CLINICAL LINGUISTICS & PHONETICS
https://doi.org/10.1080/02699206.2018.1504988



# Segmental and metrical complexity during non-word repetition in adults who stutter

Geoffrey A. Coalson [a], Courtney T. Byrd [b], Shanley B. Treleaven [a], and Lillian Dang [a]

[a]Department of Communication Sciences and Disorders, Louisiana State University, Baton Rouge, LA, USA; [b]Department of Communication Sciences and Disorders, The University of Texas at Austin, Austin, TX, USA

**ABSTRACT**

Non-word repetition is weaker for adults who stutter (AWS) compared to adults who do not stutter (AWNS) as phonological demands increase. However, non-word stimuli used in previous studies varied by length, but did not vary with regard to segmental or metrical complexity. The purpose of the present study was to examine the unique influence of these two distinct types of complexity on non-word repetition in AWS and AWNS via administration of the *Test of Phonological Structure* (TOPhS). Twenty-four adults (12 AWNS, 12 AWS) repeated 96 non-words within a soundproof booth immediately after auditory presentation. All 96 non-word targets included on the TOPhS were one to four syllables in length and ranked based on segmental complexity (simple, moderate and complex) and metrical complexity (simple, moderate and complex). No main effect of metrical complexity was detected between groups, and no differences in accuracy were observed for non-words with simple or moderate segmental complexity. However, AWS were significantly more likely to produce a phonemic error when repeating words with complex segmental structure than AWNS, irrespective of metrical complexity. Segmental complexity may contribute to the differences in phonological working memory in AWS when controlling for metrical complexity and length.

**ARTICLE HISTORY**
Received 30 April 2018
Revised 20 July 2018
Accepted 23 July 2018

**KEYWORDS**
Stuttering; phonology; adult; psycholinguistics

## Introduction

Production of words and non-words requires rapid integration of two distinct but critical types of information prior to motor programming: segmental information (i.e. the sounds that comprise a word) and metrical information (i.e. the number of syllables and location of syllabic stress; see Levelt, Roelofs, & Meyer, 1999). Difficulty accurately producing non-words may reflect, at least in part, difficulties encoding phonological speech plans – a critical level of processing implicated in several theories of stuttering (Arenas, 2016; Postma & Kolk, 1993; Smith & Weber, 2016). It follows, then, that performance on tasks that rely heavily on phonological encoding – such as non-word repetition – often distinguish persons who stutter from their typically fluent peers. For example, children who stutter exhibit poorer accuracy than typically fluent peers (e.g. Hakim & Bernstein Ratner, 2004; Pelczarski & Yaruss, 2016; cf. Bakhitar et al., 2007) even for stimuli as short as two and three syllables (Anderson & Wagovich, 2010; Anderson, Wagovich, & Hall, 2006). This reduced accuracy may serve as a predictive factor of persistence (e.g. Spencer & Weber-Fox, 2014). Adults who stutter (AWS)

**CONTACT** Geoffrey A. Coalson gcoals1@lsu.edu Department of Communication Sciences and Disorders, Louisiana State University, 73 Hatcher Hall, Baton Rouge, LA 70803, USA

may also be uniquely compromised when repeating or recalling novel stimuli compared to adults who do not stutter (AWNS) as the length of the target non-word increases (>5 syllables; Byrd, McGill, & Usler, 2015; Byrd, Vallely, Anderson, & Sussman, 2012; Sasisekaran & Weisberg, 2014). Additional research has demonstrated AWS are significantly less accurate than AWNS, even when repeating shorter non-words, when the segmental complexity (three syllables; Sasisekaran & Weisberg, 2014) and/or metrical complexity (two syllables; Coalson & Byrd, 2015, 2017) are manipulated. Taken together, these data suggest that phonological encoding and/or working memory in AWS is sensitive to both the segmental and metrical properties of a target utterance and, similar to children who stutter, poorer performance is not contingent on increased length. However, the overlapping contribution of segmental and metrical complexity within traditional tests of non-word repetition makes it difficult to isolate which aspect of the phonological code is more problematic for individuals who stutter.

## Segmental properties of non-word stimuli within stuttering research

Only a few studies have examined whether individuals who stutter exhibit greater difficulty retaining a novel phonological sequence consisting of complex segmental features. Ludlow, Siren, and Zikria (1997) reported poorer phoneme accuracy for AWS ($n = 5$) than AWNS ($n = 7$) when producing one of two 6-syllable non-words ('abisthwoychleet', 'eepashfwujbok'). Although the influence of target complexity was not directly manipulated in their study, the segmental difficulty of non-word targets is consistent with the notion that segmental complexity may differentiate groups. In contrast, Smith, Sadagopan, Walsh, and Weber-Fox (2014) reported near ceiling performance for AWS ($n = 17$) and AWNS ($n = 17$) for 2-, 3- and 4-syllable non-words during the non-word repetition task (NRT; Dollaghan & Campbell, 1998), and similar accuracy for 1- to 4-syllable 'mab' non-word set developed for kinematic analysis [mab, mabshibe, mabfieshabe, mabshytidoib, mabteebeebee]. The 'mab' non-words described in their study simultaneously increased the length and segmental complexity of four target non-words, with the exception of the fifth 'simple' 4-syllable target [mabteebeebee] to compare the effects of length versus complexity. The phonemic accuracy between groups when repeating the simple and complex 4-syllable non-words was not reported. However, authors did report that during accurate production, lip aperture variability was higher for both groups for the 4-syllable complex non-word than its 4-syllable, simpler form.

Sasisekaran and Weisberg (2014) administered an NRT that required AWNS ($n = 10$) and AWS ($n = 10$) to complete the NRT and then repeat a set of eight novel words developed for kinematic analyses which were systematically varied in segmental complexity. Of these eight non-words, six included simple and complex targets at 3 syllable lengths (3, 4, 6 syllables). Complex stimuli were defined by inclusion of 'middle and late 8' consonants and/or 2 or more consonant clusters. The final non-word pair included simple and complex three-syllable non-words that also included sound combinations not present in English (simple [maebthwaipfkrob], complex [maebshfujtshloib]). Similar to Smith et al. (2010), no group differences were detected for NRT performance other than the expected length effect for both groups (3- and 4-syllable non-words were less accurate than 1- and 2-syllable non-words). Unlike Smith et al. (2010), phonemic accuracy between the simple and complex experimental targets was compared at each length for AWS and AWNS. As expected, and similar to previous studies (Byrd et al., 2015, 2012; Ludlow et al., 1997), AWS were less accurate than AWNS when repeating longer 6-syllable non-words, irrespective of segmental complexity. However, two findings indicated that length may not necessarily be the only mediating factor between groups. First, when averaged across lengths, AWS were less accurate than AWNS when repeating complex than simple non-words. Second, AWS were significantly less accurate than AWNS when repeating 3-syllable non-words with non-native sound combinations compared to all other lengths and word types. These findings suggest that when segmental complexity was increased, AWS demonstrated greater difficulty irrespective of length.

Combined, these studies present an inconsistent account of the effects of segmental complexity during non-word repetition in AWS. However, all non-word stimuli used in Sasisekaran and Weisberg (2014), as well as Smith et al. (2010), were presented with alternating STRONG–weak stress patterns – the dominant, native stress patterns within English. Perhaps, the use of high-frequency metrical stress patterns may have improved the accuracy of both groups and muted any potential group differences in each study.

## Metrical properties of non-word stimuli within stuttering research

Metrical properties refer to the assignment of syllabic stress and syllable boundaries within the intended speech plan. To date, only three studies have been conducted in children who stutter or AWS that specifically examined the influence of metrical stress on phonological working memory. Hakim and Bernstein Ratner (2004) found that children who stutter ($n$ = 8; ages 4 to 8 years old) repeated stimuli from the *Children's Test of Nonword Repetition* (Gathercole & Baddeley, 1996) (CNRep) with poorer accuracy compared to fluent peers ($n$ = 8). In an additional analysis, researchers compared repetition accuracy for 4-syllable non-words presented with non-English stress pattern (i.e. word-final stress) to the same 4-syllable non-words with standard English stress. Although group differences did not reach significance, children who stutter produced a greater number of phoneme errors compared to fluent peers when repeating targets with atypical stress patterns.

Two studies specifically examining non-word repetition accuracy based on manipulation of stress assignment of short, 2-syllable non-words have been completed with AWS. Coalson and Byrd (2015) reported a greater number of phonemic errors and stress errors for AWS ($n$ = 11) when producing 2-syllable non-words with less frequent iambic stress (i.e. weak–STRONG) than AWNS ($n$ = 11), but comparable differences during identical non-words with high-frequency trochaic stress (i.e. STRONG–weak). In a follow-up study, Coalson and Byrd (2017) found AWS ($n$ = 13) were less able than AWNS ($n$ = 13) to accurately recall these short, iambic non-words than trochaic non-words upon removal of auditory–orthographic cues. AWNS exhibited no significant difference in phonemic accuracy based on manipulation of syllabic stress. Taken together, these data suggest that when length and segmental composition remain constant, manipulation of stress pattern alone can result in greater phonemic error during repetition in individuals who stutter. However, these differences are attributed to the manipulation of metrical stress alone. Similar to Sasisekaran and Weisberg (2014), it is possible that more robust differences would have emerged if segmental complexity had been manipulated as well.

## Test of Phonological Structure

To date, researchers that have considered the influence of segmental complexity and metrical complexity during non-word repetition in AWS have manipulated only one of these two critical properties without manipulation of the other. However, segmental properties and metrical properties are both necessary components of a phonological speech plan – novel or otherwise. Because each property has been measured in isolation from each other in previous studies, findings reported thus far may not accurately represent the ability of AWS to encode and retain phonological sequences in working memory. One measure – the *Test of Phonological Structure* (TOPhS; Van Der Lely & Harris, 1999) – provides stimuli that systematically vary in segmental and metrical properties. The TOPhS was developed, in part, to highlight the importance of prosodic complexity during non-word repetition, which has been infrequently varied using standard measures of non-word repetition. Gallon, Harris, and Van Der Lely (2007) found that phonemic accuracy of language-impaired participants ($n$ = 13, 12–20 years of age) was lower than language-matched peers ($n$ = 24, 4–8 years of age), when repeating bisyllabic iambic sequences (59.6%) compared to trochaic sequences (80.1%), suggesting that greater metrical complexity impacted segmental accuracy. Although we do not expect AWS to demonstrate similar difficulties to young children, or children with language impairment, the systematic variation of segmental and metrical complexity of stimuli developed for TOPhS provides an opportunity to disambiguate if one of these two phonological properties may be more problematic for AWS.

## Rationale for current study

Of the studies which have considered phonological complexity of non-word stimuli, researchers either (a) manipulated segmental complexity without varying metrical properties (Sasisekaran & Weisberg, 2014; Smith et al., 2010) or (b) manipulated segmental complexity without varying segmental properties (Coalson & Byrd, 2015, 2017). To date, and to these authors' knowledge, no study has explored whether or not one of these two factors may contribute more significantly to the differences in non-word performance noted thus far. Identifying whether one of these two factors is uniquely challenging to persons who stutter is a critical step towards maximizing the diagnostic or prognostic power of existing nonword repetition tasks (NRTs) during clinical assessment and intervention.

Thus, the purpose of the present study was to measure the accuracy of AWS and AWNS using non-words developed for the TOPhS (Van Der Lely & Harris, 1999). The stimuli on the TOPhS were developed to incrementally increase the segmental complexity and metrical complexity of four simple, bisyllabic non-words, resulting in a set of 96 non-words balanced for segmental and metrical complexity that do not exceed four syllables in length. From the minimal available research, we predicted that segmental complexity and metrical complexity would each independently influence the accuracy of AWS. Based on the theoretical independence of segmental encoding and metrical encoding proposed by Levelt et al. (1999) during phonological encoding, we also predict that increased complexity in both domains will have an aggregate influence of each on the accuracy of AWS, with the greatest effect observed in the presence of both increased segmental and metrical complexity. If differences are observed for AWS based on one property, but not the other, findings may reflect an underlying difficulty in specific phonological properties of speech rather than an overall increased demand. Thus, we asked the following three questions:

(1) Do AWNS and AWS differ in non-word repetition accuracy as segmental complexity increases, while controlling for metrical complexity?
(2) Do AWNS and AWS differ in non-word repetition accuracy as metrical complexity increases, while controlling for segmental complexity?
(3) Do AWNS and AWS differ in non-word repetition accuracy as both segmental *and* metrical complexity increase?

## Method

Twenty-four adults (12 AWS, 12 AWNS) were included in the current study (9 males, 3 females per group; AWNS age range: $M$ = 22.23 $SD$ = 3.24; AWS age range: $M$ = 23.58 $SD$ = 6.43; $p$ = 0.61). All participants completed a 90-min session that included a speech sample, a series of standardized assessments (expressive vocabulary, *Expressive Vocabulary Test – Second Edition* [EVT-2], Williams, 2007; receptive vocabulary, *Peabody Picture Vocabulary Test – Fourth Edition* [PPVT-4], Dunn & Dunn, 2007; phonological processing and working memory, *Comprehensive Test of Phonological Processing – Second Edition* [CTOPP-2], Wagner, Torgesen, Rashotte, & Pearson, 2013; nonverbal intelligence; *Test of Nonverbal Intelligence – Fourth Edition* [TONI-4], Brown, Sherbenou, & Johnsen, 2010), binaural hearing screening (American Speech-Language-Hearing Association [ASHA], 1997) and the experimental NRT (TOPhS; Van Der Lely & Harris, 1999). General demographic information, medical history, treatment history and language history were collected prior to these tasks. All participants provided oral and written consent at the beginning of the session, and the testing protocol was approved by the first author's institutional review board.

Participants were excluded from the study if they did not meet any of the following criteria: (a) reported native monolingual English profciency, (b) passed hearing screening, (c) no reported signifcant medical history and/or (d) scored within two SD of the standard mean in measures of vocabulary, nonverbal intelligence or phonological processing abilities.

## Talker classification and stuttering severity

Participants were considered an AWS if he or she self-identified as a person who stutters and had previously received a formal diagnosis of stuttering by a licensed speech-language pathologist. In the absence of a formal diagnosis, the first author, a licensed, ASHA-certified speech-language pathologist, confirmed AWS status. Stuttering severity was determined by the frequency, duration, and physical concomitants that accompanied stuttering-like disfluencies (SLDs) during the reading sample provided within the *Stuttering Severity Index – Fourth Edition* (SSI-4; Riley, 2009). SLDs were defined based on Yairi and Ambrose (1995) standard definition of atypical disfluencies. To ensure inter-reliability of severity across speech samples, audio-video recordings of all participants were reviewed by a research assistant trained in disfluency analysis and the third author (100% agreement, kappa = 1.0). To ensure intra-rater reliability, all recordings were reviewed again by the trained research assistant (100% agreement, kappa = 1.0).

## Vocabulary, nonverbal intelligence and phonological processing

EVT-2 (Williams, 2007), PPVT-4 (Dunn & Dunn, 2007), TONI-4 (Brown et al., 2010), phonological awareness (CTOPP-2, Wagner et al., 2013; Elision [Subtest I] and Blending Words [Subtest II]) and phonological working memory (CTOPP-2; Memory for Digits [Subtest IV]) were necessary to ensure that no participant in either group presented with frank impairments in vocabulary, phonological awareness, phonological working memory and nonverbal intelligence – factors which are known to influence non-word repetition performance. Standardized scores were reported for EVT-2, PPVT-4 and TONI-4. Scaled scores were reported for the three subtests of the CTOPP-2, although two of the 12 AWS exceeded the age range provided by the CTOPP-2 data (age range: 13 to 27 years).

As depicted in Table 1, no participants performed two *SD* below the standard mean for any of pre-experimental measures (EVT-2 range: 93–126; PPVT-4 range: 88–123; TONI-4 range: 85–121; CTOPP-2 range: 8–12 [Elision]; 5–16 [Blending Words]; 7–16 [Memory for Digits]). Independent *t* tests verified that AWS and AWNS did not significantly differ with respect to

**Table 1.** Participant demographics, stuttering severity and performance on measures of phonological processing, vocabulary and nonverbal intelligence.

| | Age | Gender | Ethnicity | SSI-4[a] | Severity[a] | Self-ID | Prev Dx | PPVT-4[b] | EVT-2[c] | TONI-4[d] | E[e] | BW[e] | MD[e] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AWNS-1 | 19 | Female | C | 6 | None | N | N | 104 | 110 | 104 | 9 | 14 | 11 |
| AWNS-2 | 19 | Male | AA | 4 | None | N | N | 97 | 108 | 96 | 10 | 14 | 9 |
| AWNS-3 | 21 | Female | C | 0 | None | N | N | 100 | 118 | 98 | 11 | 11 | 11 |
| AWNS-4 | 22 | Female | C | 0 | None | N | N | 95 | 93 | 90 | 12 | 16 | 15 |
| AWNS-5 | 23 | Male | C | 0 | None | N | N | 96 | 126 | 115 | 10 | 13 | 9 |
| AWNS-6 | 27 | Male | AA | 0 | None | N | N | 104 | 116 | 121 | 12 | 14 | 15 |
| AWNS-7 | 19 | Male | C | 0 | None | N | N | 123 | 126 | 119 | 12 | 12 | 16 |
| AWNS-8 | 25 | Male | C | 6 | None | N | N | 104 | 99 | 93 | 10 | 7 | 10 |
| AWNS-9 | 20 | Male | A | 4 | None | N | N | 116 | 104 | 106 | 10 | 6 | 11 |
| AWNS-10 | 27 | Male | C | 0 | None | N | N | 120 | 126 | 108 | 9 | 14 | 11 |
| AWNS-11 | 21 | Male | AA | 0 | None | N | N | 97 | 110 | 85 | 10 | 11 | 10 |
| AWNS-12 | 27 | Male | C | 7 | None | N | N | 110 | 121 | 99 | 11 | 16 | 13 |
| AWS- 1 | 21 | Female | C | 6 | None | Y | Y | 113 | 112 | 90 | 10 | 13 | 9 |
| AWS-2 | 18 | Male | AA | 12 | VM | Y | Y | 99 | 103 | 99 | 10 | 13 | 9 |
| AWS-3 | 20 | Male | C | 9 | None | Y | Y | 108 | 106 | 99 | 10 | 10 | 8 |
| AWS-4 | 34 | Male | C | 13 | VM | Y | Y | 113 | 121 | 109 | 11 | 13 | 12 |
| AWS-5 | 24 | Male | AA | 12 | VM | Y | Y | 106 | 104 | 109 | 11 | 8 | 11 |
| AWS-6 | 24 | Male | C | 8 | None | Y | Y | 111 | 114 | 98 | 10 | 12 | 13 |
| AWS-7 | 22 | Male | AA | 20 | Mild | Y | Y | 88 | 94 | 87 | 9 | 6 | 11 |
| AWS-8 | 19 | Male | AA | 11 | VM | Y | Y | 100 | 108 | 93 | 10 | 14 | 11 |
| AWS-9 | 39 | Female | C | 8 | None | Y | Y | 98 | 99 | 93 | 8 | 5 | 13 |
| AWS-10 | 19 | Female | C | 6 | None | Y | Y | 109 | 100 | 89 | 9 | 8 | 10 |
| AWS-11 | 20 | Male | AA | 11 | VM | Y | Y | 98 | 104 | 116 | 10 | 5 | 7 |
| AWS-12 | 23 | Male | C | 10 | VM | Y | Y | 107 | 114 | 84 | 11 | 12 | 11 |

*Note*. AWS: adults who stutter, AWNS: adults who do not stutter; C: Caucasian, AA: African-American; Self-ID: self-identification as an adult who stutters; none: no stuttering, VM: very mild, Mod: moderate: Sev: severe, VS: very severe; Prev Dx: diagnosis of stuttering prior to 7 years of age. [a]*Stuttering Severity Instrument* – Fourth edition (Riley, 2009); [b]*Peabody Picture Vocabulary Test* – Fourth edition (Dunn & Dunn, 2007); [c]*Expressive Vocabulary Test* – Second edition (Williams, 2007); [d]*Test of Nonverbal Intelligence* – Fourth edition (Brown et al., 2010); [e]*Comprehensive Test of Phonological Processes* – Second edition (Wagner et al., 2013; E: Elision (Subtest I); BW: Blending Words (Subtest II); MD: Memory for Digits (Subtest IV).

expressive vocabulary ($p$ = 0.23), receptive vocabulary ($p$ = 0.70), nonverbal intelligence ($p$ = 0.15) or phonological subtests (Elision: $p$ = 0.36; Blending Words: $p$ = 0.09; Memory for Digits: $p$ = 0.11).

## *Test of Phonological Structure* (TOPhS)

As described by Gallon et al. (2007), the 96 non-word stimuli included on the TOPhS were constructed via incremental manipulation of four simple, bisyllabic non-words (i.e. ˈdɛ.pə, ˈfɪ.pə, ˈkɛ.tə and ˈpɪ.fə) which carried trochaic stress (STRONG–weak). Segmental complexity was manipulated by varying the following properties of the root non-words:

(1) addition of onset cluster (CCV.CV; e.g. /ˈdrɛ.pə/),
(2) addition of medial cluster (CVC.CV; e.g. /ˈdɛm̱. pə/) and/or
(3) addition of final schwa/final consonant (CVC; e.g. /ˈdɛp/).

For the purposes of the present study, segmental complexity of non-word stimuli were separated into three categories: low [SEG-low], moderate [SEG-mod] and high [SEG-high]. For the segmental complexity of a non-word to be classified as low [SEG-low], no modifications were made to the original non-words (CV.CV, $n$ = 16). For the segmental complexity of a non-word to be classified as moderate [SEG-mod], one of the three parameters was manipulated (CCV.CV, CVC.CV and CVC; $n$ = 40). For the segmental complexity of a non-word to be classified as high [SEG-high], two or more of the three parameters were manipulated (two parameters: CVCC, CCVC and CCVC.CV; three parameters: CCVCC; $n$ = 40). Unlike Gallon et al. (2007), non-words in the present study with two or more segmental manipulations were combined into a single category (i.e. SEG-high) to increase the number of items per level ($n$ = 40) to the greatest degree possible, rather than two distinct categories with fewer items (two factors, $n$ = 32; three factors, $n$ = 8).

Metrical complexity of a non-word was manipulated by varying the following properties:

(1) addition of initial, unstressed syllable (weak–STRONG–weak; e.g. *bə*.ˈdɛ.pə),
(2) addition of final, unstressed syllable (STRONG–weak–weak; e.g. ˈdɛ.pə.*ri*), and/or
(3) addition of both initial and final unstressed syllables (weak–STRONG–weak–weak; e. g. *bə*.ˈdɛ.pə.*ri*).

Similar to segmental complexity, the metrical complexity of non-word stimuli was separated into three categories: low [MET-low], moderate [MET-mod] and high [MET-high]. For the metrical complexity of a non-word to be classified as low [MET-low], none of the parameters were altered (STRONG–weak*;* $n$ = 32). For the metrical complexity of a non-word to be classified as moderate [MET-mod], only the first parameter (1) was manipulated ($n$ = 32). For a non-word to be classified as high [MET-high], either the second (2) or third (3) parameter was manipulated ($n$ = 32). Unlike Gallon et al. (2007), non-words with metrical manipulations (2) or (3) were combined into a single category (i.e. MET-high) to balance the number of items within a single category ($n$ = 32) rather than two distinct categories with fewer items ($n$ = 16, $n$ = 16).

All stimuli and the corresponding segmental and metrical properties included in the TOPhS are provided in Appendix A. Non-word stimuli varied from one to four syllables in length. An overall summary of the nine complexity classifications used in the present

**Table 2.** Summary of nine categories used in the present study to classify segmental complexity and metrical complexity of TOPhS non-word stimuli.

| Metrical complexity | Segmental complexity | | | |
|---|---|---|---|---|
| | Low | Moderate | High | *N* |
| Low | ˈdɛ.pə<br>[*n* = 4] | ˈdɛ**m**.pə<br>[*n* = 4] | ˈd**r**ɛ**m**.pə<br>[*n* = 8] | 16 |
| Moderate | *bə*.ˈdɛ.pə<br>[*n* = 12] | *bə*.ˈdɛ**m**.pə<br>[*n* = 12] | *bə*.ˈd**r**ɛ**m**.pə<br>[*n* = 16] | 40 |
| High | *bə*.ˈdɛ.pə.*ri*<br>[*n* = 16] | *bə*.ˈdɛ**m**.pə.*ri*<br>[*n* = 16] | *bə*.ˈd**r**ɛ**m**.pə.*ri*<br>[*n* = 8] | 40 |
| *N* | 32 | 32 | 32 | 96 |

*Note*. **Bold** font indicates consonant included or removed to manipulate segmental complexity. *Italic* font indicates unstressed syllables included or removed to manipulate metrical complexity. Brackets indicate the number of non-words on the TOPhS within each complexity category.

study TOPhS stimuli is provided in Table 2, as well as an example of how a single non-word (e.g. ˈdɛ.pə) may vary across these nine categories.

Audio files for non-word stimuli were recorded in a soundproof room with a high-quality microphone (AKG Perception 129 USB) at a sampling rate of 22.050 kHz with 16-bit quantization. All stimuli were recorded and presented between 30 and 34 dB SPL within a soundproof booth. Non-word stimuli were produced by a monolingual, female speaker of Standard American English with no reported history of speech, language or hearing difficulties with training in phonetics and non-word repetition paradigms. All 96 non-words of the TOPhS were presented to participants individually in the fixed randomized order detailed by Van Der Lely and Harris (1999). Participants were instructed by the examiner to repeat each target non-word aloud as accurately as possible after it was presented. The duration between individual trials was controlled by the examiner to accommodate disfluent verbal responses.

## Coding, reliability and excluded tokens

Verbal responses from all 24 participants were coded offline for fluency and accuracy of production. To determine inter-rater reliability, all 2304 verbal responses (96 non-words × 24 participants) provided by participants were coded offline by two research assistants trained in disfluency analysis. After initial coding of 100% of the responses, any discrepancies were reviewed by both coders and the first author, a licensed speech-language pathologist, to reach consensus regarding the fluency and accuracy of each response prior to token exclusion and final analysis.

A phonemic error was defined as the omission, substitution or addition of at least one phoneme in the target non-word during repetition. Individual tokens produced with a stress error were excluded to ensure that phonemic accuracy reflected the speaker's attempt to produce the target without simplifying the metrical stress pattern. To ensure responses reflected phonemic accuracy without distortions of speech secondary to moments of disfluency, individual tokens produced with an SLD or typical disfluency (non-SLD; Yairi & Ambrose, 1995) were excluded. Non-word targets produced by the participant as real words were also removed from analysis (lexical error; e.g. /fımpl/as 'simple'; /klɛt/as 'clutch'). Individual tokens were also removed if the examiner was unable

**Table 3.** Tokens excluded from final analysis.

| | AWNS | AWS | Total (*n*) | Total (%) |
|---|---|---|---|---|
| *Initial corpus* | 1152 | 1152 | 2304 | |
| *Excluded tokens* | 73 | 93 | 166 | 7.20 |
| SE | 1 | 5 | 6 | 0.26 |
| SLD | 0 | 12 | 12 | 0.52 |
| nSLD | 7 | 0 | 7 | 0.30 |
| LE | 16 | 17 | 33 | 1.43 |
| TE | 34 | 25 | 59 | 2.56 |
| EC | 3 | 22 | 25 | 1.09 |
| O | 12 | 12 | 24 | 1.04 |
| *Usable tokens* | 1079 | 1059 | 2138 | 92.80 |
| Accurate | 968 | 909 | 1877 | 81.47 |
| Phonemic error | 111 | 150 | 261 | 11.33 |

*Note*. SE: stress error; SLD: stuttering-like disfluency; nSLD: non-stuttering-like disfluency; LE: lexical error; TE: technical error; EC: error combination; O: outlier.

to code the response due to recording error (technical errors; e.g. inaudible response, non-speech event such as coughing or yawning and equipment malfunction). Finally, individual tokens were removed when more than two of the error types listed above occurred on the same verbal response (error combination). In sum, analysis of phonemic errors was restricted to fluent, accurate responses and fluent responses with a phonemic error. In addition to individual response errors, item analysis was conducted to identify outliers based on overall response accuracy for all participants. Overall error rate for one non-word (/bəˈdrɛpəri/) exceeded 2.5 *SD* and was removed from analysis.

Table 3 provides a detailed breakdown of tokens excluded from final analysis. Of the potential 2304 tokens (AWNS, *n* = 1152; AWS, *n* = 1152), 7.20% were not usable (*n* = 166; AWNS, *n* = 73; AWS, *n* = 93) based on the above criteria. A total of 2138 usable tokens were included in the final analysis of phonemic accuracy (92.80%; AWNS, *n* = 1079; AWS, *n* = 1059).

## Analysis

The purpose of the present study was to assess the relationship between talker group, segmental complexity and metrical complexity when repeating non-words. AWS and AWNS participants produced non-words which varied in segmental complexity [SEG-low, SEG-mod and SEG-high] and metrical complexity [MET-low, MET-mod and MET-high]. Each non-word, therefore, fell within one of nine complexity categories (see Table 2).

Similar to Sasisekarn and Weisberg (2014), a generalized linear mixed-model analysis was conducted to examine non-word phonemic accuracy between AWNS and AWS based on segmental and metrical complexity (*lme4* statistical package, Bates & Machler, 2009). Multilevel analysis accommodated non-independence of data within each category (i.e. each participant provided multiple responses within and across categories), non-normal distribution of phonemic errors and unequal number of tokens excluded for each talker group (see Table 2). Talker group (AWNS and AWS), segmental complexity (SEG-low, SEG-mod and SEG-high) and metrical complexity (MET-low, MET-mod and MET-high) served as categorical fixed effects. Participants served as the random effect. The presence or absence of phonemic error during non-word repetition served as the binomial dependent variable. Length, as defined by number of syllables, was also included as a covariate.

**Table 4.** Analysis of deviance (Type II Wald Chi-square tests) for phonemic accuracy of non-word repetition by adults who do and do not stutter (talker group) based on the phonological complexity of non-words (segmental complexity, metrical complexity)..

| *Fixed effects* | $\chi^2$ | *df* | $p\ (>\chi^2)$ |
|---|---|---|---|
| Talker group | 2.48 | 1 | 0.115 |
| Segmental complexity | 5.72 | 2 | 0.058 |
| Metrical complexity | 0.78 | 2 | 0.678 |
| Segmental complexity × Metrical complexity | 6.28 | 4 | 0.178 |
| Talker group × Segmental complexity | 6.23 | 2 | 0.044* |
| Talker group × Metrical complexity | 1.65 | 2 | 0.439 |
| Talker group × Segmental complexity × Metrical complexity | 4.64 | 4 | 0.323 |
| *Covariates* | | | |
| Length | 28.29 | 1 | 0.865 |
| Order of presentation | 0.03 | 1 | < .001*** |

**Table 5.** Estimated mean phonemic error for adults who do and do not stutter (AWS, AWNS) when repeating non-words at each level of segmental and metrical complexity.

| Complexity | | AWNS | | AWS | |
|---|---|---|---|---|---|
| *Segmental* | *Metrical* | *M* | *SE* | *M* | *SE* |
| Low | Low | 3.6 | 2.3 | 10.7 | 5.3 |
| Low | Mod | 12.4 | 4.2 | 12.6 | 4.0 |
| Low | High | 6.7 | 4.1 | 4.0 | 2.4 |
| Mod | Low | 7.9 | 1.6 | 10.9 | 3.2 |
| Mod | Mod | 9.0 | 1.7 | 9.3 | 2.0 |
| Mod | High | 17.2 | 6.0 | 8.5 | 4.0 |
| High | Low | 7.4 | 1.5 | 14.1 | 4.0 |
| High | Mod | 10.4 | 2.6 | 18.6 | 2.9 |
| High | High | 7.6 | 4.2 | 25.0 | 6.7 |

Although non-word stimuli were presented in a fixed randomized order per the protocol of the TOPhS (see Appendix A), presentation order was also included as a covariate to control for potential trends in accuracy across 96 trials. Bonferroni-adjusted *p* values were applied to all planned pairwise comparisons.

Although all variables were included in the model, the primary variables of interest were the talker group by complexity interactions (segmental complexity and metrical complexity) and the three-way interaction between these variables. Full model output is provided in Table 4, and estimated means per talker group and complexity category are provided in Table 5.

## Results

### Talker group, segmental complexity and metrical complexity

No main effect was detected for talker group $\chi^2(1) = 2.45$, $p = 0.116$, segmental complexity $\chi^2(2) = 5.72$, $p = 0.058$ or metrical complexity $\chi^2(2) = .78$, $p = 0.678$. No significant interaction was detected between segmental complexity and metrical complexity $\chi^2(4) = 6.28$, $p = 0.179$.

A significant interaction was detected between talker group and segmental complexity $\chi^2(2) = 6.23$, $p = 0.044$. Post-hoc analysis of this interaction indicated that AWS produced segmentally complex non-words with significantly more phonemic errors ($M = 0.18$, $SE = 0.02$) than AWNS ($M = 0.08$, $SE = 0.02$, $p = 0.005$). No significant group differences were observed for non-words of low and moderate segmental complexity. AWS were also significantly less accurate when producing non-word with high segmental complexity than moderate complexity ($M$ = 0.10, $SE$ = 0.02, $p$ = 0.003) or low complexity ($M$ = 0.08, $SE$ = 0.03, $p$ = 0.019). No significant difference in accuracy was observed for AWNS based on segmental complexity (low: $M$ = 0.07, $SE$ = 0.02; moderate: $M$ = 0.11, $SE$ = 0.02; high: $M$ = 0.08, $SE$ = 0.02).

No significant interaction was detected between talker group and metrical complexity $\chi^2(2) = 1.65$, $p = 0.439$. AWNS produced non-words with increasing metrical complexity with comparable accuracy (MET-low: $M$ = 0.06, $SE$ = 0.02; MET-mod: $M$ = 0.11, $SE$ = 0.02; MET-high: $M$ = 0.10, $SE$ = 0.03), as did AWS (MET-low: $M$ = 0.12, $SE$ = 0.03; MET-mod: $M$ = 0.13, $SE$ = 0.02; MET-high: $M$ = 0.10, $SE$ = 0.03).

Finally, no significant three-way interaction was detected between talker group, segmental complexity and metrical complexity $\chi^2(4) = 4.64$, $p = 0.326$. As depicted in Table 5 and Figure 1, AWS were less accurate when producing non-words with high segmental complexity than moderate segmental complexity for the most complex metrical patterns. AWNS, on the other hand, did not exhibit differences in accuracy based on segmental complexity within or between any metrical patterns. In general, AWS produced segmentally complex non-words with greater error than moderate or simple target across metrical configuration. AWNS did not. One exception was during the simplest metrical patterns (STRONG–weak), where neither AWNS nor AWS exhibited any notable differences in accuracy based on segmental stress.

## Non-word length and presentation order covariates

Presentation order was significant as a covariate $\chi^2(1) = 28.29$, $p < 0.001$. Length of stimuli, however, was not a significant predictor of phonemic accuracy $\chi^2(1) = 0.03$, $p = 0.865$.

### *Vocabulary, nonverbal intelligence, phonological processing and stuttering severity*

Although groups did not significantly differ with respect to vocabulary knowledge, phonological processing abilities or nonverbal intelligence, the potential influence of non-significant trends favouring AWNS warrants consideration. The possible influence of stuttering severity, as measured by the SSI-4, should also be examined to ensure response accuracy during the TOPhS did not share a predictable relationship with individual severity. To examine these potential contributing factors, correlational analysis was conducted between all pre-experimental measures and phonemic accuracy during TOPhS. Phonemic accuracy on TOPhS did not correlate with vocabulary knowledge (PPVT-4: $r$ = 0.087, $p$ = 0.686; EVT-2: $r$ = 0.053, $p$ = 0.806), nonverbal intelligence (TONI-4: $r$ = 0.143, $p$ = 0.505), phonological processing (Elision: $r$ = −0.003, $p$ = 0.989; Blending Words: $r$ = −0.230, $p$ = 0.279; Memory for Digits: $r$ = −0.117, $p$ = 0.586) or stuttering severity ($r$ = 0.106, $p$ = 0.744). Outcomes reported in the original multilevel analyses did not change upon inclusion of these seven factors as covariates, nor were any significant as covariates ($p$ value range: 0.243–0.945). That is, talker group by segmental complexity remained the only significant main effect or interaction $\chi^2(2) = 6.13$, $p = 0.047$.

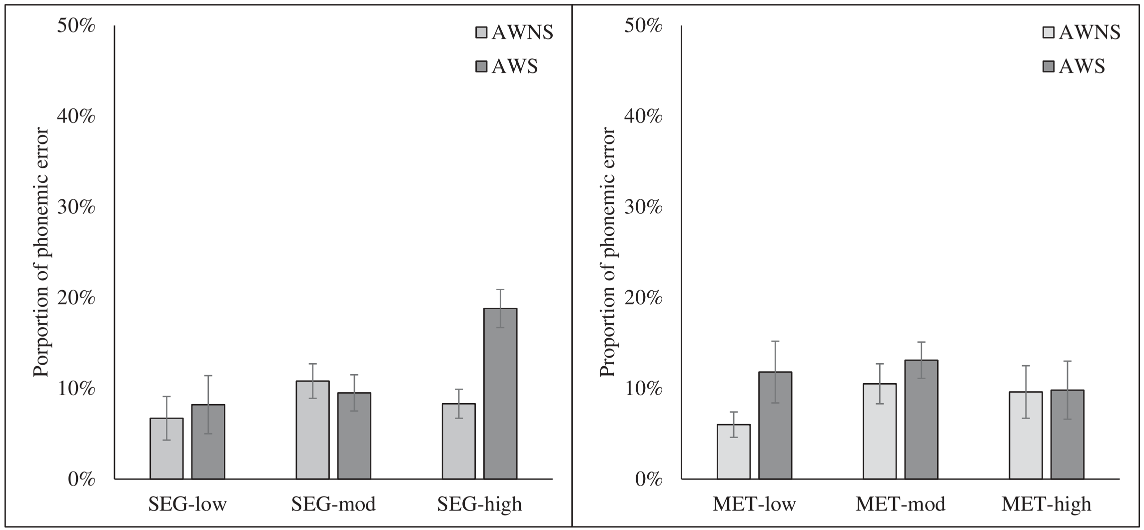


**Figure 1.** Number of phonemic errors produced by adults who do and do not stutter (AWS, AWNS) when repeating non-words averaged across each level of segmental complexity [SEG-low, SEG-mod, SEG-high] and each level of metrical complexity [MET-low, MET-mod, MET-high].

## Discussion

The purpose of the present study was to examine whether AWS differ from AWNS in their ability to accurately repeat non-words based on increased segmental complexity, increased metrical complexity, or both. AWS and AWNS completed the TOPhS nonword repetition tasks, wherein non-words systematically vary relative to both segmental and metrical complexity. Findings indicate that high segmental complexity resulted in greater phonemic error for AWS. AWNS, on the other hand, were minimally impacted by the segmental complexity of non-word stimuli. For both groups, repetition accuracy was not mediated by metrical complexity. Results suggest that despite non-word lengths well within the expected word-length effect (greater than four syllables), AWS remained less accurate during non-word repetition based on the internal complexity of the target utterance – specifically the segmental properties – compared to typically fluent peers.

## Segmental complexity

Based on previous research, we predicted that increased segmental complexity would reduce non-word repetition accuracy in AWS compared to AWNS. Our findings supported this prediction and indicated that AWS were less accurate than AWNS when repeating complex non-word targets [SEG-high], but were comparable to AWNS for targets with low or moderate segmental complexity [SEG-low, SEG-mod]. Less accurate repetition of non-words with high segmental complexity by AWS corroborates previous work by Ludlow et al. (1997) and Sasisekaran and Weisberg (2014). Although converging outcomes across studies are an encouraging first step towards isolating which aspects of phonological processing are most problematic for AWS, several methodological and procedural differences between studies should be considered. First, measures of segmental complexity in previous studies were dissimilar from the TOPhS classification used in the present study, and the segmental demand of stimuli was higher. Ludlow et al. used two 4-syllable non-word stimuli comprised of segmental sequences that exceed the most complex 4-syllable non-words in the present study (SEG-high), which included intra- and inter-syllable clusters comprised of two to four consonants (i.e. V.[CVC.CCV].CCVC; C [CVC.CCVC].CVC) and sound combinations not native to English-speaking participants (i.e./a.bɪs.θwoi.ʧlit/,/i.pæʃ.fwuʤ.bok/). Sasisekaran and Weisberg used two 3-syllable non-words that were also more complex than the SEG-high stimuli used in present study, with intra- and inter-syllabic clusters comprised of 2 to 4 consonants (i.e. [CVC.CCVC].CCVC; [CVC.CCVCC].CVC) and illegal sound combinations (i.e./mæb.θwaipf.krob/,/mæb.ʃfuʤ.ʧoib/). In the present study, segmental combinations that were phonotactically legal did not exceed two consonants. It is possible, therefore, that the participants in prior studies were more likely to produce a phonemic error than those in the present study, and were perhaps responding to the low phonotactic *frequency* of non-native sound combinations more so than the complexity of known sound combinations in our SEG-high stimuli. This may be reflected in the smaller number of errors observed for the most complex stimuli in the present study (AWNS = 92% accuracy; AWS = 82% accuracy) relative to Sasisekaran and Weisberg (AWNS = 40%–60% accuracy; AWS = 30%–35% accuracy; based on visual inspection of Figure 2, p. 10).

Second, both Ludlow et al. (1997) and Sasisekaran and Weisberg (2014) provided participants multiple opportunities to practice target non-words prior to experimental data collection, and each target was produced multiple times throughout the experiment. These practice trials and repeated productions were necessary to secure the level of accuracy necessary for kinematic analyses. Indeed, two of the 10 AWS from Sasisekaran and Weisberg (2014) were eventually excluded from analyses based on minimal success in accurately producing the target non-words, and two participants required additional blocks to achieve the required number of correct productions. In the present study, however, each participant received only one opportunity to repeat each non-word target with no pre-experimental practice. It is possible that the participants in our study were less prepared for the task and performed less accurately during initial production, as reported for AWS for longer non-words (Byrd et al., 2015, 2012). However, given the large number of errors in these previous studies, the benefit of additional practice to either group was small and did not offset the heightened segmental complexity of their stimuli.

Our findings did not corroborate non-word repetition accuracy reported by Smith et al. (2010). Unlike the increased error observed for AWS when repeating SEG-high non-words in the present study, AWS and AWNS exhibited remarkably similar overall accuracy when repeating five 1- to 4-syllable non-words of increasing length and segmental complexity. As noted, researchers did not report phonemic accuracy for AWNS and AWS when producing 4-syllable targets with high complexity (i.e. /mæb.ʃei.taɪ.dɔɪb/, [CVC.CV.CV.CVC]) versus low complexity (i.e. /mæb.ti.bi.bi/, [CVC.CV.CV.CV]), but rather the overall accuracy during repetition across all non-word lengths (AWNS: *Mdn* = 7.0%; AWS: *Mdn* = 9.0%). To the extent that behavioural data can be contrasted, overall error rate across all non-words were low and do not suggest, directly or indirectly, that excessive errors were present in either group for any specific non-word type, including the critical simple versus complex contrast pair. One contributor to this potential discrepancy is the relative simplicity of stimuli used in their study. Using the TOPhS metric, the complex 4-syllable non-word (i.e. 'mabshaytaidoib') would be most closely classified as SEG-mod (i.e. addition of a medial cluster to the primary STRONG–weak sequence; [CVC.CV]CV.CVC]), for which we also observed no accuracy differences between AWS and AWNS. A second possible reason, similar to Ludlow et al. (1997) and Sasisekaran and Weisberg (2014), is the additional (but necessary) practice provided to participants prior to kinematic analysis and repeated productions during experimental analyses. Combined with the relative simplicity of their non-word stimuli, these factors may have minimized the potential for phonemic error for AWS during production of their most complex stimuli.

## Metrical complexity

We predicted that AWS would demonstrate greater difficulty when accurately repeating non-words as metrical complexity increased. Our findings did not support this prediction and, instead, indicated that metrical complexity alone was not sufficient to differentiate groups. This was unexpected, given that the metrical complexity used in the present study was more challenging than the 2-syllable iambic structure for non-words used in previous studies by Coalson and Byrd (2015, 2017). It is critical to note that, unlike these studies, participants in the present study provided verbal responses immediately after hearing the target non-word. This auditory input may have provided auditory priming of relevant phonological information just prior to response and improved overall accuracy. Coalson and Byrd (2017) reported no significant effect of metrical stress during immediate repetition between groups, only during short-term recall wherein auditory–orthographic cues were removed. Thus, while the influence of metrical stress contributes to the demands placed on AWS, the presence of external phonological input may have overridden its effects in the present study.

Non-significant differences in accuracy between AWNS and AWS based on less frequent metrical stress are consistent with Hakim and Bernstein Ratner (2004), although this previous study did report a non-significant trend toward poorer phonemic accuracy by children who stutter when non-words carried infrequent stress patterns. In contrast, no discernible trends based on metrical stress alone were observed in the present study for either group. Several considerations should be made when comparing outcomes across studies. First, Hakim and Bernstein Ratner assessed children who do and do not stutter (ages 4 to 8) rather than adults, and arguably the influence of metrical stress may be more evident in participants with less mature speech and language systems. Second, the stress patterns used in the present study were all present in the participants' native language, whereas Hakim and Bernstein Ratner presented the same 4-syllable target twice: once with legal stress pattern and once with non-native stress pattern (i.e. word-final). It is possible that the participants in their study were less accurate due to low familiarity of the stress pattern, rather the metrical complexity, or perhaps increased difficulty when producing the same phonetic stress with two distinct stress patterns.

## Segmental and metrical complexity

Our final prediction was that the combined influence of increased segmental and metrical complexity on non-word repetition in AWS would be greater than either property in isolation. Non-significant three-way interaction between talker group, segmental complexity and metrical complexity did not support this prediction and, instead, further indicated that increased segmental complexity disrupts phonological working memory in AWS, but not AWNS, regardless of metrical configuration.

To date, no study has directly compared the combined influence of segmental and metrical complexity on non-word repetition in persons who stutter, despite previous studies that have suggested metrical complexity as a contributing factor to phonological demand (Coalson & Byrd, 2015, 2017; Hakim & Bernstein Ratner, 2004). Findings from the present study suggest a more refined interpretation is that when segmental complexity is sufficiently high, metrical complexity contributes to a lesser extent in AWS. Although the three-way interaction was non-significant, AWS in the present study demonstrated a small but notable increase in errors for SEG-high non-words as metrical complexity increased from MET-low [14.1%] to MET-mod [18.6%] to MET-high [25.0%]. AWNS, on the other hand, exhibited a more modest overall error rate for segmentally complex non-words across metrical patterns (MET-low: 7.4%, MET-mod: 10.4%) and an unexpected drop in errors for the highest metrical complexity (MET-high: 7.6%). Less frequent stress patterns may provide a smaller, incremental increase in difficulty for AWS the further metrical structure deviates from high-frequency, familiar stress patterns. Nevertheless, the influence of metrical complexity in AWS may be minimal in the presence of increased length or segmental complexity.

Present findings confirm those of previous studies that indicate increased demand during non-word repetition impairs performance of AWS more so than AWNS (Byrd et al., 2015, 2012; Ludlow et al., 1997; Sasisekaran & Weisberg, 2014). However, unlike previous studies, our data provide greater specificity about the type of demands that are most problematic for AWS. After controlling for the well-documented effects of length and the potential effects of metrical complexity, segmental composition remained a relevant factor to the accuracy of AWS, but not AWNS. These findings suggest that the phonological difficulties observed in children who stutter may persist into adulthood and, as noted in previous studies, may provide critical prognostic information about persistence of stuttering at earlier ages (see Spencer & Weber-Fox, 2014).

In terms of clinical implications, the influence of increased complex segmental sequences on production accuracy in AWS, but not AWNS, provides further evidence that the phonological weaknesses near the onset of stuttering do not always subside during childhood (see Gregg & Yairi, 2012). This raises the question of whether targeting phonological awareness may be warranted during adulthood to improve the efficacy of intervention, which requires future examination in AWS (for children who stutter, see Conture, Louko, & Edwards, 1993). From a broader perspective, it is clinically informative that any adult, even those with depressed phonological skills such as AWS, would demonstrate difficulties when reproducing the 'complex' segmental sequences provided in the TOPhS. The most difficult stimulus presented was a 4-syllable non-word which included (a) two consonant clusters and (b) a final consonant. Further, these non-words were produced within a low-demand communicative environment (i.e. speaking aloud within soundproof laboratory with no co-occurring interference) and low-demand linguistic context (i.e. single-word response with no semantic or syntactic encoding). When considered within the framework of multifactorial models of stuttering (e.g. Smith, 1999), or the 'central stage bottleneck' proposed by Tsai and Bernstein Ratner (2016), clinicians should be aware of how much segmental complexity an AWS client can tolerate, even with undivided attention, before estimating the additional demands of (a) semantic and syntactic processing, (b) bidirectional, propositional speech, and (c) cognitive and affective factors that may co-occur with speech production – fluent or not – in AWS.

Although the present study did not detect differences in accuracy based on metrical complexity, the role of metrical complexity may be greater in younger children who stutter, rather than adults, for whom difficulties with prosodic structure during non-word repetition are more evident (2–4 years of age; Chiat & Roy, 2007; Roy & Chiat, 2004). As noted, Anderson and colleagues (Anderson & Wagovich, 2010; Anderson et al., 2006) reported that children who stutter at 2–4 years of age repeat bisyllabic non-words from the CNRep ($M$ = 5.4 of 10 bisyllabic non-words) with less accuracy than typically fluent peers ($M$ = 8.3 of 10 bisyllabic non-words). Consistent with the present study, group differences found in the previous studies may be based on the segmental complexity of CNRep stimuli – nine of the 10 bisyllabic non-words on the CNRep would be classified as SEG-mod or SEG-high using the TOPhS classification system. However, all were presented, and presumably produced, with trochaic stress. It is possible that children who stutter may show even greater difficulty in phonemic accuracy as metrical complexity increases, as opposed to adult participants in the present study. Manipulation of metrical stress, as well as segmental complexity, may also strengthen the predictive properties of non-word repetition reported in Spencer and Weber-Fox (2014; using NRT) to differentiate children who persist in stuttering from those who recover without increasing non-word length. This may be of particular value in younger populations due to potential floor effects during non-word repetition. Similar to Anderson et al., Hakim and Bernstein Ratner (2004) reported a non-significant trend observed towards less accurate repetition of 4- and 5-syllable non-words (children who stutter: $M$ = 2.7 and $M$ = 2.3, typically fluent children: $M$ = 4.9, $M$ = 3.2, respectively). Future studies may examine the performance on the TOPhS in younger children who do and do not stutter to examine whether this is the case.

## Metrical complexity and basal ganglia dysfunction in AWS

Although it was not our intent to interpret behavioural outcomes from a neuropathological perspective, difficulties based on variation of metrical stress in AWS – if observed – could be viewed as support for theories of stuttering that implicate basal ganglia and sensorimotor dysfunction (Alm, 2004; Chang, Chow, Wieland, & McAuley, 2016; Chang & Zhu, 2013; Craig-McQuaide, Akram, Zrinzo, & Tripoliti, 2014; Etchell, Johnson, & Sowman, 2014). In general, these theories suggest that atypical basal ganglia-thalamocortical circuits (BGTC) disrupt the internal timing network for self-generated movement, including speech production, resulting in delayed activation of the upcoming syllable in persons who stutter. Difficulties generating internal timing cues due to BGTC dysfunction have also been linked to weaker ability to perceive or predict external 'beats' within non-linguistic signals, such as tempo (e.g. Grahn & Rowe, 2009; for children who stutter see Chang et al., 2016; Wieland, McAuley, Dilley, & Chang, 2015), and linguistic signals, such as syllabic stress (Morrill, Dilley, & McAuley, 2014; Selkirk, 1984). Although the perception of syllabic stress has yet to be examined in AWS, Kotz et al. (see Kotz & Schwartze, 2010; Kotz, Schwartze, & Schmidt-Kassow, 2009, Kotz, & Schmidt-Kassow, 2015) found that neural timing deficits may degrade segmental or prosodic information if the acoustic signal does not maintain a predictable, alternating stress patterns. If this is the case, one might have expected AWS to have greater difficulty identifying, or reproducing, the phonemic sequences within non-words that carried irregular or less predictable stress pattern (e.g. weak–STRONG–weak–weak) compared to regular, alternating stress pattern (STRONG–weak). This was not the case – metrical stress did not mediate phonemic accuracy in AWS even with simultaneous increases in segmental complexity. More specifically, AWS did not demonstrate increased segmental errors due to difficulties perceiving or processing specific metrical 'beats'. That being said, our findings cannot refute BGTC accounts of stuttering, as AWS in this study could have applied compensatory strategies supported by different neural regions (e.g. right hemisphere, premotor–cerebellum network, see Chang et al., 2016; Chang & Zhu, 2013) to maintain phonemic accuracy in the presence of metrical variation.

## Conclusion

The present study was conducted to assess whether the combined influence of segmental complexity and metrical complexity impacted non-word repetition accuracy in AWS to a greater degree than AWNS. Findings indicate that increased segmental complexity influenced phonemic accuracy for AWS. Metrical complexity had minimal influence and did not mediate the effects of segmental complexity. AWNS demonstrated no differences based on segmental or metrical complexity. Future studies should consider the role of segmental complexity when administering nonword repetition tasks in AWS, and perhaps metrical complexity for younger children who stutter.

## Acknowledgements

We would like to thank the Michael and Tami Lang Stuttering Institute and Dr Jennifer and Emanuel Bodner for their endowed support of our research efforts. A special thanks to all the adults who do and do not stutter who participated in this study, as well as Mary Claire Fontenot and Andrea Gugliuzza who assisted in data processing and reliability efforts.

## Funding

This project was supported by the LSU-ORED Faculty Research Grant as well as the Louisiana Board of Regents [LEQSF-EPS(2015)-PFUND-392] and [LEQSF-EPS(2015-18)-RD-A-03].

## Declaration of interest

The authors report no conflicts of interest.

## ORCID

Geoffrey A. Coalson http://orcid.org/0000-0003-1179-2499

## References

Alm, P. (2004). Stuttering and the basal ganglia circuits: A critical review of possible relations. *Journal of Communication Disorders*, *37*, 325–369. doi:10.1016/j.jcomdis.2004.03.001

American Speech-Language-Hearing Association [ASHA]. (1997). *Guidelines for audiologic screening* [Guidelines]. Available at www.asha.org/policy.

Anderson, J. D., & Wagovich, S. A. (2010). Relationships among linguistic processing speed, phonological working memory, and attention in children who stutter. *Journal of Fluency Disorders*, *35*, 216–234. doi:10.1016/j.jfludis.2010.04.003

Anderson, J. D., Wagovich, S. A., & Hall, N. E. (2006). Nonword repetition skills in young children who do and do not stutter. *Journal of Fluency Disorders*, *31*, 177–199. doi:10.1016/j.jfludis.2006.05.001

Arenas, R. M. (2016). Conceptualizing and inverstigating the contextual variability of stuttering: The speech and monitoring interaction (SAMI) framework. *Speech, Language, and Hearing*, *20*, 15–28. doi:10.1080/2050571X.2016.1221877

Bakhtiar, M., Ali, D. A. A., & Sadegh, S. P. M. (2007). Nonwords repetition ability of children who do and do not stutter and covert repair hypothesis. *Indian Journal of Medical Sciences*, *61*, 462–470. doi:10.4103/0019-5359.33711

Bates, D., & Mächler, M. (2009). lme4: Linear mixed-effects models using S4 classes. *R Package Version*, *3.1.3*.

Brown, L., Sherbenou, R. J., & Johnsen, S. K. (2010). *Test of nonverbal intelligence: TONI-4*. Austin, TX: Pro-Ed.

Byrd, C. T., McGill, M., & Usler, E. (2015). Nonword repetition and phoneme elision in adults who stutter: Vocal and nonvocal performance differences. *Journal of Fluency Disorders*, *44*, 17–31. doi:10.1016/j.jfludis.2015.01.004

Byrd, C. T., Vallely, M., Anderson, J. D., & Sussman, H. (2012). Nonword repetition and phoneme elision in adults who do and do not stutter. *Journal of Fluency Disorders*, *37*, 188–201. doi:10.1016/j.jfludis.2012.03.003

Chang, S. E., Chow, H. M., Wieland, E. A., & McAuley, J. D. (2016). Relation between functional connectivity and rhythm discrimination in children who do and do not stutter. *NeuroImage: Clinical*, *12*, 442–450. doi:10.1016/j.nicl.2016.08.021

Chang, S. E., & Zhu, D. C. (2013). Neural network connectivity differences in children who stutter. *Brain*, *136*, 3709–3726. doi:10.1093/brain/awt275
Chiat, S., & Roy, P. (2007). The preschool repetition test: An evaluation of performance in typically developing and clinically referred children. *Journal of Speech, Language, and Hearing Research*, *50*, 429–443. doi:10.1044/1092-4388(2007/030)
Coalson, G. A., & Byrd, C. T. (2015). Metrical encoding in adults who do and do not stutter. *Journal of Speech, Language, and Hearing Research*, *58*, 601–621. doi:10.1044/2015_JSLHR-S-14-0111
Coalson, G. A., & Byrd, C. T. (2017). Nonword repetition in adults who stutter: The effects of stimuli stress and auditory-orthographic cues. *PLoS ONE*, *12*, e0188111. doi:10.1371/journal.pone.0188111
Conture, E. G., Louko, L. J., & Edwards, M. L. (1993). Simultaneously treating stuttering and disordered phonology in children: Experimental treatment, preliminary findings. *American Journal of Speech-Language Pathology*, *2*, 72–81. doi:10.1044/1058-0360.0203.72
Craig-McQuaide, A., Akram, H., Zrinzo, L., & Tripoliti, E. (2014). A review of brain circuitries involved in stuttering. *Frontiers in Human Neuroscience*, *8*, 884. doi:10.3389/fnhum.2014.00884
Dollaghan, C., & Campbell, T. F. (1998). Nonword repetition and child language impairment. *Journal of Speech, Language, and Hearing Research 41*, 1136–1146. *PMID*: 9771635.
Dunn, L. M., & Dunn, D. M. (2007). *Peabody picture vocabulary test: PPVT-4*. San Antonio, TX: Pearson clinical assessment.
Etchell, A. C., Johnson, B. W., & Sowman, P. F. (2014). Behavioral and multimodal neuroimaging evidence for a deficit in brain timing networks in stuttering: A hypothesis and theory. *Frontiers in Human Neuroscience*, *8*, 467. doi:10.3389/fnhum.2014.00467
Gallon, N., Harris, J., & Van Der Lely, H. (2007). Non-word repetition: An investigation of phonological complexity in children with Grammatical SLI. *Clinical Linguistics and Phonetics*, *21*, 435–455. doi:10.1080/02699200701299982
Gathercole, S. E., & Baddeley, A. D. (1996). *The Children's Test of Nonword Repetition (CNRep)*. London, England: Pearson Assessment.
Grahn, J. A., & Rowe, J. B. (2009). Feeling the beat: Premotor and striatal interactions in musicians and nonmusicians during beat perception. *Journal of Neuroscience*, *29*, 7540–7548. doi:10.1523/JNEUROSCI.2018-08.2009
Gregg, B. A., & Yairi, E. (2012). Disfluency patterns and phonological skills near stuttering onset. *Journal of Communication Disorders*, *45*, 426–438. doi:10.1016/j.jcomdis.2012.08.001
Hakim, H. B., & Bernstein Ratner, N. (2004). Nonword repetition abilities of children who stutter: An exploratory study. *Journal of Fluency Disorders*, *29*, 179–199. doi:10.1016/j.jfludis.2004.06.001
Kotz, S. A., & Schmidt-Kassow, M. (2015). Basal ganglia contribution to rule expectance and temporal predictability in speech. *Cortex*, *68*, 48–60. doi:10.1016/j.cortex.2015.02.021
Kotz, S. A., & Schwartze, M. (2010). Cortical speech processing unplugged: A timely subcortico-cortical framework. *TRENDS in Cognitive Sciences*, *14*, 392–399. doi:10.1016/j.tics.2010.06.005
Kotz, S. A., Schwartze, M., & Schmidt-Kassow, M. (2009). Non-motor basal ganglia functions: A review and proposal for a model of sensory predictability in auditory language perception. *Cortex*, *45*, 982–990. doi:10.1016/j.cortex.2009.02.010
Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, *22*, 1–75.
Ludlow, C. L., Siren, K., & Zikria, M. (1997). Speech production learning in adults with chronic developmental stuttering. In W. Hulstijn, H. F. M. Peters, & P. H. H. M. Van Lieshout (Eds.), *Speech production: Motor control, brain research, and fluency disorders* (pp. 221–230). Amsterdam, The Netherlands: Elsevier Science.
Morrill, T. H., Dilley, L. C., & McAuley, J. D. (2014). Prosodic patterning in distal speech context: Effects of list intonation and f0 downtrend on perception of proximal prosodic structure. *Journal of Phonetics*, *46*, 68–85. doi:10.1016/j.wocn.2014.06.001
Pelczarski, K. M., & Yaruss, J. S. (2016). Phonological memory in young children who stutter. *Journal of Communication Disorders*, *62*, 54–66. doi:10.1016/j.jcomdis.2016.05.006
Postma, A., & Kolk, H. (1993). The covert repair hypothesis: Prearticulatory repair processes in normal and stuttered disfluencies. *Journal of Speech and Hearing Research*, *36*, 472–487.

Riley, G. D. (2009). *Stuttering Severity Instrument for children and adults, fourth edition*. Austin, TX: Pro-Ed.

Roy, P., & Chiat, S. (2004). A prosodically controlled word and nonword repetition task for 2- to 4-year olds: Evidence from typically developing children. *Journal of Speech, Language, and Hearing Research*, *47*, 223–234. doi:10.1044/1092-4388(2004/019)

Sasisekaran, J., & Weisberg, S. (2014). Practice and retention of nonwords in adults who stutter. *Journal of Fluency Disorders*, *41*, 55–71. doi:10.1016/j.jfludis.2014.02.004

Selkirk, E. (1984). *Syntax and phonology: The relation between sound and structure*. Cambridge, MA: MIT Press.

Smith, A. (1999). Stuttering: A unified approach to a multifactorial, dynamic disorder. In N. Bernstein Ratner & E. C. Healey (Eds.), *Stuttering research and practice: Bridging the gap* (pp. 26–44). Mahwah, NJ: Lawrence Erlbaum.

Smith, A., Sadagopan, N., Walsh, B., & Weber-Fox, C. (2010). Increasing phonological complexity reveals heightened instability in inter-articulatory coordination in adults who stutter. *Journal of Fluency Disorders*, *35*, 1–18. doi:10.1016/j.jfludis.2009.12.001

Smith, A., & Weber, C. (2016). Childhood stuttering – Where are we and Where are we going? *Seminars in Speech and Language*, *37*, 291–297. doi:10.1055/s-0036-1587703

Spencer, C., & Weber-Fox, C. (2014). Preschool speech articulation and nonword repetition abilities may help predict eventual recovery or persistence of stuttering. *Journal of Fluency Disorders*, *41*, 32–46. PMID: 25173455. doi:10.16/j.jfludis.2014.06.001

Tsai, P. T., & Bernstein Ratner, N. (2016). Involvement of the central cognitive mechanism in word production in adults who stutter. *Journal of Speech, Language, and Hearing Research*, *59*, 1269–1282. doi:10.1044/2016_JSLHR-S-14-0224

Van Der Lely, H. K. J., & Harris, D. (1999). *Test of phonological structure (TOPhS), available from authors, centre for developmental language disorders and cognitive neuroscience*. London, England: University College London.

Wagner, R. K., Torgesen, J. K., Rashotte, C. A., & Pearson, N. A. (2013). *Comprehensive test of phonological processes – second edition (ctopp-2)*. Austin, tx: pro-ed.

Wieland, E. A., McAuley, J. D., Dilley, L. C., & Chang, S. E. (2015). Evidence for a rhythm perception deficit in children who stutter. *Brain and Language*, *144*, 26–34. doi:10.1016/j.bandl.2015.03.008

Williams, K. T. (2007). EVT-2: Expressive vocabulary test. In *Pearson Assessments*. Minneapolis, MN: Pearson Assessments.

Yairi, E., & Ambrose, N. (1995). *Early childhood stuttering*. Austin, TX: Pro-Ed, Inc.

# Appendix A

| | | Segmental Complexity | | | Metrical complexity | | Complexity classification (present study) | | |
|---|---|---|---|---|---|---|---|---|---|
| Order | Non-word | Onset cluster | Rhyme cluster | Final consonant | Initial unstressed | Final, unstressed | Segmental category | Metrical category | Complexity category |
| 47 | 1.1 dɛpə | 0 | 0 | 0 | 0 | 0 | SEG-low | MET-low | 1 |
| 52 | 1.2 fɪpl | 0 | 0 | 0 | 0 | 0 | SEG-low | MET-low | 1 |
| 22 | 1.3 pɪfi | 0 | 0 | 0 | 0 | 0 | SEG-low | MET-low | 1 |
| 53 | 1.4 kɛtə | 0 | 0 | 0 | 0 | 0 | SEG-low | MET-low | 1 |
| 62 | 2.1 dɛp | 0 | 0 | 1 | 0 | 0 | SEG-mod | MET-low | 2 |
| 7 | 2.2 fɪp | 0 | 0 | 1 | 0 | 0 | SEG-mod | MET-low | 2 |
| 11 | 2.3 pɪf | 0 | 0 | 1 | 0 | 0 | SEG-mod | MET-low | 2 |
| 76 | 2.4 kɛt | 0 | 0 | 1 | 0 | 0 | SEG-mod | MET-low | 2 |
| 82 | 3.1 dɛmpə | 0 | 1 | 0 | 0 | 0 | SEG-mod | MET-low | 2 |
| 12 | 3.2 fɪmpl | 0 | 1 | 0 | 0 | 0 | SEG-mod | MET-low | 2 |
| 19 | 3.3 pɪlfi | 0 | 1 | 0 | 0 | 0 | SEG-mod | MET-low | 2 |
| 50 | 3.4 kɛstə | 0 | 1 | 0 | 0 | 0 | SEG-mod | MET-low | 2 |
| 49 | 4.1 dɛmp | 0 | 1 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 67 | 4.2 fɪmp | 0 | 1 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 14 | 4.3 pɪlf | 0 | 1 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 4 | 4.4 kɛst | 0 | 1 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 31 | 5.1 drɛpə | 1 | 0 | 0 | 0 | 0 | SEG-mod | MET-low | 2 |
| 93 | 5.2 frɪpl | 1 | 0 | 0 | 0 | 0 | SEG-mod | MET-low | 2 |
| 46 | 5.3 prɪfi | 1 | 0 | 0 | 0 | 0 | SEG-mod | MET-low | 2 |
| 70 | 5.4 klɛtə | 1 | 0 | 0 | 0 | 0 | SEG-mod | MET-low | 2 |
| 80 | 6.1 drɛp | 1 | 0 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 90 | 6.2 frɪp | 1 | 0 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 41 | 6.3 prɪf | 1 | 0 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 1 | 6.4 klɛt | 1 | 0 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 34 | 7.1 drɛmpə | 1 | 1 | 0 | 0 | 0 | SEG-high | MET-low | 3 |
| 75 | 7.2 frɪmpl | 1 | 1 | 0 | 0 | 0 | SEG-high | MET-low | 3 |
| 29 | 7.3 prɪlfi | 1 | 1 | 0 | 0 | 0 | SEG-high | MET-low | 3 |
| 40 | 7.4 klɛsti | 1 | 1 | 0 | 0 | 0 | SEG-high | MET-low | 3 |
| 44 | 8.1 drɛmp | 1 | 1 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 87 | 8.2 frɪmp | 1 | 1 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 33 | 8.3 prɪlf | 1 | 1 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 72 | 8.4 klɛst | 1 | 1 | 1 | 0 | 0 | SEG-high | MET-low | 3 |
| 30 | 9.1 bədɛpə | 0 | 0 | 0 | 1 | 0 | SEG-low | MET-mod | 4 |
| 73 | 9.2 dɪfɪpl | 0 | 0 | 0 | 1 | 0 | SEG-low | MET-mod | 4 |
| 35 | 9.3 sɪpɪfi | 0 | 0 | 0 | 1 | 0 | SEG-low | MET-mod | 4 |
| 63 | 9.4 fəkɛtə | 0 | 0 | 0 | 1 | 0 | SEG-low | MET-mod | 4 |
| 21 | 10.1 bədɛp | 0 | 0 | 1 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 8 | 10.2 dɪfɪp | 0 | 0 | 1 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 91 | 10.3 sɪpɪf | 0 | 0 | 1 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 9 | 10.4 fəkɛt | 0 | 0 | 1 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 25 | 11.1 bədɛmpə | 0 | 1 | 0 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 24 | 11.2 dɪfɪmpl | 0 | 1 | 0 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 95 | 11.3 sɪpɪlfi | 0 | 1 | 0 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 16 | 11.4 fəkɛstə | 0 | 1 | 0 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 79 | 12.1 bədɛmp | 0 | 1 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 64 | 12.2 dɪfɪmp | 0 | 1 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 51 | 12.3 sɪpɪlf | 0 | 1 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 38 | 12.4 fəkɛst | 0 | 1 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 10 | 13.1 bədrɛpə | 1 | 0 | 0 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 54 | 13.2 dɪfrɪpl | 1 | 0 | 0 | 1 | 0 | SEG-mod | MET-mod | 5 |

(*Continued*)

(Continued).

| | | Segmental Complexity | | | Metrical complexity | | Complexity classification (present study) | | |
|---|---|---|---|---|---|---|---|---|---|
| 28 | 13.3 sɪprɪfi | 1 | 0 | 0 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 83 | 13.4 fɛklɛtə | 1 | 0 | 0 | 1 | 0 | SEG-mod | MET-mod | 5 |
| 71 | 14.1 bədrɛp | 1 | 0 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 57 | 14.2 dɪfrɪp | 1 | 0 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 32 | 14.3 sɪprɪf | 1 | 0 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 5 | 14.4 fəklɛt | 1 | 0 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 86 | 15.1 bədrɛpə | 1 | 1 | 0 | 1 | 0 | SEG-high | MET-mod | 6 |
| 2 | 15.2 dɪfrɪmpl | 1 | 1 | 0 | 1 | 0 | SEG-high | MET-mod | 6 |
| 58 | 15.3 sɪprɪlfi | 1 | 1 | 0 | 1 | 0 | SEG-high | MET-mod | 6 |
| 27 | 15.4 fəklɛstə | 1 | 1 | 0 | 1 | 0 | SEG-high | MET-mod | 6 |
| 68 | 16.1 bədrɛmp | 1 | 1 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 20 | 16.2 dɪfrɪmp | 1 | 1 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 55 | 16.3 sɪprɪlf | 1 | 1 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 59 | 16.4 fəklɛst | 1 | 1 | 1 | 1 | 0 | SEG-high | MET-mod | 6 |
| 65 | 17.1 dɛpəri | 0 | 0 | 0 | 0 | 1 | SEG-low | MET-high | 7 |
| 37 | 17.2 fɪpələ | 0 | 0 | 0 | 0 | 1 | SEG-low | MET-high | 7 |
| 17 | 17.3 pɪfɪtə | 0 | 0 | 0 | 0 | 1 | SEG-low | MET-high | 7 |
| 42 | 17.4 kɛtələ | 0 | 0 | 0 | 0 | 1 | SEG-low | MET-high | 7 |
| 39 | 18.1 dɛmpəri | 0 | 1 | 0 | 0 | 1 | SEG-mod | MET-high | 8 |
| 3 | 18.2 fɪmpələ | 0 | 1 | 0 | 0 | 1 | SEG-mod | MET-high | 8 |
| 92 | 18.3 pɪlfɪtə | 0 | 1 | 0 | 0 | 1 | SEG-mod | MET-high | 8 |
| 60 | 18.4 kɛstələ | 0 | 1 | 0 | 0 | 1 | SEG-mod | MET-high | 8 |
| 84 | 19.1 drɛpəri | 1 | 0 | 0 | 0 | 1 | SEG-mod | MET-high | 8 |
| 23 | 19.2 frɪpələ | 1 | 0 | 0 | 0 | 1 | SEG-mod | MET-high | 8 |
| 6 | 19.3 prɪfɪtə | 1 | 0 | 0 | 0 | 1 | SEG-mod | MET-high | 8 |
| 66 | 19.4 klɛtələ | 1 | 0 | 0 | 0 | 1 | SEG-mod | MET-high | 8 |
| 94 | 20.1 drɛmpəri | 1 | 1 | 0 | 0 | 1 | SEG-high | MET-high | 9 |
| 81 | 20.2 frɪmpələ | 1 | 1 | 0 | 0 | 1 | SEG-high | MET-high | 9 |
| 36 | 20.3 prɪlfɪtə | 1 | 1 | 0 | 0 | 1 | SEG-high | MET-high | 9 |
| 78 | 20.4 klɛstələ | 1 | 1 | 0 | 0 | 1 | SEG-high | MET-high | 9 |
| 74 | 21.1 bədɛpəri | 0 | 0 | 0 | 1 | 1 | SEG-low | MET-high | 7 |
| 26 | 21.2 dɪfɪpələ | 0 | 0 | 0 | 1 | 1 | SEG-low | MET-high | 7 |
| 18 | 21.3 sɪpɪfɪtə | 0 | 0 | 0 | 1 | 1 | SEG-low | MET-high | 7 |
| 88 | 21.4 fəkɛtələ | 0 | 0 | 0 | 1 | 1 | SEG-low | MET-high | 7 |
| 61 | 22.1 bədɛmpəri | 0 | 1 | 0 | 1 | 1 | SEG-mod | MET-high | 8 |
| 96 | 22.2 dɪfɪmpələ | 0 | 1 | 0 | 1 | 1 | SEG-mod | MET-high | 8 |
| 77 | 22.3 sɪpɪlfɪtə | 0 | 1 | 0 | 1 | 1 | SEG-mod | MET-high | 8 |
| 13 | 22.4 fəkɛstələ | 0 | 1 | 0 | 1 | 1 | SEG-mod | MET-high | 8 |

(*Continued*)

(Continued).

| | | Segmental Complexity | | | Metrical complexity | | Complexity classification (present study) | | |
|---|---|---|---|---|---|---|---|---|---|
| 45 | 23.1 bədrɛpəri | 1 | 0 | 0 | 1 | 1 | SEG-mod | MET-high | 8 |
| 15 | 23.2 dɪfrɪpələ | 1 | 0 | 0 | 1 | 1 | SEG-mod | MET-high | 8 |
| 85 | 23.3 sɪprɪfɪtə | 1 | 0 | 0 | 1 | 1 | SEG-mod | MET-high | 8 |
| 43 | 23.4 fəklɛtələ | 1 | 0 | 0 | 1 | 1 | SEG-mod | MET-high | 8 |
| 56 | 24.1 bədrɛmpəri | 1 | 1 | 0 | 1 | 1 | SEG-high | MET-high | 9 |
| 69 | 24.2 dɪfrɪmpələ | 1 | 1 | 0 | 1 | 1 | SEG-high | MET-high | 9 |
| 89 | 24.3 sɪprɪlfɪtə | 1 | 1 | 0 | 1 | 1 | SEG-high | MET-high | 9 |
| 48 | 24.4 fəklɛstələ | 1 | 1 | 0 | 1 | 1 | SEG-high | MET-high | 9 |

*Note*. Adapted version of the Test of Phonological Structure (Van Der Lely & Harris, 1999) used in Gallon et al. (2007), reprinted with permission (Chloe Marshall, Harvard University, December 7, 2017).