x LAC interaction ($p = 0.002$) resulted in a significant Group x Category x Age x LAC effect ($p = 0.002$). As shown in Fig. A3, more errors in the rhyme category were evident in the younger CWS, and in the older CWS with lower LAC scores. A significant interaction of Group x Category x SOA x LAC scores was obtained ($p = 0.006$). Across the range of LAC scores, the CWS showed more errors in both the short and the long SOA conditions of the rhyme category compared to the nonrhyme and replica categories. In contrast, the CWNS showed comparatively fewer errors in the rhyme category than the CWS and the category differences were not evident in the CWNS with LAC scores higher than the group average.

3.3. Tone task: RT analysis

3.3.1. Main effects

Table A3 shows the significant effects from the mixed method analysis. Significant effects of SOA ($p < 0.001$) and Category ($p < 0.001$) were obtained. In contrast to the rhyme task, responses to the short SOA condition were significantly slower compared to the long SOA condition ($p < 0.001$). Similar to the rhyme task, tone decision responses for the replica and rhyme categories were faster compared to the nonrhyme category ($p < 0.001$). LAC was a significant predictor of tone task RT ($p = 0.006$).

3.3.2. Interaction effects

The interaction of SOA x Age x LAC scores was significant ($p = 0.007$). Averaged across both groups, the effect of LAC scores on RT was most evident in the older children, and in both the SOA conditions. Although the Group x SOA effect was not significant, the significant interaction of Group x SOA x LAC scores ($p = 0.038$) indicated a modulatory influence of LAC scores on the group differences observed in the SOA conditions. Fig. A4 shows the significant Group x SOA x LAC interaction. In both the groups and for both the SOA conditions, LAC scores correlated negatively with tone task RT (Long SOA, CWNS $= -0.44$, $p < 0.002$; CWS, $r = -0.43$, $p = 0.003$). Additionally, for the CWNS with higher LAC scores than the group average the correlation with RT was highly significant for the Short SOA condition (Short SOA, CWNS $= -0.66$, $p < 0.0001$; CWS, $r = -0.42$, $p = 0.004$). Therefore, while the CWS and CWNS were generally comparable in the RT difference between the Short vs. Long SOA conditions, with increase in LAC scores the SOA-based differences reduced in the CWNS.

3.4. Tone task: error analysis

The groups were comparable in detecting the low, medium, and high frequency tones (CWNS, Low pitch, *Mean* errors = 3.32 %, *SD* = 0.049; Medium = 3.31 %, *SD* = 0.063, High = 3.32 %, *SD* = 0.078; CWS, Low pitch, *Mean* errors = 3.31 %, *SD* = 0.063; Medium = 3.32 %, *SD* = 0.078, High = 3.34 %, *SD* = 0.063).

3.4.1. Main effects

Table A4 presents the main and interaction effects from the mixed methods analysis. The main effect of Category ($p = 0.008$) was significant. RT to the tone task in the replica condition was significantly faster compared to the nonrhyme condition ($p = 0.021$). RT to the nonrhyme vs. rhyme and rhyme vs. replica conditions were comparable.

3.4.2. Interaction effects

The Category x SOA effect was significant ($p = 0.033$), although the relevant comparisons were not significant at post-hoc testing.

4. Discussion

We compared school-age CWS and CWNS in a dual-task requiring word-level rhyming decisions during silent picture naming and pitch decisions. The effort allocation associated with dual tasking was varied in an overlapping task paradigm (OTP) through the

Table A1
Mixed method analysis of response time from the rhyme task with Group, Category, and SOA as fixed effects, age and phoneme awareness as relevant factors.

	df	F value	Pr(>F)	
Group	1,30	0.026	0.874	
Category	2,150	27.456	0.000	***
SOA	1,150	39.305	0.000	***
Age	1,30	0.800	0.378	
Phoneme awareness	1,30	6.209	0.018	*
Group x Category	2,150	0.734	0.482	
Group x SOA	1,150	0.441	0.508	
Category x SOA	2,150	0.859	0.426	
Group x Age	1,30	2.093	0.158	
Category x Age	2,150	3.568	0.031	*
SOA x Age	1,150	1.962	0.163	
Group x Phoneme awareness	1,30	0.097	0.757	
Category x Phoneme awareness	2,150	1.746	0.178	
SOA x Phoneme awareness	1,150	3.416	0.067	.
Age x Phoneme awareness	1,30	0.978	0.331	
Group x Category x SOA	2,150	0.190	0.827	
Group x Category x Age	2,150	0.893	0.412	
Group x SOA x Age	1,150	1.148	0.286	
Category x SOA x Age	2,150	0.899	0.409	
Group x Category x Phoneme awareness	2,150	0.295	0.745	
Group x SOA x Phoneme awareness	1,150	3.093	0.081	.
Category x SOA x Phoneme awareness	2,150	0.611	0.544	
Group x Age x Phoneme awareness	1,30	0.000	0.985	
Category x Age x Phoneme awareness	2,150	2.919	0.057	.
SOA x Age x Phoneme awareness	1,150	0.500	0.481	
Group x Category x SOA x Age	2,150	0.362	0.697	
Group x Category x SOA x Phoneme awareness	2,150	0.154	0.857	
Group x Category x Age x Phoneme awareness	2,150	0.084	0.920	
Group x SOA x Age x Phoneme awareness	1,150	0.507	0.477	
Category x SOA x Age x Phoneme awareness	2,150	0.191	0.826	
Group x Category x SOA x Age x Phoneme awareness	2,150	0.581	0.561	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' >0.05 '.'.

manipulation of temporal separation (SOA) between the stimuli of the primary and the secondary tasks. RQ1 investigated the PRP effects associated with the SOA manipulation (long vs. short SOA) in the primary and secondary tasks in both the groups. RQ 2 investigated performance in the primary rhyme task involving rhyming between orthographically and phonologically congruent stimuli pairs from three categories (nonrhyme, rhyme, and replica) in the short vs. long SOA conditions. RQ3 investigated SOA-based performance differences in the secondary tone task. The findings and the implications for rhyming and dual tasking in school-age CWS and CWNS are discussed.

4.1. PRP dual-task effects

RQ 1 investigated the PRP response for the rhyme and the tone tasks in the dual-task. The hypothesized PRP response in dual-task studies involves no effects of SOA on the primary task performance and slower response to the secondary task at the short compared to the long SOA condition. However, based on the findings from other studies (Cook & Meyer, 2008; Sasisekaran & Donohue, 2016; Sasisekaran & Lei, 2021), we hypothesized slower RT and more rhyming errors in the long than the short SOA condition. In contrast, slower RT and more tone response errors were expected in the short SOA condition. In response to RQ1, the findings from the present study confirmed the dual-task expectations for the RT data and the groups were similar in the PRP response. In both the groups, RT to the rhyme task was significantly slower at the long SOA condition while RT to the tone task was significantly slower at the short SOA condition. We did not observe an effect of SOA on accuracy. These varying effects of the SOA manipulation in the primary vs. the secondary task RT within the OTP have also been reported in the other dual-task studies involving fluent adults and children.

Theories of dual tasking (e.g., Kahneman, 1973) have not attributed a SOA-based effect in the primary task due to the expected prioritization of resources for responding to this task first. However, based on a recent review Strobach, Schütz, and Schubert (2015) concluded that an SOA effect in the primary task is a strategic product of flexible scheduling of limited cognitive resources. Such an effect in the long SOA condition of the rhyme task in this study suggested potential overlap of several resource demanding processes occurring concurrently at a later time point in the rhyme task, thereby resulting in slower responses (for a similar interpretation, see Cook & Meyer, 2008). In contrast, slower response in the short SOA condition of the tone task suggested heightened cognitive resource demands associated with concurrent processing of the tone task stimuli when presented at short temporal separation from the rhyme task stimuli. The task-based differences in the effects of SOA observed in this study suggested that independent mechanisms mediate the SOA effects in the primary and the secondary tasks. For the rhyme task such mechanisms are specific to implementing the processes involved in silent naming, encoding and matching of rhymes from the auditory word – picture pairs varying in the extent of

Table A2
Mixed method analysis of errors from the rhyme task with Group, Category, and SOA as fixed effects, age and phoneme awareness (scores from LAC) as relevant factors.

	df	F value	Pr(>F)	
Group	1,30	12.617	0.001	**
Category	1,150	24.620	0.000	***
SOA	1,150	1.918	0.168	
Age	1,30	3.948	0.056	.
Phoneme awareness	1,30	1.853	0.184	
Group x Category	2,150	6.262	0.002	**
Group x SOA	1,150	0.001	0.972	
Category x SOA	2,150	0.049	0.952	
Group x Age	1,30	8.700	0.006	**
Category x Age	2,150	0.147	0.864	
SOA x Age	1,150	0.041	0.841	
Group x Phoneme awareness	1,30	0.620	0.437	
Category x Phoneme awareness	2,150	1.025	0.361	
SOA x Phoneme awareness	1,150	1.784	0.184	
Age x Phoneme awareness	1,30	0.176	0.678	
Group x Category x SOA	2,150	0.975	0.379	
Group x Category x Age	2,150	0.714	0.491	
Group x SOA x Age	1,150	1.637	0.203	
Category x SOA x Age	2,150	0.132	0.877	
Group x Category x Phoneme awareness	2,150	0.427	0.653	
Group x SOA x Phoneme awareness	1,150	3.077	0.081	.
Category x SOA x Phoneme awareness	2,150	0.154	0.858	
Group x Age x Phoneme awareness	1,30	0.980	0.330	
Category x Age x Phoneme awareness	2,150	6.625	0.002	**
SOA x Age x Phoneme awareness	1,150	1.526	0.219	
Group x Category x SOA x Age	2,150	2.585	0.079	.
Group x Category x SOA x Phoneme awareness	2,150	5.268	0.006	**
Group x Category x Age x Phoneme awareness	2,150	6.576	0.002	**
Group x SOA x Age x Phoneme awareness	1,150	0.918	0.340	
Category x SOA x Age x Phoneme awareness	2,150	1.957	0.145	
Group x Category x SOA x Age x Phoneme awareness	2,150	1.537	0.218	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' >0.05 '.'.

orthographic and phonological congruence, and mapping these on to categorical yes vs. no responses. For the tone task such mechanisms are specific to managing resource allocation associated with processing the tone task stimuli occurring immediately after the rhyme task stimuli.

4.2. Effects of dual tasking in the primary rhyme task

4.2.1. Effects of dual tasking on rhyming

The primary task in this study required participants to monitor rhymes in auditory word – picture pairs. The stimuli pairs varied minimally in complexity and orthographical /phonological congruence between the stimuli pairs in each rhyme category was maintained (O-R- or O + R+ rather than O-R + or O + R-). The significant effect of Category showed RT differences between the nonrhyme, rhyme, and replica pairs in the rhyme task, which we interpret based on studies of rhyming in typically developing children and adults. Such studies indicate that the ability to rhyme is acquired by 5 years (e.g., Coch et al., 2005), while ongoing changes in rhyming performance are evident in older children and adults for the more complex stimuli involving orthographical and phonological incongruence (e.g., Bitan et al., 2009; Booth et al., 2004). The main effect of Category showed faster responses for the replica and the rhyme compared to the nonrhyming stimuli pairs in both the CWNS and the CWS, although all three stimuli categories were congruent for orthography and phonology. Additionally, more errors were observed for the rhyme compared to the nonrhyme and replica categories in both the groups, thereby suggesting that the rhyme category may have involved comparatively complex stimuli processing requirements. Faster and accurate processing of complex rhyme stimuli has been attributed to greater convergence between the peripheral neural centers involved in rhyming and the executive control centers in the frontal lobe that enhances the salience of the stimuli properties to enable efficient rhyming. The findings of differences between the different categories of the rhyme task in the present study are also in agreement with the behavioral findings reported in Johnston and McDermott (1986) and Seidenberg and Tanenhaus (1979) in adults.

4.2.2. Rhyming in CWS vs. CWNS

In response to RQ 2, we hypothesized that school-age CWS will differ from CWNS in the primary rhyme task (e.g., Gerwin et al., 2019; Mohan & Weber, 2015). The most support for group differences in rhyming was found in the error data. The findings of significant Group and Group x Age effects confirmed more rhyming errors and a positive correlation between rhyming errors and age in the CWS. Furthermore, the significant Group x Category interaction resulted in more errors in the rhyme compared to the nonrhyme

Table A3
Mixed method analysis of response time (ms) from the tone task with Group, Category, and SOA as fixed effects, age and phoneme awareness (scores from LAC) as relevant factors.

	df	F value	Pr(>F)	
Group	1,30	0.844	0.365	
Category	2,150	35.805	0.000	***
SOA	1,150	226.123	0.000	***
Age	1,30	2.073	0.160	
Phoneme awareness	1,30	8.635	0.006	**
Group x Category	2,150	2.224	0.112	
Group x SOA	1,150	0.715	0.399	
Category x SOA	2,150	0.967	0.383	
Group x Age	1,30	0.669	0.420	
Category x Age	2,150	0.361	0.698	
SOA x Age	1,150	0.000	0.994	
Group x Phoneme awareness	1,30	0.001	0.974	
Category x Phoneme awareness	2,150	0.375	0.688	
SOA x Phoneme awareness	1,150	0.263	0.609	
Age x Phoneme awareness	1,30	1.746	0.196	
Group x Category x SOA	2,150	0.471	0.625	
Group x Category x Age	2,150	1.636	0.198	
Group x SOA x Age	1,150	0.895	0.346	
Category x SOA x Age	2,150	1.185	0.309	
Group x Category x Phoneme awareness	2,150	0.120	0.887	
Group x SOA x Phoneme awareness	1,150	4.364	0.038	*
Category x SOA x Phoneme awareness	2,150	0.793	0.454	
Group x Age x Phoneme awareness	1,30	0.041	0.841	
Category x Age x Phoneme awareness	2,150	0.445	0.642	
SOA x Age x Phoneme awareness	1,150	7.475	0.007	**
Group x Category x SOA x Age	2,150	0.435	0.648	
Group x Category x SOA x Phoneme awareness	2,150	0.293	0.746	
Group x Category x Age x Phoneme awareness	2,150	0.638	0.530	
Group x SOA x Age x Phoneme awareness	1,150	0.279	0.598	
Category x SOA x Age x Phoneme awareness	2,150	0.472	0.624	
Group x Category x SOA x Age x Phoneme awareness	2,150	0.417	0.660	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' >0.05 '.'.

and replica category decisions in the rhyme task. A difference that was evident in both the younger and the older CWS and across a range of phoneme awareness skills. Least differences in the category-based rhyming errors were observed between the groups for the older children with higher phoneme awareness skills. These findings are similar to Weber-Fox et al. (2008), who reported reduced overall accuracy and more errors in rhyming in school-age CWS when the task required the encoding of different phonological representations from words that were orthographically similar (O + P-; Cow – Snow). In the present study, we found similar group differences in congruent rhyme stimuli pairs perhaps because the rhyme task was performed within the context of a dual-task.

Hence, the Group x Age effect in rhyming accuracy in the present study is attributable either to a deficit in rhyming itself or to a deficit in rhyming in a dual-task. Difficulties with rhyming in a dual-task due to limitations in the effective management of neural resources should have resulted in a significant Group x SOA effect for RT and or errors. This expectation was confirmed by a significant interaction of Group x Category x SOA x phoneme awareness. While the CWNS showed a speed accuracy trade-off in the rhyme category with slower RT and fewer errors in the more resource demanding long SOA condition, the CWS showed comparable RT to the CWNS and significantly more errors in both the short and the long SOA conditions.

A rhyming deficit should have resulted in more errors in the younger CWS thereby suggesting immature rhyming abilities. To the contrary, we found more rhyming errors with age in the CWS group associated with the processing of more complex rhyme stimuli. Bitan et al. (2009) reported developmental changes in brain activation pattern in areas including the fusiform gyrus, inferior frontal gyrus, left temporal cortex, and the medial frontal gyrus in children between 6 and 15 years. Better rhyme performance in the older children (Bitan et al., 2009) and adults (e.g., Booth et al., 2004) for rhyme pairs involving conflicting orthography and phonology (e.g., O + P- or O-P+) has been interpreted to suggest the use of cognitive control strategies due to increased frontal lobe connectivity. Such strategies enhance selective attention to phonological aspects of covert speech in working memory due to the greater convergence between the neural centers involved in rhyme processing resulting in the co-activation or suppression of orthographic information to facilitate rhyming. In the present study, the Group x Age interaction was enhanced further by the Group x Category effect which showed that the rhyming errors in CWS were specific to the rhyme rather than the nonrhyme or the replica pairs. Additionally, this interaction was modulated by factors that have previously been identified to influence rhyming in a dual-task, including age and phoneme awareness skills (e.g., Sasisekaran & Lei, 2021). Our findings of more errors in the rhyme rather than the nonrhyme category confirmed the findings reported in other studies of CWS. For instance, Gerwin and Weber (2020) reported significant group differences in the anterior N400 Rhyme Effect (RE) indexing rhyme pair decisions in 7 to 8-year-old CWS compared to age-matched CWNS in a rhyme perception task. The groups were comparable in the posterior RE indexing decisions from nonrhyme pairs. Furthermore, individual differences were observed in the anterior RE. The use of mixed method analysis in this study took into consideration such

Table A4
Mixed method analysis of errors from the tone task with Group, Category, and SOA as fixed effects, age and phoneme awareness (scores from LAC) as relevant factors.

	df	F	pr(>F)	
Group	1,30	1.406	0.245	
Category	2,150	4.875	0.008	**
SOA	1,150	0.275	0.601	
Age	1,30	0.482	0.493	
Phoneme awareness	1,30	1.632	0.211	
Group x Category	2,150	0.359	0.699	
Group x SOA	1,150	0.001	0.983	
Category x SOA	2,150	3.481	0.033	*
Group x Age	1,30	0.228	0.637	
Category x Age	2,150	0.008	0.992	
SOA x Age	1,150	0.273	0.602	
Group x Phoneme awareness	1,30	0.016	0.901	
Category x Phoneme awareness	2,150	2.032	0.135	
SOA x Phoneme awareness	1,150	0.268	0.606	
Age x Phoneme awareness	1,30	0.979	0.330	
Group x Category x SOA	2,150	2.171	0.118	
Group x Category x Age	2,150	2.619	0.076	.
Group x SOA x Age	1,150	0.002	0.967	
Category x SOA x Age	2,150	1.503	0.226	
Group x Category x Phoneme awareness	2,150	1.234	0.294	
Group x SOA x Phoneme awareness	1,150	0.968	0.327	
Category x SOA x Phoneme awareness	2,150	0.130	0.878	
Group x Age x Phoneme awareness	1,30	0.001	0.970	
Category x Age x Phoneme awareness	2,150	0.754	0.473	
SOA x Age x Phoneme awareness	1,150	0.650	0.421	
Group x Category x SOA x Age	2,150	0.162	0.851	
Group x Category x SOA x Phoneme awareness	2,150	0.507	0.603	
Group x Category x Age x Phoneme awareness	2,150	1.115	0.331	
Group x SOA x Age x Phoneme awareness	1,150	1.511	0.221	
Category x SOA x Age x Phoneme awareness	2,150	0.968	0.382	
Group x Category x SOA x Age x Phoneme awareness	2,150	0.129	0.879	

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ >0.05 ‘.’.

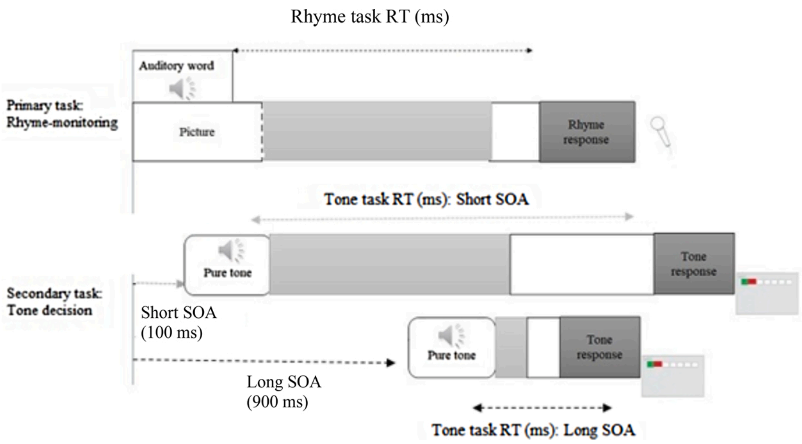

Fig. A1. Events in each trial of the rhyme – tone dual-task.

individual differences in task performance and found significant group differences only in rhyme decisions that required additional effort compared to decisions that are based entirely on visual similarities (e.g., replica pairs) and dissimilarities (e.g., nonrhyme pairs). Hence, in response to RQ 1 we found limitations in the effective encoding of the phonological aspects of covert speech supporting rhyming in CWS. Compared to age matched CWNS, we found protracted development of rhyming abilities involving complex rhyme pairs in the cross-section of CWS between 7 and 16 years that may be mitigated to some extent by phoneme awareness skills.

4.3. Effects of dual tasking in the secondary tone task

We investigated the effects of dual tasking in a secondary tone decision task in the CWS and CWNS. The SOA-based RT effect in the

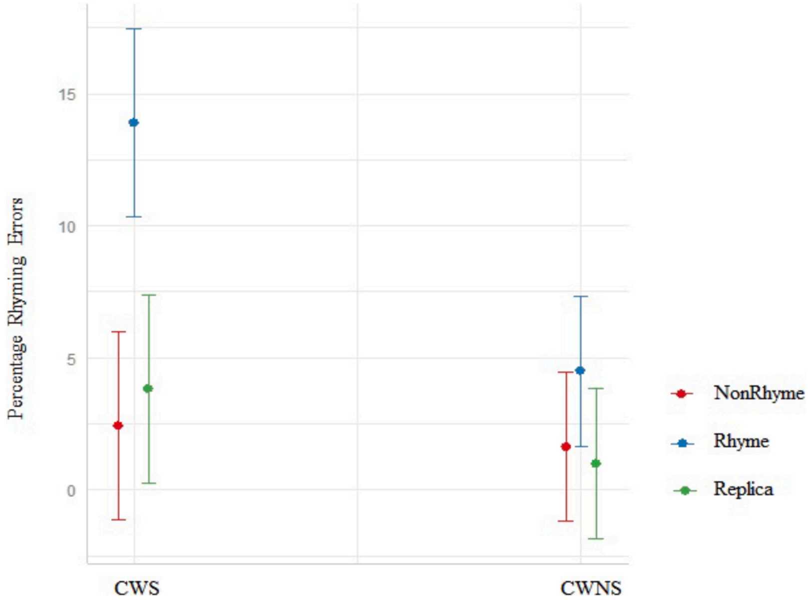

Fig. A2. Mean and Standard Deviation of rhyming errors by stimuli categories (nonrhyme, rhyme, and replica) in the rhyme task.

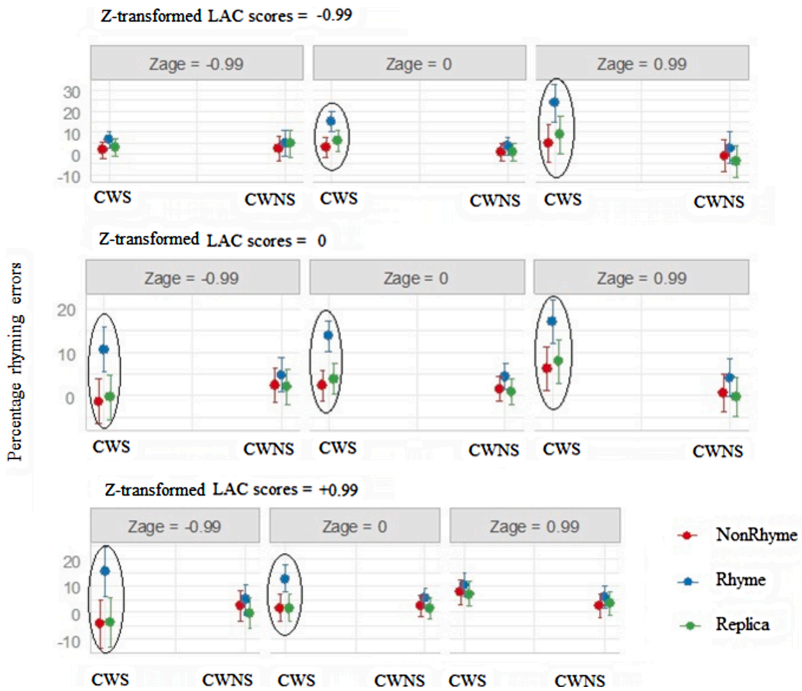

Fig. A3. Mean and Standard Deviation of rhyming errors by category, Z-transformed age and phoneme awareness skills (scores from LAC). LAC: Lindamood and Lindamood Auditory Conceptualization Test, 3rd version.

tone task (short > long SOA) was evident in both the groups and was comparable, thereby suggesting that the tone task was not sufficiently complex to elicit group differences in the secondary task. Additionally, the groups were comparable in differentiating the tone frequencies used in the tone task. At the outset the lack of a main effect of Group in the tone task is contradictory to Sasisekaran and Basu (2017), who reported more errors in a similar tone task in a dual-task in school-age CWS compared to the CWNS (also see event-related potential findings from Maxfield et al. (2016), for similar results in AWS). Several factors are considered in interpreting the present findings. First, the primary task used in Sasisekaran and Basu (2017) was a more complex phoneme-monitoring task and the task elicited variable performance in the CWS. Yoncheva, Maurer, Zevin, and McCandliss (2014) reported that attending to

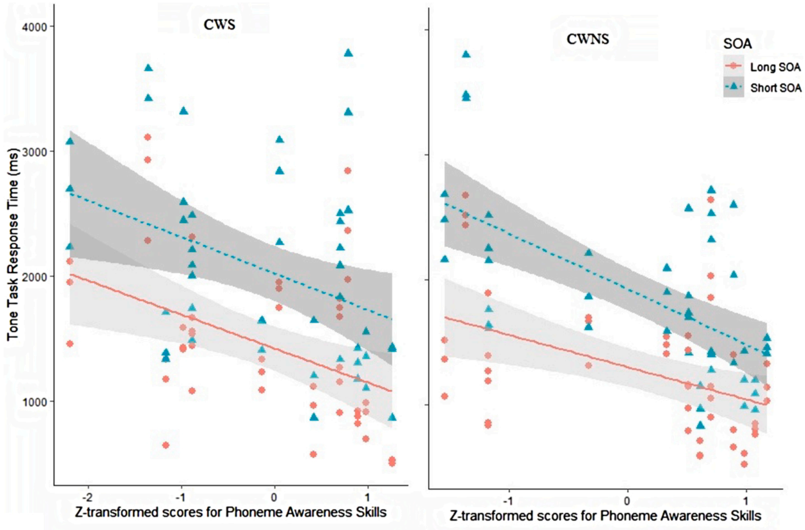

Fig. A4. Mean response time (ms) from the tone task by Group, SOA, and phoneme awareness skills (Z-transformed scores from LAC). LAC: Lindamood and Lindamood Auditory Conceptualization Test, 3rd version.

phonological (rhyme unit of auditory words) information in covert speech resulted in more neural recruitment than attending to non-phonological melodic information in the same stimuli, thereby suggesting that phonological encoding in covert speech is a comparatively resource demanding process. On a developmental scale, tasks involving phonemic segmentation are acquired later than those involving holistic rhyme units (e.g., Brooks & MacWhinney, 2000; Sasisekaran & Weber-Fox, 2012). Therefore, the group differences in the secondary tone task in Sasisekaran and Basu (2017) is attributable to the more complex primary task. Indeed, Brutten and Trotter (1986) reported significant differences in the primary task for different secondary tasks, all involving varying demands on language planning and speech production. Furthermore, the findings from this study do not entirely rule out group differences in the secondary task. The significant Group x SOA x LAC interaction confirmed that factors influencing rhyme task performance also influenced performance in the tone task. A subgroup of CWNS with higher phoneme awareness skills showed reduced RT difference between the long and the short SOA conditions thereby suggesting higher efficiency with resource allocation for dual tasking.

Two interrelated mechanisms involving cognitive effort have been identified as contributing to dual-task performance, including: (a) Executive processes involved in task set reconfiguration (e.g., goal planning and rules for stimulus – response mapping differences between the primary and secondary tasks), and (b) Task processes including facilitation /inhibition effects from the primary task stimuli to the secondary task (Strobach et al., 2018). The findings from this study suggested that both of these interrelated processes may be involved in determining the extent to which the primary task can influence performance in the secondary task in CWS. Preliminary evidence for this was obtained in the effects of phonemic awareness skills on the SOA-based group differences in the tone task itself, which suggested better performance in the tone task with higher LAC scores. Since phoneme awareness skills are more directly relevant for performance in the rhyme task, the use of more complex rhyme pairs may have obviated group differences in the tone task responses at the short SOA condition. Additionally, with increase in rhyme task complexity, that is, with more complex stimulus-to-response mapping for the primary task (e.g., varying levels of orthographic and phonological congruence and incongruence resulting in a simplified yes vs. no response), the rhyme stimuli might exert a more direct influence on the tone task performance. Indeed, previous dual-task studies have found that rhyme pairs involving incongruent orthography and phonology resulted in larger dual-task effects in both the primary and the secondary tasks in AWS compared to AWNS (Jones et al., 2012). In the present study, the rhyme task categories were all congruent for orthography and phonology and may have involved limited demands on the response reorganization required for task switching. Hence, in response to RQ3 we found weak evidence for group differences in the effects of dual tasking on the secondary task.

4.4. Conclusions and limitations

In the present study, we investigated performance in a rhyme - tone dual-task with carefully selected stimuli that varied minimally in orthographic and phonological congruence. The three research questions compared CWS and CWNS in the PRP pattern of dual-task performance for this task combination and determined performance differences in the rhyme and the tone tasks. Both CWS and CWNS showed comparable SOA-based PRP effects for the rhyme (RT, Long > Short SOA) and the tone tasks (RT, Short > Long SOA). We found age-based limitations in rhyming and protracted development of rhyming abilities involving rhyme pairs compared to nonrhyme and replica pairs in the CWS compared to the CWNS. Additionally, the CWNS showed a speed-accuracy trade-off in the more cognitively demanding long SOA condition of the rhyme task for the rhyme stimuli pairs, while the CWS did not show a similar effect. Poor rhyming associated with the rhyme pairs in this study suggested limited intersystem integration to facilitate processing of the more complex stimuli pairs used in the study. The neural systems facilitating this integration evolve between 7 and 15 years (see Booth et al.,

2004) and the findings from this study suggested that rhyming errors for complex stimuli pairs increase in the CWS in this age range. Our findings also suggested that poor rhyming abilities in CWS are mitigated to some extent by strengths in phoneme awareness. The findings from the secondary tone task did not offer unequivocal support for difficulties with resource allocation in the CWS. However, a subgroup of CWNS with higher phoneme awareness skills showed higher efficiency with resource allocation for dual tasking.

Rhyme cues in connected speech have been reported to facilitate recall, word learning, and speech fluency (Bosshardt et al., 2002; Nairne & Kelley, 1999). Future studies should determine the extent to which rhyme cues can influence resource allocation in dual-tasks involving connected speech and fluency, particularly since the findings from this study suggested that the factors influencing performance in the rhyme task also influenced performance in the secondary tone task. Although we did not find an effect of dual tasking in the secondary task, other studies have reported such effects. Increasing primary and secondary task complexity and varying the extent to which such tasks rely on similar cognitive resources offers the opportunity to test for factors influencing dual tasking in CWS.

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Appendix A

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