Aphasiology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/paph20

Repeated attempts, phonetic errors, and syllabifications in a case study:Evidence of impaired transfer from phonology to articulatory planning

Dinesh Ramoo, Andrew Olson & Cristina Romani

To cite this article: Dinesh Ramoo, Andrew Olson & Cristina Romani (2021) Repeated attempts, phonetic errors, and syllabifications in a case study:Evidence of impaired transfer from phonology to articulatory planning, Aphasiology, 35:4, 485-517, DOI: 10.1080/02687038.2021.1881349

To link to this article: https://doi.org/10.1080/02687038.2021.1881349

Published online: 02 Apr 2021.

APHASIOLOGY
2021, VOL. 35, NO. 4, 485–517
https://doi.org/10.1080/02687038.2021.1881349

Repeated attempts, phonetic errors, and syllabifications in a case study:Evidence of impaired transfer from phonology to articulatory planning

Dinesh Ramoo[a], Andrew Olson[b] and Cristina Romani[c]

[a]Department of Psychology, Thompson Rivers University, Kamloops, Canada; [b]School of Psychology, University of Birmingham, Birmingham, UK; [c]Department of Psychology, Aston University, Birmingham, UK

ABSTRACT

Background: In aphasia, impairments affecting stages after lexical access have been subdivided into three types: 1. impairments specifying a sequence of phonemes after lexical access (the reproduction variety of conduction aphasia, CA); 2. impairments holding on to these representations during articulatory planning (the short-term memory (STM) variety of CA); and 3. Impairments specifying integrated articulatory/motor plans for clusters of phonemes (apraxia of speech, AoS). Models of speech production, however, suggest more articulated possibilities (i.e., different subtypes of articulatory impairments).

Aims: We investigated the impairment in a person with aphasia whose preliminary assessment revealed mixed speech characteristics, combining features typically used to identify CA – phonological errors across tasks and repeated attempts at the target – with features typically used to identify AoS – phonetic errors and word dysfluencies (phoneme elongations and syllabifications). Our preliminary hypothesis was that there was a difficulty transferring information from an (intact) phonological output buffer to articulatory planning. Slow/noisy transfer would predict dysfluencies, errors selecting motor programs, but also repeated attempts (RA) at revising the output in the face of intact feedback and intact original representations. This hypothesis also predicts effects of position and phonological complexity.

Method and Procedure: We tested CS's word and nonword repetition, word reading, and picture naming. We quantified lexical and non-lexical errors, repeated attempts, phonetic errors, and syllabifications. We assessed effects of word frequency, word length, phoneme position, and syllabic and phonological complexity.

Results: CS made similar errors across tasks, consistent with a post-lexical impairment. His RAs most often built up a correct target from fragments and/or previously incorrect attempts, similar to a conduite d'approche. He also produced more errors in later positions, and more repeated attempts on longer words. However, inconsistent with decay from an output buffer, phonological errors did not increase with word length. Finally, frequency mattered,

ARTICLE HISTORY
Received 3 June 2020
Accepted 22 January 2021

KEYWORDS
Apraxia of speech; phonological encoding; articulatory programming; conduite d'approche; error revisions; sequences of phonemic approximations

CONTACT Cristina Romani C.Romani@Aston.ac.uk School of Life and Health Sciences, Aston University, Aston Triangle, Birmingham B4 7ET, England

consistent with easier/faster access to simpler/more practiced motor plans.
Conclusions: CS's speech characteristics and anatomical lesion are consistent with transfer limitations between phonology and articulatory planning. However, CS has more difficulties in computing articulatory plans than in selecting and retaining phonological representations, as commonly attributed to CA. CS's case suggests that different varieties of phonological and articulatory disorders need to be distinguished, beyond a strict dichotomy AoS/CA (e.g., involving transfer limitations and difficulties in computing, selecting, and/or initiating articulatory plans).

All common models of speech production include stages representing word meanings and corresponding sequences of phonemes. Difficulties in retrieving representations at these stages are known as *anomia*. Traditionally, four types of post-lexical stages and corresponding impairments have been identified. 1) Impairments involving "phonological encoding" (Buchwald & Miozzo, 2011; Canter et al., 1985; Goldrick & Rapp, 2007;Kohn, 1984); 2) Buffer impairments (Caramazza et al., 1986; Shallice et al., 2000); 3) Impairments in articulatory/motor planning (Code, 1998; Laganaro, 2012; Ogar et al., 2005; Romani & Galluzzi, 2005; Ziegler, 2009); and 4) Impairments affecting motor implementation (Duffy, 2005). Impairments of type 1 and 2 have been clinically associated with the label conduction aphasia (CA of either the reproduction or the repetition/STM subtype, e.g., Caplan et al., 1986; Shallice & Warrington, 1977). Impairments of type 3 have been associated with the label apraxia of speech (AoS); impairments of type 4 with dysarthria. The aim of this paper is to contribute to the characterization of post-lexical impairments by presenting the case of an aphasic speaker whose speech does not fit neatly with the characteristics commonly used to identify different impairments. The most salient feature of CS's speech is repeated attempts at word production, which typically come closer to the target (commonly described as a conduite d'approche). This symptom is often considered a defining characteristic of CA. However, in CS, repeated attempts occur in the context of high rates of phonetic errors and dysfluencies (syllabifications, elongations of phonemes) which typically characterize AoS. The aim of this paper is to analyse CS's repeated attempts in some detail, together with length and positional effects, associated with buffer impairments, and syllabic and phonemic simplifications, associated with articulatory impairments. Our results highlight difficulties in diagnosis and possible variability in types of AoS.

Figure 1 shows a simplified word production model with stages that have some consensus even if different terminologies are used for labelling. Lexical activation involves identifying the correct phonological representation in the lexicon. Deficits will cause anomia. Phonological errors can be made at this stage, but there should be some lexical errors. More crucially, errors will occur mainly in tasks where representations need to be recovered (as in picture naming), rather than simply reproduced (as in repetition). After lexical access, most authors assume a stage called phonological encoding where the sequences of phonemes specified at the lexical level are unpacked into bundles of features representing articulatory targets. For example, the phoneme/p/would be represented as "lip closure" for a labial consonant and glottal abduction with timing specified

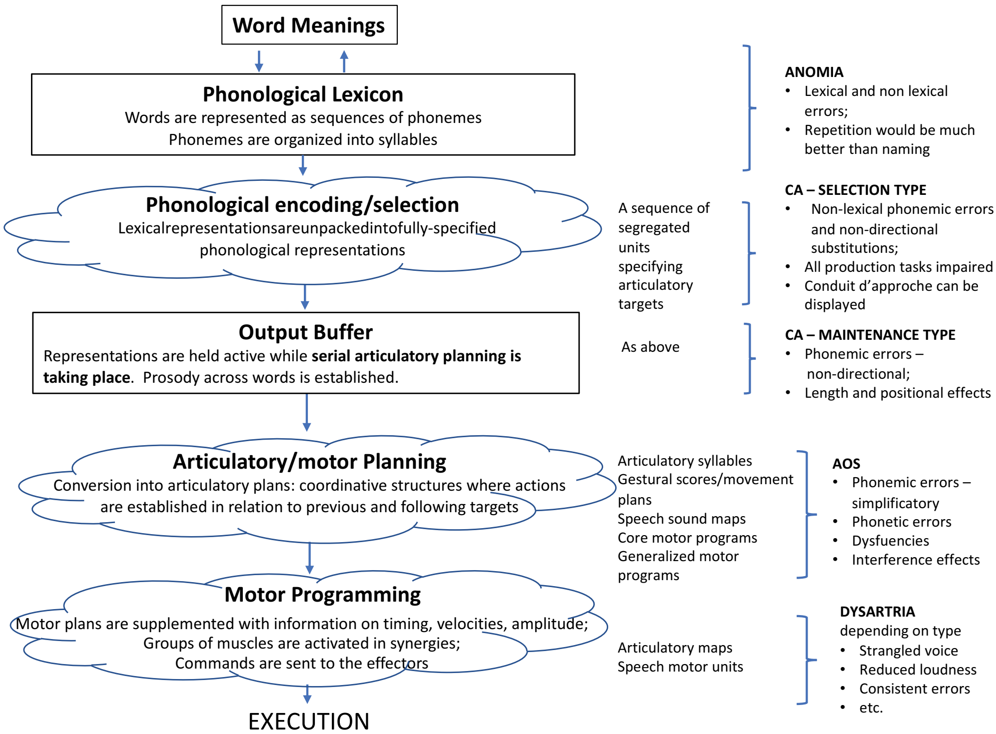

Figure 1. A schematic model of word production.

for an unvoiced consonant.[1] Whether this level should be called phonological or phonetic encoding is ambiguous, but the units of representation are still "abstract, invariant, and segregated" (see Postma, 2000; see also Kohn, 1984). Degraded representations would result in non-lexical errors which are phonologically close to the target and can be interpreted as the erroneous production of one or more phonemes, with errors describable as substitutions, deletions, insertions, and movements of phonemes. Substitutions will be mainly non-directional (e.g., t→f as frequent as f→t), without systematic simplifications (e.g., Galluzzi et al., 2015). A conduite d'approche can be displayed (Joanette et al., 1980; Kohn, 1984; Shallice & Warrington, 1977).

Representations held in a buffer are the basis for the subsequent process of articulatory/motor planning. These further levels will represent actions in time instead of targets of actions. Units will be sets of gestures occurring at the same time and/or in a precisely coordinated manner (see Kelso et al., 1984; Saltzman & Kelso, 1987). Since articulatory planning/programming must take into account the context of previous and following targets and is a sequential process, it must operate on buffered representations which allow a look-ahead window (Guenther, 2015; Lashley, 1951). The need for an output buffer is particularly important in connected speech to allow for coarticulation between words and for prosody to be established. A reduction in buffer capacity will produce clear length effects with performance progressively worse for longer words, when words are considered as whole, but also when the rate of error *per phoneme* is considered (e.g., see Romani et al., 2011bb). It may also produce positional effects where phonemes in the middle or at the end of words are produced less accurately than at the beginning. Middle phonemes are more susceptible to interference from flanking phonemes (a U-shaped serial position curve) and non-initial phonemes have more chance to decay while the beginning of the word is being produced (a linearly decreasing curve; Glasspool et al., 2006; Olson et al., 2010; Romani et al., 2011b; Ward & Romani, 1998).

Articulatory planning will compute integrated gestures (articulatory plans). Well-established articulatory plans could be stored as pre-computed routines which could be of different sizes (for articulatory syllable-sized units see Cholin, 2008; Levelt et al., 1999; Tilsen, 2016; (but also Croot et al., 2017); for articulatory word units, see Varley & Whiteside, 2001). Defining characteristics of AoS are the presence of phonetic errors and word dysfluencies (see Baum, 1992; Deal & Darley, 1972; Johns & Darley, 1970; McNeil et al., 2016McNeil et al., 1990) and phonological simplifications (see Galluzzi et al., 2015).Phonetic errors may result from articulatory gestures which are not precisely tuned or from conflicting motor commands to the articulators. Dysfluencies may result from delayed access to articulatory plans which will produce inter-syllabic pauses and elongations of phonemes. Phonological simplifications will be motivated by the need to keep the target within the articulatory competency of the speaker (see Cunningham et al., 2016; Haley et al., 2017 for using syllable durations as a preliminary diagnostic criterion; see Galluzzi et al., 2015; Romani et al., 2011, 2017 for using phonetic errors).

Finally, some authors distinguish a further stage after articulatory planning. Van der Merwe (Van Der Merwe, 2020), who has been a strong advocate, calls this stage motor programming and assumes it involves specifying further details of motor plans including timing, velocities, amplitude and strength of muscle activation. At this level, motor commands to the effectors are delivered and impairments will cause dysarthria. Different types of dysarthria will result in different characteristics (e.g., reduced loudness, strangled voice, slurred speech etc.), but a shared characteristic is consistency of impairment across linguistic contexts.

In our review of the literature, we have presented a relatively simple association between stages in a production model and behavioural characteristics of impairment:

(1) A conduite d'approach and non-directional substitutions with deficits of phonological/phonetic encoding (the reproduction/phoneme selection variety of CA);
(2) Length effects and U-shaped positional effects with buffer impairments (the STM/maintenance variety of CA);
(3) Phonetic errors, dysfluencies, phonological simplifications with impairments in articulatory/motor planning (AoS).

However, associations between symptoms and impairments may not be so univocal and it may be necessary to distinguish more varieties of impairment. Many models distinguish processing that selects motor plans (articulatory planning) from processing that controls the feeding of phonological information to articulatory planning. For example, the DIVA/GODIVA model (Guenther, 2015; Miller & Guenther, 2020) hypothesizes that speech requires interplay between a *motor loop* (including an initiation map and the speech sound map) and a *planning loop* (including a phonological content buffer and a sequential structure buffer). The dynamic model of Tilsen (2013) requires an interplay between a mechanism that *selects* motor plans through competitive activation and a mechanism that *coordinates* timing of execution through oscillatory systems (see also Klapp, 2003 for a distinction between INT – for selecting internal motor plans and SEQ for sequencing the plans for delivery to the articulators). These models predict different varieties of AoS.

Previous research has suggested that AoS could involve difficulties in selecting the right motor programs from a store of pre-computed gestures (see Aichert & Ziegler, 2004; Maas & Mailend, 2012; Mailend et al., 2019; Varley & Whiteside, 2001) as well as difficulties in computing articulatory plans from phonological input so that plans are simplified (e.g., Buchwald, 2009; Code, 1998; Den Ouden & Bastiaanse, 2003; Galluzzi and Romani, 2015; Romani & Galluzzi, 2005; Romani et al., 2011, 2017). Similarly, in progressive forms of apraxia of speech, different types have been distinguished (Duffy et al., 2020). One associated with a predominance of phonetic and phonological errors and another with a predominance of prosodic abnormalities, including slowed and segmented speech (separated into syllables or words). The first pattern may arise from selection difficulties, the second from difficulties with sequencing and coordination. Additionally, difficulties could arise when phonological information is not fed swiftly enough to motor planning (from the buffer to motor/articulatory planning in Figure 1). A capacity limitation of this type could account for the co-occurrence of articulatory difficulties (e.g., dysfluencies and phonetic errors) and repeated attempts, which aim to produce the target in a correct and fluent way, as we noted in our case, CS. Dysfluencies would arise because the articulatory planner does not receive information at the right time. Phonetic errors could arise because, due to time-constraints, a program with all the right specifications is not selected or a mixed program is selected with characteristics that are intermediate between different phonological specifications. However, CS's pattern could also arise because of overlaid phonological and articulatory impairments, where difficulties at the articulatory level simply combine with difficulties in selecting phonemes and/or with fast decay of representations from an output buffer.

The aims of our investigation are twofold. First, we want to better document the characteristics of RAs in a PWA with associated evidence of articulatory difficulties. Studies describing RA are very limited, both in the context of AoS (see Darley, 1968; Harmon et al., 2019; Trost, 1970) and in the context of CA (e.g., Christman et al., 2004; Franklin et al., 2002; Joanette et al., 1980; Kohn, 1984, 1989; Marshall & Tompkins, 1982). For RAs we mean both false starts, where a fragment of the word is produced followed by a more complete response, and response revisions/self-corrections, where a complete but erroneous response is produced followed by spontaneous new attempts at the target (similarly to a conduite d'approche). Second, we want to test our preliminary hypothesis that CS's difficulties arise from limitations in the transfer of information between intact phonological representations held in an output buffer and mechanisms of articulatory planning/programming.

If CS has a normal output buffer (i.e., his phonological representations do not degrade quicker than normal), but suffers from a limitation in transferring information to the articulatory planner, we expect phonological errors to be sensitive to word position because delays will accumulate across the word, leading to more errors for later positions. For the same reason, RAs will be more common on longer words. However, the error rate per phoneme should not increase with length independent of position. For example, the same rate of errors should be produced for the 3rd position in word, independent of the overall length of the word (e.g., 4 or 7 phonemes). This is because the third position will be subject to the same amount of delay in feeding information to the articulatory planner no matter how many positions follow. If the capacity of the buffer were reduced, instead, the third position should suffer more when a word has 7 phonemes compared to 4 phonemes (e.g., see Houghton, 1990; Houghton, 2018). Moreover, if CS suffers from a phonological impairment that was independent of articulatory difficulties, his phonological errors should be independent of phonological and syllabic complexity. Since errors will arise in selecting units with the right phonological features, they should be phonologically related to the target, but not occur more often on complex structures, nor systematically substitute a simpler alternative for a more complex one (see Galluzzi et al., 2015; Romani & Galluzzi, 2005; Romani et al., 2011, 2017). Alternatively, if errors arise at the interface between phonology and articulation, we expect fewer errors when the motor plan/ programs are easier to access because they are simpler and/or more practiced.

In our experimental investigation, we will first establish that CS's impairment is post-lexical by demonstrating a similar level and quality of performance across output tasks. Second, we will document characteristics consistent with an articulatory impairment (phonetic errors and syllabifications) and analyse the nature of repeated attempts. Finally, we will consider evidence provided by effects of 1) word length, word position, and word frequency; and 2) phonological and syllabic complexity.

1. Case study

CS was a 75-year-old, right-handed man who had suffered an ischemic stroke 2 years before testing. His CT scan showed a wedge-shaped area of low attenuation in the left parietal region (middle cerebral artery territory) with some normal density within it. This indicates a partial infarction with some tissue perfusion within the damaged area (see Figure 2). Damage in the inferior parietal lobes potentially affects white matter fibres subserving the supramarginal gyrus and/or tissues of the supramarginal gyrus itself, although it is possible that there is also intact tissue within the affected region. He was recruited for this study via the South Birmingham Community Support Centre for the Stroke Association.

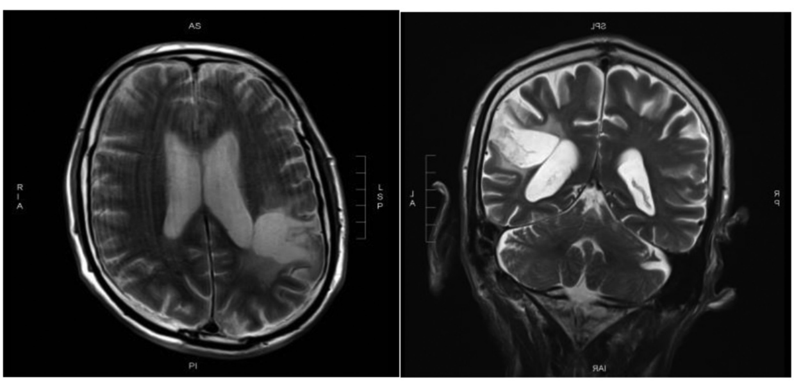

Figure 2. CS's CT scan.

CS completed a B.Sc. (Hons) in Electrical Engineering. He worked as an engineer for the BBC before taking early retirement. At the time of testing, CS was married and enjoyed an active life, with lots of hobbies. He liked sports and previously played hockey, golf, and badminton. After his stroke, he engaged in orienteering, hill walking, and worked in his allotment. He was tested at the University of Birmingham between 2012 and 2014 (before suffering a new stroke in 2015). Ethical approval was granted by the University of Birmingham School of Psychology Ethics Committee. Testing sessions were compatible with CS's obligations and lasted no more than two hours each time.

CS's speech was grammatical with a good range of words, but with a halting quality, characterized by false starts, groping, elongation of phonemes, syllabified words, and phonological errors. There was a notable conduite d'approche where target words were built up from progressively larger speech units. These RAs were often followed by a correct and fluent production of the target.

2. Initial assessment

CS's language skills were initially assessed using the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA; Kay et al., 1996). His phonological STM capacity was investigated with a digit span task, a matching span task, and with rhyming and semantic categorization probe tasks. In each of the probe tasks, word lists of increasing length were presented spoken. Immediately after presentation of the list, a probe word was presented (also spoken). In the rhyming probe task, CS had to decide if the probe rhymed with any word in the preceding list. In the semantic task, he had to decide if the probe belonged to the same semantic category as any word in the preceding list. For each list length, half of the probes were positive, and half negative. For the positive probes, the matching word occurred an equal number of times in each list position. The number of lists for each length varied between 20 and 36.

Results are shown in Table 1. CS demonstrated good semantic knowledge, good phonological input processing, and good ability to retain input phonological representations (good phonological STM). CS also demonstrated a modest impairment with the Apraxia Battery for Adults-Second Edition (ABA-2; Dabul, 2000).

3. Experimental word production

3.1. Stimuli

CS's word production was investigated with an extensive set of stimuli for word repetition, non-word repetition, reading, and picture naming. When some tests were repeated, this was after a lag of several months. Results are presented together since there were no discernible changes.

Some of the stimuli came from PALPA lists while others were ad-hoc lists created by the authors. Total stimuli were, for word repetition = 2344; for nonword repetition = 202; for word reading = 1620; for picture naming = 289. The lists included words of different lengths and syllabic structures representative of the English language. The nonwords respected phonotactic constraints and were derived from words by changing a single phoneme. For each task, CS was asked to produce a word in his own time. His responses

Table 1. CS's performance in semantic tasks, input tasks, and STM. All tasks, except for the probe task, are from PALPA.

	N corr	N stim	% correct
Semantics			
Spoken Word-Picture Matching	40	40	**100**
Written Word-Picture Matching	40	40	**100**
Synonyms – Auditory	30	30	**100**
Synonyms – Written	30	30	**100**
Word semantic association			
high imageability	13	15	**86.7**
low imageability	11	15	**73.3**
Lexical input			
Lex decision spoken	79	80	**98.8**
Lex decision written	60	60	**100**
Sentence comprehension			
Auditory	35	36	**97.2**
Written	33	36	**91.7**
Locative relationships			
Auditory	24	24	**100**
Written	24	24	**100**
Phonological Input			
Same/different nonwords	66	72	**91.7**
Same/different words	59	72	**81.9**
Written word selection: minimal pairs	68	72	**94.4**
Picture word selection: minimal pairs	35	40	87.5
STM			
Digit span (Repetition)	**5**		
Digit span (Matching)	**7**		
Probe -rhyme span	**4.1**		
Probe -semantic categories span	**5.7**		

were recorded with a digital audio recorder and transcribed for analysis. Task analyses collapsed items across lists.

3.2. General error analyses

CS's incorrect responses were categorized as lexical errors, non-lexical errors, and repeated attempts (RAs). Lexical errors were errors where a different word of the language, generally phonologically very close to the target, was produced. Non-lexical errors involved phonological changes that did not result in a real word. The great majority of these errors could be unambiguously interpreted as transformations of individual phonemes. RAs were responses where the target was attempted more than one time, with a clear separation or re-start between attempts and following an initial response which was either partial or else complete, but wrong. The final response could be correct, a lexical error or a non-lexical error (e.g., target: altitude[æltɪtjuːd]; response: *ætɪtju* … *ætɪʧəʊ* … *ætɪʧ* …. *ætɪ* … *ætɪ* … *ʧjuːd. æltɪʧjuːd*; scoring: repeated attempt resulting in the nonword error *æltɪʧjuːd*). CS's responses were coded by both the first and the last author based on recordings and software for manipulating and labelling audio files (Audacity; www.audacityteam.org). Discrepancies were resolved by discussion.

Table 2 reports CS's number correct and types of errors across tasks. For these analyses, words produced dysfluently and/or containing phonetic errors (see below for details) were considered correct if the sequence of phonemes was correct. Unfortunately, in the

Table 2. CS's errors in repetition, reading and naming. For naming only initial full responses were scored. Percentages are based on the number of word stimuli.

	Word Repetition		Non-Word Repetition		Reading		Naming		Total	
	N	%	N	%	N	%	N	%	N	%
Stimuli	2339		202		1620		289		4450	
Correct	1847	**79**	46	**22.8**	1204	**74.3**	222	**76.8**	3319	**74.6**
Pure Nonlexical Errors	162	**33.1**	43	**27.6**	241	**57.9**	56	**83.6**	504	**44.6**
Pure Lexical Errors	110	**22.4**	24	**15.4**	35	**8.4**	11	**16.4**	181	**16**
Phonological	87	17.8	24	15.4	34	8.2	8	11.9	154	13.6
Morphological	19	3.9	0	0	1	0.2	0	0	20	1.8
Visual	–		–		–		3	4.5	3	0.3
Repeated attempts	218	**44.5**	89	**57.1**	140	**33.7**	–	–	446	**39.4**
Outcome: Correct	149	30.4	18	11.5	100	24	–	–	244	21.6
Outcome: Lexical Error	13	2.7	11	7.1	4	1	–	–	27	2.4
Outcome: Nonlexical Error	56	11.4	60	38.5	36	8.7	–	–	151	13.4
Total Errors	490	**20.9**	156	**77.2**	416	**25.7**	67	**23.2**	1131	**25.4**

case of picture naming, only CS's last response was transcribed and the digital sound files could not be located for re-scoring. Therefore, for this task, RAs could not be analysed. CS, however, was also given computerized repetition, reading and naming tasks (Romani et al., in preparation). With these tasks, he showed a similar distribution of RAs across tasks.

Error rates were compared using log-linear analysis. Overall error rate was similar across word tasks, with a small but reliable difference between repetition and reading (79.1% vs 74.3% correct, $G^2 = 12.9$, $p < .001$) and no difference in repetition vs naming ($G^2 = 0.9$, $p = .35$) or reading vs naming ($G^2 = 0.8$, $p = .36$). Instead, CS was much better at repeating words than nonwords ($G^2 = 265.1$, $p < .001$, 79% vs 23% correct). Across tasks, qualitative performance was similar. Non-lexical errors were always more numerous than lexical errors which were phonologically related to the target (the difference was less marked in repetition, where there were more lexical errors). Repeated attempts resulted in a correct production to a similar degree in word repetition and reading (69% and 72%, $G^2 = 3.04$, $p = .22$). Instead, fewer repeated attempts ended up correct in nonword repetition (20% vs 69%; $G^2 = 62.6$, $p < .001$; Table 2).

Table 3. Proportion of different kinds of phoneme errors across tasks. Note that the number of non-lexical errors is higher in this analysis because a non-lexical error may contain more than one phonemic error (e.g., two different phoneme substitutions or a substitution plus a deletion). Percentages are based on the total number of individual phoneme errors.

Type of individual non-lexical error	Word Repetition		Non-Word Repetition		Read		Naming		Total	
	N	%	N	%	N	%	N	%	N	%
Substitution	154	**66.4**	78	**67.2**	240	**72.5**	42	**64.6**	514	**69.1**
Consonant	117	76.0	67	85.9	151	62.9	21	50.0	356	69.3
Vowel	37	24.0	11	14.1	89	37.1	21	50.0	158	30.7
Deletion	26	**11.2**	24	**20.7**	16	**4.8**	4	**6.2**	70	**9.4**
Consonant	25	96.2	18	75.0	16	100.0	4	100.0	63	90.0
Vowel	1	3.8	6	25.0	0	0.0	0	0.0	7	10.0
Insertion	49	**21.1**	13	**11.2**	72	**21.8**	18	**27.7**	152	**20.4**
Consonant	33	67.3	10	76.9	33	45.8	4	22.2	80	52.6
Vowel	16	32.7	3	23.1	39	54.2	14	77.8	72	47.4
Movement	3	**1.3**	1	**0.9**	3	**0.9**	1	**1.5**	8	**1.1**
Consonant	2		1		3		1		7	
Vowel	1		0		0		0		1	
Total	232		116		331		65		744	

Individual phoneme transformations (up to three per word) are reported in Table 3, categorized as phoneme substitutions (e.g., “valour”/vælə/→/bælə/), deletions (e.g., “profits”/prɒfɪts/→/pɒfɪts/), insertions (e.g., “wrestling”/rɛslɪŋ/→/rɛsəlɪŋ/), and movements from one position in the word to another (e.g., “lightbulb”/laɪtbʌlb/→/laɪtblʌb/). Most individual errors involved phoneme substitutions, but a sizeable number involved insertions (see later for an analyses of these transformations). There were few movement errors, as is typical for word production (see also Ardila et al., 1989; Romani et al., 2011; Wilshire, 2002). Most substitutions involved consonants rather than vowels. There were, however, similar rates of vowel and consonant insertions.

Conclusions: CS’s speech production is similarly impaired across tasks with many RAs and non-lexical phonological errors, which mostly involve individual phonemes and often phoneme substitutions. This is consistent with a post-lexical deficit affecting all spoken tasks. If the problem were in lexical access, providing a model to copy, as in repetition, should have made performance close to normal. Producing more RAs with words than nonwords also suggests that RAs rely on the support of lexical representations which are not available for nonwords after the input record decays (see also Franklin et al., 2002; Kohler et al., 1998; Kohn, 1984) .

3.3. Phonetic errors and syllabifications

Phonetic errors and inter-syllabic pauses are typically considered signs of articulatory difficulties. In fact, these are the two most common characteristics used for identification of AoS in published studies (see Molloy & Jagoe, 2019). Here, we quantify the rate of phonetic errors and syllabications in CS. We counted phonetic errors when sounds were slurred, imprecise, or clearly elongated, or, in any case, when produced in a manner not typical of a native English speaker. We counted syllabifications when there was a clear discontinuity between adjacent syllables. In repeated attempts, a syllabified response was counted when at least one of the attempts, on its own, was syllabified.

Rates of phonetic errors and syllabifications were estimated using subsets of items from reading and repetition, sampled starting from a random point in the randomized stimulus lists. For repetition, we scored 232 stimuli from the length and long word lists. For reading, we scored 311 stimuli from the syllable list. Phonetic errors were scored independently by all three authors by carefully listening and re-listening to the digital recordings. Any discrepancy was solved according to majority judgement or by consensus. Scoring across judges was relatively consistent (74% agreement before resolution of differences). Although scoring phonetic errors is rightly considered difficult and produces a degree of disagreement, all judges identified a sizeable number of phonetic errors in CS’s corpus, ranging between 21% and 29% of the responses. Syllabifications were scored independently by two of the authors. Consistency was high (92% for reading, 91% for repetition).

In repetition, CS made 47/232 (20.2%) phonetic errors and 52/232 (22.4%) syllabifications. In reading, he made 45/311 (14.4%) phonetic errors and 47/311 (15.1%) syllabifications. A higher rate of phonetic errors in repetition may be due to the stimuli including longer words (average word length for repetition = 8.6, SD = 2.3; for reading = 6.0; SD = 1.6).

3.3.1. Conclusions

CS's speech production is characterized not only by phonological errors but also by many phonetic errors and syllabifications (>10%, see previous studies of patients where more or fewer phonetic errors are associated with different types of errors and different classifications, e.g., Galluzzi et al., 2015). These would clinically classify CS as having AoS (Miller & Guenther, 2020).

3.4. Repeated attempts

In the context of CA, RAs (or "sequences of phonemic approximations") have been described both as revisions of complete responses (e.g., from Joanette et al., 1980, for "crayon" [pencil]/krɛjɔ/>krava>krəbɛ>krevɔ> krɛjɔ̃; from; Valdois et al., 1989, for "cadaver" [corpse]/kadavR:/> tava >tRava> tavjaR > tavaR> kJb> kaba> kadRav> kadavR; see also Gandour et al., 1994) and as sequences where more complete responses are built up from initial fragments (e.g., from Christman et al., 2004; for "dominoes">/nam/>/namoz/>/naminoz/). RAs indicate that a mismatch has been detected between what has been produced (or is about to be produced) and a target lexical representation. For this reason, RAs have been considered to occur after lexical access, at the level of phonological encoding (Christman et al., 2004; Kohn, 1984; Kohn & Smith, 1995) and they have been associated with CA (see Franklin et al., 2002; Gandour et al., 1994; Joanette et al., 1980; Kohn & Smith, 1994; Marshall & Tompkins, 1982; Valdois et al., 1989). RAs, however, could also arise at a later stage in motor planning/programming where an incorrect motor plan is revised. Consistent with this second locus, they have also been observed in AoS (Darley, 1968; Harmon et al., 2019; Trost, 1970).

Only a few studies have formally analysed RAs in AoS, and, while some authors have described them as similar to a conduite d'approche (e.g., Liss, 1998), others have described them as stutter-like dysfluencies, where the beginning syllable is repeated (see Bailey et al., 2017; see also Johns & Darley, 1970, page 580 where people with AoS are described as "secondary stutterers"). Moreover, successful progression towards the target does not appear to distinguish RAs in AoS vs CA. As the name conduite d'approche implies, RAs can move responses closer to the target, but they can also be unsuccessful, or, in some cases, move the response away from the target (Gandour et al., 1994; Joanette et al., 1980; Valdois et al., 1989). Original studies reported more successful progression in CA than in other syndromes (M. R. McNeil et al., 1995; Valdois et al., 1989), but the number of participants in these studies was very small. Other studies showed a relatively low percentage of successful outcomes in speakers with CA (36% and 30%, respectively, in Gandour et al., 1994; Kohn, 1989). Still other studies showed a similar incidence of RAs across clinical classifications (Harmon et al., 2019; Marshall & Tompkins, 1982). It is unclear, therefore, whether RAs have different characteristics in speakers with AoS and CA.

In this section, we analyse CS's repeated attempts to see whether they are closer to a conduite d'approche (error revisions building towards a more complete or more correct response) or closer to stutter-like behaviours, where the beginning of the word is repeated before a complete response.

3.4.1. Method and results

Analyses of RAs were carried out, collapsing across word repetition and word reading since performance was similar in these tasks. RAs were scored when any initially phonologically incorrect or incomplete response was revised. RAs are subdivided into two main categories: 1. revisions of initially phonologically wrong, but complete responses (e.g., rattle>/ræpəl … rætəl/), and 2. revisions of initially incomplete responses where the initial fragment was either phonologically correct (e.g., deficiency> dɪ … dɪf … dɪfɪʃ … dɪfɪʃənsɪ; Westminster> wɛst … wɛstmɪnstə) or incorrect (e.g., hospital> hɒf … hɒspɪtəl; representative> rɛm... rɛprɪs... rɛprɪzɛntətɪv).

Table 4 shows the rates of different kinds of RAs together with correct/incorrect final outcomes. Most of CS's RAs involved revisions of initially wrong responses that were either complete, 30% (106/358), or fragments, 32% (115/358). CS made, on average, two attempts before his final response. He made slightly more attempts when he did not eventually reach the target (average = 1.8, SD = 1.2, range = 1–11 vs average = 2.1, SD = 1.4, range = 1–9; t = 1.9; p = .053). Revisions were successful most of the time (249/358 = 69.6%). Success followed initially incomplete responses more often than initially complete responses (73.8% vs 59.4%; $\chi^2 = 7.3$; p = .007) but was equally likely whether the initial fragment was correct or incorrect.

Initial incomplete responses were of different sizes corresponding to syllables (one-syllable, N = 64; two-syllables, N = 18; three-syllables, N = 2) or a variable number of phonemes not respecting the syllabic boundaries of the target (one-phoneme, N = 30; two, N = 32; three, N = 50; four, N = 23; five, N = 15; six+, N = 9). Often a correct response was built up from progressively larger chunks (e.g., inhibition>/ɪnhɪ. ɪnhɪ … ɪnhɪbʃ … ɪnhɪbɪʃən/). However, there were also cases where the process derailed in the middle and then went back on track (e.g., conquest >/kɒn … kɒn … kɒnf … kɒnkwɪ … kɒŋkwɛst/; pushchair>/pʊʃ … pʊʃ … pʊʃt … pʊʃt. pʊʃʧɛə/) and, less frequently, cases where the outcome was not completely successful (e.g., graduation>/grædʒʊ … grædʒʊ … grædʒʊleʃən/; interview>/ɪntə … ɪntərvɪl … ɪntəvəjuː/).

In the previous section, we reported CS's rate of syllabifications on a random sample of stimuli. Here we ask how often CS produced a fluent response after a syllabified initial response. We considered only multisyllabic words where an initial response was syllabified. There were 50 such trials in repetition and 42 in reading. The final response was fluent 38% of the time (13/50 in repetition and 19/42 in reading). Some of these prosodic revisions were accompanied by revisions of word phonology, but others involved only prosody (7 vs. 6 in repetition; 14 vs 5 in reading).

Table 4. Number of repeated attempts according to type of initial response and outcome (word repetition and reading collapsed). Incomplete responses can either start correct and build up the target from smaller units or start incorrect. Percentages are based, initially, on the total number of word stimuli (column 3) and then on the number of responses of each type (columns 5 and 7).

			FINAL OUTCOME			
INITIAL RESPONSE			CORRECT		INCORRECT	
	N	% out of stimuli	N	%	N	%
Wrong, but complete	106	2.7	63	**59.4**	43	**40.6**
Incomplete	252	6.4	186	**73.8**	66	**26.2**
starts correct	*137*	*3.5*	*101*	*73.7*	*36*	*26.3*
starts wrong	*115*	*2.9*	*85*	*73.9*	*30*	*26.1*
Total	358	9	249	**69.6**	109	**30.4**

3.4.2. Conclusions

CS's RAs resemble a conduite d'approche more than stutter-like disfluencies. RAs often involved revisions of phonologically incorrect responses and not just repetitions of correct initial fragments. As in a conduite d'approache, success was common, but not guaranteed. Successful revisions indicate intact auditory feedback and/or an intact forward model where the system stops because what is said, or is about to be said, does not match the intended target (see DIVA, Miller & Guenther, 2020; Tilsen, 2013, dynamic model). However, CS's RA also involved revisions of responses that were phonologically correct but incomplete, or phonologically correct but dysfluent. Taken together, these characterstics point to a system where phonology is not fed to articulation fast or accurately enough. Slower/noisier transmission means less time to resolve competition resulting in phonetic errors and delays within words resulting in syllabifications. Repeated attempts will lead to success by priming correct articulatory plans.

3.5. Effects of length, frequency and position

If there is a slower or noisier transmission from phonology to articulation, as we have hypothesized, delays should accumulate across the word, leading to position effects independent of word length.

More phonemes offer more opportunities for errors. Thus, longer words are expected to be more often incorrect following a variety of problems, including difficulties in phonological encoding, in keeping phonemes active over time, and in articulatory planning. Considering the rate of errors *per phoneme* and effects of word position is more informative. A buffer impairment predicts that error rates *per phoneme* will increase at all positions in longer words because all phonemes will deteriorate faster/be more susceptible to interference when more of them need to be stored (a *disproportionate* length effect, see Olson et al., 2010; Romani et al., 2011b). A buffer impairment may also predict linear positional effects since phonemes at the end of the word may have more chance to decay (Glasspool et al., 2006; Schiller et al., 2001; Ward & Romani, 1998). However, a buffer impairment predicts a length effect that is independent of positional effects. Performance on the same position (e.g., 3rd position in the word) should be more susceptible to interference if it belongs to a longer compared to a shorter word. A reduced capacity to transfer information from phonology to articulation, instead, predicts the opposite: a positional effect *without* a length effect because later positions will be more affected by accumulating delays regardless of how many items follow in a short compared to a long word.

In this section, we ask if there are independent effects of length and position and whether any effect is influenced by word frequency. Originally, buffer impairments were not expected to produce effects of word frequency given the buffer's post-lexical location (e.g., Caramazza et al., 1986). Subsequent studies, however, have shown that lexical variables can influence performance in patients with an alleged output buffer impairment (Shallice et al., 2000).

3.5.1. Analyses of length and frequency

To assess length effects, we categorized words as ***short*** (3–5 phonemes), ***medium*** (6–7 phonemes), ***long*** (8–9 phonemes), and ***very long*** (≥10 phonemes). Words of different lengths were matched for frequency using the Celex corpus based on a sample of 17.9 million words (Baayen et al., 1993). For repetition, mean log frequency: short words = 2.2, SD = 0.84; medium words = 2.0, SD = 0.92; long words = 2.1, SD = 0.79; very long words = 2.0, SD = 0.8; reading: short words = 2.2, SD = 0.85; medium words = 2.0, SD = 0.95; long words = 2.0, SD = 0.84; very long words = 1.8, SD = 0.8; naming: short words = 2.2, SD = 0.69; medium words = 2.0, SD = 0.83; long words = 1.8, SD = 0.92; very long words = 1.1, SD = 0.85). Across length and frequency words were also matched for complexity, imageability and grammatical class. Results are given in Table 5, which shows length effects by task for errors per word (whole word correct or incorrect), RAs per word, and errors per phoneme.

To tabulate effects of word frequency, we categorized words as ***low frequency*** (log frequency<2.5, mean frequency = 92, range = 1–314), ***medium frequency*** (log frequency = 2.5–2.99, mean frequency = 562, range = 318–993), and ***high frequency*** (log = 3–4.2, mean frequency = 2422, range = 1001–13,345). Words of different frequencies had similar lengths (repetition: high-frequency = 6.3, SD = 1.9; medium frequency = 7.1, SD = 2.2; low frequency = 6.9, SD = 2.3; reading: high-frequency = 5.3, SD = 1.6; medium-frequency = 5.7, SD = 1.6; low-frequency = 5.8, SD = 1.7; naming: high-frequency = 5.0, SD = 1.3; medium frequency = 5.0, SD = 1.3; low frequency = 5.6,SD = 1.7). Results are shown in Table 6.

Results were analysed with binomial regression using word correct/incorrect, presence/absence of RAs or phoneme correct/incorrect as the dependent variable and length and log frequency as independent continuous variables. Models with and without terms for length and log frequency were compared using likelihood ratio chi-square values (G^2). For whole words, length was significant across all tasks (repetition, $G^2 = 19.7$, $p < .001$; reading, $G^2 = 40.9$, $p < .001$; naming, $G^2 = 4.6$, $p = 0.03$). For RAs, length was significant in repetition ($G^2 = 72.4$, $p < .001$) and naming ($G^2 = 4.6$, $p = 0.03$), but not in reading ($G^2 = 9.9$, $p = 0.99$). For individual phonemes, length was also significant in repetition ($G^2 = 4.7$, $p = 0.03$), but not in reading ($G^2 = 2.9$, $p = 0.09$). Naming had too few errors to analyse.

Frequency was significant across tasks, considering whole words (repetition, $G^2 = 27.1$, $p < .001$; reading, $G^2 = 26.1$, $p < .001$; naming, $G^2 = 15.2$, $p < .001$), RAs (repetition, $G^2 = 8.2$, $p = .004$; reading, $G^2 = 0.8$, $p = .36$) and individual phonemes (repetition, $G^2 = 16.8$, $p < .001$; reading, $G^2 = 13.9$, $p < .001$). There were no interactions between length and frequency (all $p > .08$).

3.5.2. Position

We used number of *preserved* phonemes to analyse effects of length and position together. Preserved phonemes are an approximate mirror image of the number of errors (insertions are not considered). To score preserved phonemes without bias, we used a longest common subsequence algorithm which identified the longest set of phonemes included in both target and response in the same relative order; e.g., the error/stænd/ (“stand”) >/stɪdæn/would have 4 preserved phonemes–/s/, /t/, /æ/, and /n/ – in positions 1, 2, 5 and 6. /d/is also present, but not in the right relative order. Correct responses, non-lexical errors and phonologically related lexical errors were entered in the analysis, including those produced after RAs. Semantic errors were excluded.

Figure 3 plots preserved phonemes by position for words of different lengths. If there are only length effects, positional effects should be flat, but the lines representing longer

Table 5. Errors by word length in number of phonemes: a) % errors over number of target words: b) % of repeated attempts (RAs) over number of target words; c) percentage of individual phoneme errors over number of target phonemes. Indiv Err = Individual phonological errors. Percentages are based on the total number of word stimuli in each length category and then on the total number of individual phonemes in the stimuli.

	Word Repetition			NW repetition			Word Reading			Naming		
a) Word Errors	N words	N errors	% Errors	N words	N errors	% Errors	N words	N errors	% Errors	N words	N errors	% Errorsr
Short (3–5)	751	127	16.9	35	17	48.6	839	167	19.9	183	30	16.4
Medium (6–7)	703	132	18.8	38	28	73.7	536	157	29.3	73	21	28.8
Long (8–9)	590	141	23.9	70	57	81.4	214	86	40.2	26	13	50
Very long >10	295	88	29.8	59	54	91.5	31	7	22.6	7	3	42.9
Gradient			4.3			14.3			0.9			8.8
b) RAs	N words	N RA	% RA	N words	N RA	% RA	N words	N RA	% RA			
Short (3–5)	751	28	3.7	35	10	28.6	839	57	6.8			
Medium (6–7)	703	54	7.7	38	11	28.9	536	58	10.8			
Long (8–9)	590	83	14.1	70	35	50.0	214	20	9.3			
Very long >10	295	57	19.3	59	33	55.9	31	2	6.5			
Gradient			5.2			9.1			−0.1			
c)Indiv Phoneme Errors	N phonemes	N indiv Error	% Errors	N phonemes	N indiv Error	% Errors	N phonemes	N indiv Error	% Errors	N phonemes	N indiv Error	% Errors
Short (3–5)	3380	55	1.6	158	5	3.2	3776	106	2.8	824	28	3.4
Medium (6–7)	4570	63	1.4	247	11	4.5	3484	119	3.4	475	20	4.2
Long (8–9)	5074	55	1.1	602	14	2.3	1840	79	4.3	224	17	7.6
Very long >10	3039	29	1.0	608	13	2.1	319	9	2.8	72	3	4.2

Table 6. Number of errors in different frequency categories. Percentages are based on the number of stimulus words in each category. RA=repeatedattempts

	Word Repetition			Word Reading			Naming		
Word errors	N words	N errors	% Errors	N words	N errors	% Errors	N words	N errors	% Errors
High Frequency	301	39	13	260	36	14	33	2	6
Medium Frequency	485	90	19	301	75	25	50	6	12
Low Frequency	1558	357	23	1059	305	29	206	59	29
Gradient			10			15			23
RAs	N words	N RA	% RA	N words	N RA	% RA			
High Frequency	301	17	6	260	15	6			
Medium Frequency	485	41	8	301	31	10			
Low Frequency	1558	164	11	1059	91	9			
Gradient			5			3			
Individual phoneme errors	N phonemes	N indiv Error	% Errors	N phonemes	N indiv Error	% Errors	N phonemes	N indiv Error	% Errors
High Frequency	1886	42	2.2	1401	43	3.1	168	2	1.2
Medium Frequency	3433	98	2.9	1749	85	4.9	253	10	4.0
Low Frequency	10,744	402	3.7	6269	343	5.5	1174	67	5.7
Gradient			1.5			2.4			4.5

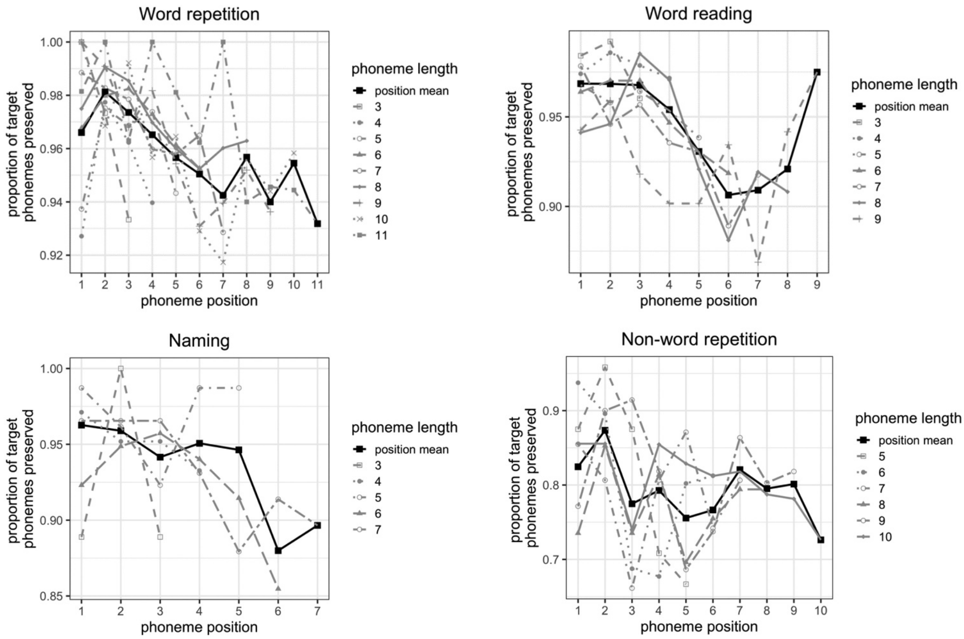

Figure 3. Percentage of phonemes produced correctly as a function of serial position in the target and target length.

words should be displaced downward, reflecting a lower rate of phonemes preserved at all positions. If there are only effects of position, lines should decrease with position, but lines for longer and shorter words should overlap. Finally, if there are both effects of position and length, lines should angle downward with position, but lines for longer words should also be offset (see Olson et al., 2010). Results were analysed using binomial regression with phonemes preserved/not preserved as the dependent variable and word length and position as the independent variables. There was an effect of position in all tasks (word repetition, G^2 = 56.4; $p < .001$; word reading, G^2 = 25.9; $p < .001$; picture naming, G^2 = 4.1; $p = .04$; and nonword repetition, G^2 = 7.3, $p = .007$). An effect of phoneme length was inconsistent (paradoxical effect in repetition, G^2 = 21.8; $p < .001$; expected effect in reading, G^2 = 11.3; $p < .001$; no effect in naming, G^2 = 0.1; $P = .77$; or nonword repetition, G^2 = 0.9, $p = .35$). There were interactions between length and position in word repetition (G^2 = 7.1; $p = .008$) and reading (G^2 = 6.7; $p = .01$) because length was less important for later positions, but data at these positions are limited.

3.5.3. Conclusion

CS showed effects of length considering whole words correct/incorrect and a length effect on RAs, but no length effect per phoneme when positional effects were taken into account (see also Odell, McNeil, Rosenbek & Hunter, 1990). This last result argues against a fast degradation of phonological representations. Instead, CS showed clear positional effects, independent of length. In word repetition, nonword repetition and picture naming, errors increased with word position. Reading showed some recovery for the last two or three positions, but this could be an artefact of small N. These results are compatible with capacity limitations in articulatory planning. With longer words, the planner would run into more difficulties because delays accumulate and increase pressure to select articulatory plans for the final items. Finally, CS shows clear frequency effects. If we assume that his difficulties are at the level of articulatory planning, this indicates that the ability to compile articulatory plans is affected by practice, possibly with plans corresponding to more common chunks of phonological information stored in a pre-compiled form and strung together in speech production (see Klapp, 2003; see also shifts between competitive and coordinative control in; Tilsen, 2016).

So far, we have interpreted CS's results as suggesting a problem at the interface between phonology and articulation. However, one could argue that CS has two separate impairments: One that affects phonological representations and is responsible for phonological errors, and one that affects articulatory planning and is responsible for phonetic errors. Positional effects would be due to accumulating delays in phonological encoding if this is also a sequential process (for a sequential view see Dell et al., 1993; Houghton, 1990; Kawamoto et al., 1999; for a parallel view see Levelt et al., 1999; Meyer, 1991; Roelofs, 1996, 1997; see also Wilshire, 1999 for a discussion). In the next section, we will examine effects of syllabic and phonemic complexity. Significant effects will be consistent with an impairment affecting transmission to articulatory planning; no effects with an earlier phonological impairment affecting phoneme selection.

3.6. Syllabic and phonemic complexity

Early studies have shown that syllabic simplifications and phoneme substitutions which reduce complexity are more prevalent in patients with a clinical classification of AoS than CA (see Lecours & Lhermitte, 1976; Nespoulous et al., 1984, 1987). More recent studies have shown that these errors highly correlate with phonetic errors (Galluzzi et al., 2015; Romani et al., 2002, 2011; Romani & Galluzzi, 2005; see also Den Ouden, 2002; Den Ouden & Bastiaanse, 2003). PWA who produced higher rates of phonetic errors (>10%) also made errors which simplified syllables and phonemes and showed other indications of articulatory difficulties, such as a tendency to make a majority of substitutions on consonants rather than vowels (Galluzzi et al., 2015; Haley et al., 2012; Romani et al., 2011). Instead, PWA who produced few phonetic errors (arguably those with CA), simplified and complicated syllables equally often and substituted related phonemes without a clear directionality. Furthermore, in PWA who simplified targets, error rates on different phonemes correlated with average age of acquisition. The later a phoneme is acquired by children, the higher the error rate in these patients, with the same types of substitution errors made by children and aphasic speakers. Instead, no correspondence was found in PWA who did not systematically simplify responses (Romani et al., 2017).

Taken together, these results show that simplification errors are associated with articulatory impairments. Phonological representations are simplified so that articulatory plans can be successfully computed or implemented even after damage has reduced the capacity of the articulatory system (see also Den Ouden et al., 2018, for vowel formant dispersion as another indication of articulatory difficulties). In this section, we will assess complexity effects in CS's word production.

Table 7. Deletion and insertion errors which simplify or complicate syllable structure. N err = Number of errors.

SIMPLIFICATIONS			COMPLICATIONS		
Type of error	Result	N err	Type of error	Result	N err
Consonant Deletions			**Consonant Insertions**		
e.g., rɛplɪkə>rɛtɪkɑ	eliminate onset complexity	**27**	e.g., loɪəltɛ>loɪəltr	create complex onset	**24**
e.g., ʃʌvəl>ʃvə	eliminate coda	**6**	e.g., lædə>lædəl	create coda	**8**
e.g., əflɪkt>əfli:k	decrease coda complexity	**11**	e.g., tu:θbrʌʃ>tu:θbrʌkʃ	increase coda complexity	**18**
Vowel Insertions			**Vowel Deletions**		
e.g., ɪntəvju>ɪntəvəju:	eliminate onset complexity	**66**	e.g., frətnɛtɪ> rɛtɛ:nt	create coda	**1**
Consonant Insertions			**Vowel Insertions**		
e.g., stəʊɪk>stʊɪrɪk	Decrease peak complexity eliminate hiatus	**14**	e.g., stɛlθɪ>stɛlθa	increase peak complexity/creates hiatus	**11**
Total		**124**	**Total**		**62**

Table 8. Number and percentages of errors on different phonemes across production tasks (word repetition, word reading, and picture naming). stim = stimuli; sub = substitution errors; Most common = most common substitution error for a given phoneme. Percentages are based on the total number of individual phonemes in the stimuli.

Phoneme		N stim	N sub	% sub	Most common	N	Phoneme		N stim	N sub	% sub	Most common	N
Nasals													
	m	846	7	0.83	m > n	5							
	n	1823	11	0.60	n > l	8							
	ŋ	200	1	0.50									
		2869	19	**0.64**									
Stops							**Stops**						
unvoiced	**p**	789	12	1.52	p > f	8	voiced	**b**	697	36	5.16	b > v	9
	t	1706	29	1.70	t >tʃ	11		**d**	918	21	2.29	d >dʒ	9
	k	1188	22	1.85	k >t	17		**g**	308	10	3.25	g > d	9
		3683	63	**1.69**					1923	67	**3.57**		
Fricatives							**Fricatives**						
unvoiced	**f**	689	13	1.89	f > s	3	voiced	**v**	306	15	4.90	v > b	11
	s	1358	25	1.84	s >ʃ	12		**z**	247	15	6.07	z > s	5
	θ	119	3	2.52	θ > t	3		**ð**	20	2	10.00	ð > d/z	2
		2166	41	**2.08**					573	32	**6.99**		
Palatalized Fricatives							**Palatalized Fricatives**						
unvoiced	**ʃ**	452	23	**5.09**	ʃ>tʃ	12	voiced	**ʒ**	23	2	**8.70**	3>dʒ/z	
Affricates							**Affricates**						
	ʧ	146	9	6.16	tʃ>k/t	3		**ʤ**	243	7	2.88	dʒ> d	3
		598	32	**5.63**					266	9	**5.79**		
Liquids													
	r	1411	17	1.20	r>10	10							
	l	1947	12	0.62	l>r	5							
		3358	29	**0.91**									
Glides													
	j	285	6	2.11	j > l	4							
	w	225	2	0.89	w > m/r	2							
		510	8	**1.50**									

3.6.1. Syllabic complexity

To increase the power of our analyses, we have considered errors made across all word production tasks. Analyses of syllabic complexity have been carried out on deletion and insertion errors which modify the syllable template of the target. We considered errors to be simplifications if they moved a template closer to the simplest consonant-vowel (CV) template, i.e., errors which reduced the number of consonants in a complex onset (e.g., CCV>CV; or CCCV>CCV); errors which eliminated or reduced the number of consonants in coda (*e.g.*, CVC → CV; CVCC → CVC) and errors which eliminated a sequence of two vowels (a hiatus) or reduced a complex vowel peak to a single vowel (*e.g.*, CV.VC → CV. CVC;). For consonant clusters, simplifications could be achieved either through a consonant deletion or a vowel insertion (e.g., CCV→CV or CV.CV). For vowel sequences, simplifications could be achieved either through a vowel deletion or a consonant insertion (e.g., VV→V or V.CV). Results are shown in Table 7.

Consonant deletions and insertions resulted in similar decreases and increases of complexity in onset and coda. CS, however, made a large number of vowel insertions to break consonant clusters. Taken together, therefore, CS's errors showed a tendency to simplify (110/172 = 64%), but this tendency is weaker than that reported by Romani and colleagues for patients with hypothesized AoS (mean 74.3%; SD = 11.0 in Galluzzi et al.,

2015) and the pattern is different, since CS reduced clusters by vowel insertion more than consonant deletion (for insertions in AoS see also Code et al., 2011; Rosenbek et al., 1984).

3.6.2. Phonological complexity (markedness)

There is consensus that phonemes can be ordered by ease of production: Nasals and stops are easier to produce than fricatives, affricatives and liquids; fricatives are easier than affricates; palatalized segments are particularly difficult; and, among liquids, /r/is harder than/l/ (for a review see Romani et al., 2017; see also Tilsen, 2013). Voiced segments may also be harder than unvoiced segments, although this is more controversial in a language like English where unvoiced stops are aspirated in onset position. Glides have a mixed status because they are articulatorily easy but, like liquids, they often occur in complex clusters. Table 8 reports the rate of errors on phonemes organized by class. Nasals were produced better than stops (χ^2 = 14.2.; $p < .001$). Stops were produced better than fricatives, but only for voiced segments (χ^2 = 5.1.; p = .02). Unpalatalized fricatives were produced better than palatalized fricatives and affricates (χ^2 = 8.6.; p = .003). Among liquids, /l/ was produced marginally more accurately than/r/ (χ^2 = 3.3.; p = .07). Unvoiced segments were produced better than voiced segments (for stops χ^2 = 17.5; for fricatives χ^2 = 23.8 for both $p < .001$). These results follow a complexity hierarchy closely and support the hypothesis that CS's speech production difficulties are articulatory.

We also considered the direction of the errors. If complexity played a role, errors should simplify complex targets. Therefore, one should expect that:

(a) A fricative (+ continuant, + strident) or an affricate (-continuant, + strident) is turned into a stop (-continuant, -strident);

(a) An affricate (-continuant, + strident) is turned into a fricative (+ continuant, + strident);
(b) A velar (+back) is turned into a coronal or labial (-back);
(c) A palatal fricative (+high) is turned into an alveolar fricative (-high);
(d) Voiced segments (+voiced) are turned into unvoiced segments (-voiced).

Results are reported in Table 9, which also reports errors transforming palatalized segments (+high, -back) into non-palatalized segments and vice-versa, since CS made a large number of errors of this type.

Comparing raw numbers of simplifications and complications, only 46% of CS's errors were simplifications (simplifications/[simplifications + complications]). This is different from what was reported by Galluzzi et al. (2015) for participants with evidence of articulatory difficulties (76% simplifications calculated in the same way). However, when one compares simplifications and complications considering the number of target phonemes, CS made proportionally more simplifications than complications involving place and voicing.

3.6.3. Conclusion

CS did not simplify phonology as systematically as we previously reported for a sample of Italian PWA. He also used a different simplification strategy, making fewer consonant

Table 9. Number of errors which change phonological features. Percentages are based on the number of phonemes from target stimuli. Fric = Fricative; Alv. = Alveolar; Pal = Palatalized.

SIMPLIFICATIONS					COMPLICATIONS					
	e.g.,	N errors	N stimuli	% stimuli		e.g.,	N errors	N stimuli	% stimuli	Simp vs Comp (χ^2 p-value)
MANNER					**MANNER**					χ^2 p
Fricatives > Stops	f > t/p;v > b/d; s/ > t/p;θ > t	31	3214	0.96	Stops > Fricatives	p > f;b > v;d > ð;t > s; t > θ	29	5606	0.52	
Affricates > Stops	> k; > t; > g; > d	10	389	2.57	Stops > Affricates	b/d > ;t >	28	5606	0.50	
Total		**41**	**3603**	**1.14**	**Total**		**57**	**5606**	**1.02**	**n.s.**
Affricates > Fricatives *onset*	> ; > ;	5	389	1.29	Fricative > Affricates	> ; z > ; s >	17	8345	0.20	
					onset		*12*			
					coda		*5*			
PLACE					**PLACE**					
Velars>Dental/ Bilabial	k > t; g > d	**31**	**1496**	**2.07**	**Dental/Bilabial>Velars**	t > k;d > g	**21**	**4110**	**0.51**	**<.001**
De-palatalizations					**Palatalizations**					
Affricates >Stops	> k; > t; > g; > d	10	389	2.57	Stops > Affricates	b/d > ;t >	28	5606	0.50	
Affricates> Alv. Fric	> f; > v; > s; > z	2	389	0.51	Alveolar Fric>Affricates	f > ; v > ; s > ; z >	17	2739	0.62	
Pal.Fric>Alveolar Fric	> s; > z; > θ	9	475	1.89	Alveolar Fric> Pal. Fric	s > > s; z >	12	2739	0.44	
Total		**21**	**864**	**2.43**	**Total**		**57**	**8345**	**0.68**	**<.001**
VOICING					**VOICING**					
devoicing	b > p;d > t; g > k; v > f; z > s; > ; >	**22**	**3005**	**0.73**	**add voicing**	p > b;t > d; k > g; f > v; s > z; > ; >	**18**	**6593**	**0.27**	**0.001**
onset		*16*			*onset*		*6*			
coda		*6*			*coda*		*12*			
r > l		10					8			

deletions and more vowel insertions (see Galluzzi et al., 2015). However, he did make more errors on complex than simple phonological structures and more simplifications than complications when we considered number of opportunities. The timing of information transfer could be especially critical for computing motor plans that have complex synergies. This will lead to complexity effects as well as dysfluencies, phonetic errors, and phonological errors when a different articulatory unit is activated.

4 General discussion

We have reported the case of CS, who had a speech production impairment characterized by phonological errors and frequent repeated attempts (RAs) similar to a conduite d'approche which, in the literature, have generally been associated with CA (Gandour et al., 1994; Joanette et al., 1980; S. Kohn, 1984; Valdois et al., 1989). CS, however, also produced many phonetic errors and syllabifications, which are indicative of AoS. RAs have been described in AoS, but formal investigations are very limited (see Bailey et al., 2017; Liss, 1998). We have characterized CS's RAs and analysed his production along a variety of dimensions to provide an integrated interpretation of his difficulties. His case helps us to understand different forms of impairment at the interface between phonology and articulatory planning, and to move beyond a simple dichotomy of CA and AoS.

CS had good semantic, syntactic, and phonological input processing, and good phonological STM. His difficulties affected mainly word production and involved stages after lexical access, as shown by the similar level and nature of impairment (with similar patterns of phonologically related errors) across production tasks (repetition, reading, picture naming, spontaneous speech). This indicates an impairment after lexical access, since providing a model of the target (as in repetition) did not eliminate or greatly improve his speech difficulties. Our experimental investigation first quantified phonetic errors and syllabifications, confirming high rates of distorted, slurred, and elongated phonemes (phonetic errors) and high rates of within-word discontinuities (syllabifications). Second, it characterized RAs, confirming properties consistent with a conduite d'approche. RAs most often revised an incorrect production and built up a correct response from progressively larger phonological/articulatory units. This was not consistent with "stutter-like dysfluencies" involving correct repetition of word beginnings (e.g., Bailey et al., 2017; Johns & Darley, 1970). As in a conduite d'approche, CS's responses generally, but not invariably, progressed towards a correct production although longer sequences were less often correct (see also Joanette et al., 1980). This indicates that the target word was properly maintained in memory as a source of comparison for production attempts (see also Wambaugh et al., 2016 for results showing that speakers with AoS, on average, have a good ability to judge their word productions as correct/incorrect). It would be interesting, in future studies, to evaluate how the ability to monitor and recognize errors is related to RAs in AoS.

CS's characteristics, at this point, could either result from two separate impairments, one involving degradation of phonological representations and one involving articulatory planning, or from a single impairment disrupting transfer of information from intact phonological representations to motor planning. The third part of our experimental investigation aimed to distinguish these alternatives. We reasoned that, if CS had an independent phonological impairment, his phonological errors should either arise from memory decay, and show effect of length, or arise from selection difficulties, and be independent of articulatory complexity. Alternatively, if errors arose from disrupted transfer of information between an intact linguistic system and the motor/articulatory system, errors should show effects of phoneme position, independent of word length because transfer delays should accumulate across the word. In addition, errors may be affected by articulatory complexity because simpler gestures should be easier to plan or access. CS's results were consistent with the second set of predictions.

CS showed strong effects of position independent of length, but no effect of phoneme length independent of position. This is consistent with a serial process of phonological to articulatory conversion because a given position will be influenced by the delay in processing *preceding* phonemes, but not by the number of phonemes *that follow* (and, hence, by word length). Additionally, he showed effects of word length on RAs, which is also consistent with accumulating delays and derailments at later positions.

CS's also showed some effect of syllabic and phonemic complexity. Consonant substitutions progressively increased with phoneme complexity (established on the basis of age of acquisition and the distribution of phonemes in the languages of the world; see Romani et al., 2017 for a review). However, although CS struggled with difficult segments, he did not simplify target phonemes as systematically as other Italian aphasic speakers (see Galluzzi et al., 2015; Romani et al., 2011, 2017). Substitutions did not show such strong directionality and syllables were simplified using mainly vowel insertion (usually schwa) to eliminate consonant clusters rather than consonant deletions, as has been reported for other English speakers with AoS (Buchwald, 2009; Code et al., 2013; Rosenbek et al., 1984). The reasons underlying these different patterns are not clear. However, if CS has difficulties transferring information from phonology to articulation, he may favour a strategy where he stops and tries again and/or breaks the word into smaller chunks rather than resorting to a simplification. Schwa insertions may be a way of delaying production while information arrives (similar to syllabifications and phoneme elongations), when dealing with complex gestures.

Therefore, CS's pattern can be parsimoniously interpreted as resulting from a single impairment that limits access to articulatory plans from intact phonological representations. In a system where transfer is noisy or slower than normal, phonological errors will arise when a motor plan corresponding to the wrong phoneme or group of phonemes is accessed. Phonetic errors will arise from noisy, incomplete or contradictory commands to the articulators (see Goldrick & Blumstein, 2006 for an interaction between phonological and phonetic levels of representation). Timing information is also a critical dimension at this level. Disruption with timing will predict positional effects and dysfluencies with syllabifications and possibly vowel insertions to break complex syllables into smaller units. It would also predict a conduite d'approche, where longer words are constructed bit by bit. All these features reflect difficulties accessing motor plans fast enough to allow a continuous stream of speech so that the process must be broken up into smaller chunks. Frequency and complexity effects arise because more practiced motor plans are accessed more easily. Finally, RAs may lead to successful production because correct motor plans are primed by previous attempts.

Our study raises the question of whether there are different varieties of AoS. Different authors have advanced related but not identical interpretations and stressed different features. We have suggested that difficulties in compiling complex articulatory plans produce phonetic errors, but also phonological errors which simplify the target to make articulatory plans easier to compile (as is seen in children's early speech; see Galluzzi et al., 2015; Romani et al., 2011, 2017). Aichert and Ziegler (2004) and Staiger and Ziegler (2008) have shown that speakers with AoS produce frequent syllables more successfully and suggested similar difficulties in accessing/compiling more difficult articulatory programs. Maas and Mailend (2012) and Mailend et al. (2019) have shown increased interference effects in producing pairs of phonologically related syllables and suggested a difficulty in controlling *selection* of target motor plans. Rogers and Storkel (1999) have stressed production of one syllable at a time and suggested limitations in an output buffer. Here, we documented RAs and positional effects in an aphasic speaker who also produces many phonetic errors and syllabifications and suggested that there is disrupted transfer of information between phonological representations and articulatory planning. All of these interpretations have overlapping, but also distinct features. Particularly our explanation has features overlapping with a buffer impairment. However, our explanation emphasizes limitations which are affected by the timing and ease of computing units at the following processing stage, rather than a fixed reduction in capacity which will be affected by the amount of information held in a buffer (a length effect). An important question for future studies, more generally, is whether symptoms produce theoretically meaningful clusters that relate to processing stages. Given the complexity of word production, it would be surprising if a number of different kinds of deficits did not arise, even at the latter stages of processing (see also the distinct components at the motor planning level in the models of Klapp, 2003; Miller & Guenther, 2020; Tilsen, 2013). A single case study described by Code and colleagues is a good example of such possible contrasts.

Code and colleagues (Code et al., 2013, 2011) described the case of an aphasic speaker with progressive aphasia, with a deficit that they attribute to a difficulty starting or stopping selection of articulatory plans (Code et al.'s case was also called CS, so here we use CS_1 to distinguish him from our case CS). CS_1's speech was also characterized by phonemic errors and dysfluencies which occurred across output tasks. He also produced repeated attempts at the target and used vowel insertions to break consonant clusters. Similarities, however, stopped there. CS_1's errors were not predicted by word frequency, age of acquisition or imageability, but were affected by word length (phoneme omissions, in particular). RAs often involved the final, rather the initial, part of the word (e.g., dresses> dɛ zɛ zɛ zɛ zɛ Ω; ancient> einʃə əɹ əɹ əɹ əɹ əɹ ə). These errors were never produced by CS. Moreover, in word and nonword repetition and in reading CS_1 showed strong delays in onset reaction times (RTs), but normal word durations. In contrast, when we analysed CS's onset RTs and word durations in repetition, reading and picture naming (Romani et al., in preparation), we found the opposite. Onset RTs were normal, but durations were much longer than a matched control, and showed no benefits of preparation, consistent with difficulties arising at a very late stage (after phonological encoding). These two cases, therefore, offer a direct contrast where one has difficulty starting or stopping selection of articulatory plans, and the other has difficulty feeding information to articulatory/motor planning. Code et al. (2013) suggest that CS_1's special characteristics may define articulatory difficulties arising from a progressive disease rather than a stroke, but the point remains that brain damage may affect different components of speech programming (see also Utianski et al., 2018, for prosodic and phonetic subtypes in primary progressive AoS).

The impairments suggested for the two CS patients fit different elements in current speech production models. In the DIVA model (Miller & Guenther, 2020), CS would have an impairment between the phonological planning loop and motor planning loop. In contrast, CS_1 would have a deficit in the initiation map as part of motor planning. Both speakers, however, have intact auditory feedback and forward models, given that they can monitor and correct errors (see also Harmon et al., 2019; Jacks & Haley, 2015; Maas et al., 2015 for the importance of internal mechanisms of control in AoS). To give another example, Tilsen (2013) has argued that articulatory programming occurs through the interplay of two mechanisms: a "*selection control*" mechanism, *for choosing which movement to produce*, and a *"coordination"* mechanism, *for precision control over the timing of movement execution*. Similar contrasting processes have been suggested by authors using different labels (sequencing vs timing, Mackay, 1982; succession vs synchrony, Kent, 1983; selection vs adjustment, Sakai et al., 2000). Tilsen (2013) argues that, during language development, large, integrated speech motor units, which represent coordinative structures, are established. Some speakers, like CS, may have more trouble with selecting the right articulatory plan, while others, like the Italian aphasic speakers, have more trouble with the coordination required within an articulatory plan and, for this reason, select plans that require less precision. It is also possible that some speakers, like CS, have more problems feeding information to mechanisms of selection and others, like the speakers described by Mailend et al. (2019), have more trouble controlling interference.

From a neuroanatomical perspective, speech production has been hypothesized to involve: 1) a dorsal stream mapping phonological representations into motor plans and connecting areas at the temporo-parietal boundary (supra-marginal gyrus, temporo-parietal junction) to motor areas (posterior inferior frontal gyrus, premotor cortex, anterior insula); and 2) a ventral stream mapping phonology into semantics and connecting posterior to anterior temporal areas (Gregory Hickok & Poeppel, 2007; G. Hickok & Poeppel, 2004; Ripamonti et al., 2018; G. S. Dell et al., 2013). CS's lesions involve areas at the junction between the temporal and the parietal lobe which would be important for transferring phonological information to articulatory planning. An impairment in transferring phonological information was originally associated with CA. However, traditional interpretations stress a disruption of phonological representation in CA, while in CS, we have stressed a difficulty with articulatory gestures that produces phonetic errors, syllabifications, RAs and positional/complexity effects. This view is consistent with articulatory difficulties being caused, not only by damage to anterior areas but also by damage to fibres connecting the temporal-parietal network to more anterior areas (see Gregory Hickok & Poeppel, 2007) and/or by damage to the parietal operculum and supramarginal gyrus (see Basilakos et al., 2015; Ripamonti et al., 2018). Lesions that are more circumscribed to temporal regions will, instead, produce behavioural deficits compatible with classical varieties of CA involving selection of incorrect phonemes and more fluent production. What is important, however, is not to force CS into one of the traditional binary categories of CA or AoS, but to recognize clusters of speech characteristics which identify different types of impairments. Future studies will be needed to test the consistency of clusters of symptoms across patients and their neurological correlates.

4.1. Conclusions

We have reported the case of a PWA who showed a co-occurrence of characteristics typically associated with CA (phonological errors, a conduite d'approche) and characteristics typically associated with AoS (phonetic errors and syllabifications). We have argued that these characteristics, together with positional effects and effects of phonological complexity, may be the hallmark of a speech impairment where phonological information is not fed to the articulatory planning/programming system swiftly enough. Our results suggest that articulatory difficulties may have different presentations and be associated with different neuroanatomical lesions, including posterior lesions, as in CS. Further progress will come from studies assessing the coherence of clusters of characterises across PWA and/or the neuroanatomical correlates of clusters using techniques such as voxel-based lesion-symptom mapping. Classifications based on clinical categories or the presence/absence of individual characteristics may, instead, lead to misleading or contradictory results (see also Haley et al., 2017; McNeil et al., 2016; Molloy & Jagoe, 2019).

Note

1. We do not support the view that phonological encoding involves associating phonemes to syllable positions (see Levelt et al., 1999; Roelofs, 1997) because we view syllable structure as having an important role in organizing lexical representations (Romani et al., 2011). Differently from Levelt et al.'s model, we assume that integrated speech motor units (SMU) are the last stage of production and a buffer is needed before, not after their retrieval.

Acknowledgments

We would like to thank Dawn Jevons from the Stroke Association in South Birmingham for her assistance in recruiting the participant. We are grateful to the EPS small grant scheme for the support we received (grant to Cristina Romani).

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Aichert, I., & Ziegler, W. (2004). Segmental and metrical encoding in aphasia: Two case reports. *Aphasiology*, *18*(12), 1201–1211. https://doi.org/10.1080/02687030444000516

Ardila, A., Montanes, P., Caro, C., Delgado, R., & Buckingham, H. (1989). Phonological transformations in Spanish speaking aphasics. *Journal of Psycholinguistic Research*, *18*(2), 163–180. https://doi.org/10.1007/BF01067780

Baayen, R., Piepenbrock, R., & Rijn, H. (1993). The CELEX lexical data base on CD-ROM

Bailey, D. J., Blomgren, M., DeLong, C., Berggren, K., & Wambaugh, J. L. (2017). Quantification and systematic characterization of stuttering-like disfluencies in acquired Apraxia of speech. *American Journal of Speech-Language Pathology*, *26*(2), 641–648. https://doi.org/10.1044/2017_AJSLP-16-0108

Basilakos, A., Rorden, C., Bonilha, L., Moser, D., & Fridriksson, J. (2015). Patterns of poststroke brain damage that predict speech production errors in apraxia of speech and aphasia dissociate. *Stroke*, *46*(6), 1561–1566. https://doi.org/10.1161/STROKEAHA.115.009211

Baum, S. (1992). The influence of word-length on syllable duration in Aphasia—Acoustic analyses. *Aphasiology*, *6*(5), 501–513. https://doi.org/10.1080/02687039208249487

Buchwald, A. (2009). Minimizing and optimizing structure in phonology: Evidence from aphasia. *Lingua*, *119*(10), 1380–1395. https://doi.org/10.1016/j.lingua.2007.11.015

Buchwald, A., & Miozzo, M. (2011). Finding levels of abstraction in speech production: Evidence from sound-production impairment. *Psychological Science*, *22*(9), 1113–1119. https://doi.org/10.1177/0956797611417723

Canter, G. J., Trost, J. E., & Burns, M. S. (1985). Contrasting speech patterns in apraxia of speech and phonemic paraphasia. *Brain and Language*, *24*(2), 204–222. https://doi.org/10.1016/0093-934X(85)90131-2

Caplan, D., Vanier, M., & Baker, C. (1986). A case study of reproduction conduction aphasia I: Word production. *Cognitive Neuropsychology*, *3*(1), 99–128. https://doi.org/10.1080/02643298608252671

Caramazza, A., Miceli, G., & Villa, G. (1986). The role of the (output) phonological buffer in reading, writing, and repetition. *Cognitive Neuropsychology*, *3*(1), 37–76. https://doi.org/10.1080/02643298608252669

Cholin, J. (2008). The mental syllabary in speech production: An integration of different approaches and domains. *Aphasiology*, *22*(11), 1127–1141. https://doi.org/10.1080/02687030701820352

Christman, S. S., Boutsen, F. R., & Buckingham, H. W. (2004). Perseveration and other repetitive verbal behaviors: Functional dissociations. *Seminars in Speech and Language*, *25*(4), 295–307. https://doi.org/10.1055/s-2004-837243

Code, C. (1998). Models, theories and heuristics in apraxia of speech. *Clinical Linguistics & Phonetics*, *12*(1), 47–65. https://doi.org/10.3109/02699209808985212

Code, C., Ball, M., Tree, J., & Dawe, K. (2013). The effects of initiation, termination and inhibition impairments on speech rate in a case of progressive nonfluent aphasia with progressive apraxia of speech with frontotemporal degeneration. *Journal of Neurolinguistics*, *26*(6), 602–618. https://doi.org/10.1016/j.jneuroling.2013.04.003

Code, C., Tree, J., & Ball, M. (2011). The influence of psycholinguistic variables on articulatory errors in naming in progressive motor speech degeneration. *Clinical Linguistics & Phonetics*, *25*(11–12), 1074–1080. https://doi.org/10.3109/02699206.2011.601390

Croot, K., Lalas, G., Biedermann, B., Rastle, K., Jones, K., & Cholin, J. (2017). Syllable frequency effects in immediate but not delayed syllable naming in English. *Language Cognition and Neuroscience*, *32*(9), 1119–1132. https://doi.org/10.1080/23273798.2017.1284340

Cunningham, K. T., Haley, K. L., & Jacks, A. (2016). Speech sound distortions in aphasia and apraxia of speech: Reliability and diagnostic significance. *Aphasiology*, *30*(4), 396–413. https://doi.org/10.1080/02687038.2015.1065470

Dabul, B. (2000). *Apraxia battery for adults* (2nd ed.). Pro-Ed Inc.

Darley, F. L. (1968). *Apraxia of speech: 107 years of terminological confusions*. The American Speech & Hearing Association Convention.

Deal, J., & Darley, F. (1972). Influence of linguistic and situational variables on phonemic accuracy in apraxia of speech. *Journal of Speech and Hearing Research*, *15*(3), 639. https://doi.org/10.1044/jshr.1503.639

Dell, G. S., Juliano, C., & Govindjee, A. (1993). Structure and content in language production—A theory of frame constraints in phonological speech errors. *Cognitive Science*, *17*(2), 149–195. https://doi.org/10.1016/0364-0213(93)90010-6

Dell, G. S., Schwartz, M. F., Nozari, N., Faseyitan, O., & Coslett, H. B. (2013). Voxel-based lesion-parameter mapping: Identifying the neural correlates of a computational model of word production. *Cognition*, *128*(3), 380–396. https://doi.org/10.1016/j.cognition.2013.05.007

Den Ouden, D. B., & Bastiaanse, R. .(2003). Syllable structure at different levels in the speech production process: Evidence from Aphasia. In J. Van De Weijer, V. J. Van Heuven, & H. Van Der Hulst (Eds.), *The phonological spectrum. Vol. II: Suprasegmental structure* Current Issues in Linguistic Theory 234. (pp. 81–107). John Benjamins.

Den Ouden, D.-B. (2002). Segmental vs syllable markedness: Deletion errors in the paraphasias of fluent and non-fluent aphasics. In E. Fava (Ed.), *Current issues in linguistic theory* (Vol. 227, pp. 23–45). John Benjamins Publishing Company. https://doi.org/10.1075/cilt.227.05oud

Den Ouden, D.-B., Galkina, E., Basilakos, A., & Fridriksson, J. (2018). Vowel formant dispersion reflects severity of apraxia of speech. *Aphasiology*, *32*(8), 902–921. https://doi.org/10.1080/02687038.2017.1385050

Duffy, J. R. (2005). *Motor speech disorders: Substrates, differential diagnosis, and management* (2nd ed.). Elsevier Mosby.

Duffy, J. R., Utianski, R. L., & Josephs, K. A. (2020). Primary progressive apraxia of speech: From recognition to diagnosis and care. *Aphasiology*, 1–32. https://doi.org/10.1080/02687038.2020.1787732

Franklin, S., Buerk, F., & Howard, D. (2002). Generalised improvement in speech production for a subject with reproduction conduction aphasia. *Aphasiology*, *16*(10–11), 1087–1114. https://doi.org/10.1080/02687030244000491

Galluzzi, C., Bureca, I., Guariglia, C., & Romani, C. (2015). Phonological simplifications, apraxia of speech and the interaction between phonological and phonetic processing. *Neuropsychologia*, *71* (5), 64–83. https://doi.org/10.1016/j.neuropsychologia.2015.03.007

Gandour, J., Akamanon, C., Dechongkit, S., Khunadorn, F., & Boonklam, R. (1994). Sequences of honemic approximations in a Thai conduction aphasic. *Brain and Language*, *46*(1), 69–95. https://doi.org/10.1006/brln.1994.1005

Glasspool, D. W., Shallice, T., & Cipolotti, L. (2006). Towards a unified process model for graphemic buffer disorder and deep dysgraphia. *Cognitive Neuropsychology*, *23*(3), 479–512. https://doi.org/10.1080/02643290500265109

Goldrick, M., & Blumstein, S. E. (2006). Cascading activation from phonological planning to articulatory processes: Evidence from tongue twisters. *Language and Cognitive Processes*, *21*(6), 649–683. https://doi.org/10.1080/01690960500181332

Goldrick, M., & Rapp, B. (2007). Lexical and post-lexical phonological representations in spoken production. *Cognition*, *102*(2), 219–260. https://doi.org/10.1016/j.cognition.2005.12.010

Guenther, F. H. (2015). *Neural control of speech*. The MIT Press.

Haley, K. L., Jacks, A., De Riesthal, M., Abou-Khalil, R., & Roth, H. L. (2012). Toward a quantitative basis for assessment and diagnosis of Apraxia of Speech. *Journal of Speech Language and Hearing Research*, *55*(5), S1502–S1517. https://doi.org/10.1044/1092-4388(2012/11-0318)

Haley, K. L., Jacks, A., Richardson, J. D., & Wambaugh, J. L. (2017). Perceptually salient sound distortions and Apraxia of speech: A performance continuum. *American Journal of Speech-Language Pathology*, *26*(2), 631–640. https://doi.org/10.1044/2017_AJSLP-16-0103

Harmon, T. G., Jacks, A., & Haley, K. L. (2019). Speech fluency in acquired apraxia of speech during narrative discourse: Group comparisons and dual-task effects. *American Journal of Speech-Language Pathology*, *28*(2), 905–914. https://doi.org/10.1044/2018_AJSLP-MSC18-18-0107

Hickok, G., & Poeppel, D. (2004). Dorsal and ventral streams: A framework for understanding aspects of the functional anatomy of language. *Cognition*, *92*(1–2), 67–99. https://doi.org/10.1016/j.cognition.2003.10.011

Hickok, G., & Poeppel, D. (2007). Opinion—The cortical organization of speech processing. *Nature Reviews Neuroscience*, *8*(5), 393–402. https://doi.org/10.1038/nrn2113

Houghton, G. (1990). The problem of serial order: A neural network model of sequence learning and recall. In R. Dale, C. Mellish, & M. Zock (Eds.), *Current Research in Natural Language Generation* (pp.287-319). London: Academic Press.

Houghton, G. (2018). Action and perception in literacy: A common-code for spelling and reading. *Psychological Review*,*125*(1), 83–116. https://doi.org/10.1037/rev0000084

Jacks, A., & Haley, K. L. (2015). Auditory masking effects on speech fluency in apraxia of speech and aphasia: Comparison to altered auditory feedback. *Journal of Speech, Language, and Hearing Research*, *58*(6), 1670–1686. https://doi.org/10.1044/2015_JSLHR-S-14-0277

Joanette, Y., Keller, E., & Lecours, A. R. (1980). Sequences of phonemic approximations in aphasia. *Brain and Language*, *11*(1), 30–44. https://doi.org/10.1016/0093-934x(80)90107-8

Johns, D., & Darley, F. (1970). Phonemic variability in apraxia of speech. *Journal of Speech and Hearing Research*, *13*(3), 556. https://doi.org/10.1044/jshr.1303.556

Kawamoto, A. H., Kello, C. T., Higareda, I., & Vu, J. V. Q. (1999). Parallel processing and initial phoneme criterion in naming words: Evidence from frequency effects on onset and rime duration. *Journal of Experimental Psychology-Learning Memory and Cognition*, *25*(2), 362–381. https://doi.org/10.1037/0278-7393.25.2.362

Kay, J., Lesser, R., & Coltheart, M. (1996). Psycholinguistic assessments of language processing in aphasia (PALPA): An introduction. *Aphasiology*, *10*(2), 159–180. https://doi.org/10.1080/02687039608248403

Kelso, J. A., Tuller, B., Vatikiotis-Bateson, E., & Fowler, C. A. (1984). Functionally specific articulatory cooperation following jaw perturbations during speech: Evidence for coordinative structures. *Journal of Experimental Psychology-Human Perception and Performance,10*(6), 812–832. https://doi.org/10.1037//0096–1523.10.6.812

Kent, R. D. (1983). The segmental organization of speech. In P. MacNeilage (Ed.), *The production of speech* (pp. 57–89). Springer-Verlag.

Klapp, S. T. (2003). Reaction time analysis of two types of motor preparation for speech articulation: Action as a sequence of chunks. *Journal of Motor Behavior*, *35*(2), 135–150. https://doi.org/10.1080/00222890309602129

Kohler, K., Bartels, C., Herrmann, M., Dittmann, J., & Wallesch, C. W. (1998). Conduction aphasia—11 classic cases. *Aphasiology*, *12*(10), 865–884. https://doi.org/10.1080/02687039808249456

Kohn, S. E. (1984). The nature of the phonological disorder in conduction aphasia. *Brain and Language*, *23*(1), 97–115. https://doi.org/10.1016/0093-934X(84)90009-9

Kohn, S. E. (1989). The nature of the phonemic string deficit in conduction aphasia. *Aphasiology*, *3*(3), 209–239. https://doi.org/10.1080/02687038908248992

Kohn, S. E., & Smith, K. L. (1994). Distinctions between 2 phonological output deficits. *Applied Psycholinguistics*, *15*(1), 75–95. https://doi.org/10.1017/S0142716400006986

Kohn, S. E., & Smith, K. L. (1995). Serial effects of phonemic planning during word production. *Aphasiology*, *9*(3), 209–222. https://doi.org/10.1080/02687039508248196

Laganaro, M. (2012). Patterns of impairments in AOS and mechanisms of interaction between phonological and phonetic encoding. *Journal of Speech, Language, and Hearing Research*, *55*(5), S1535-43. https://doi.org/10.1044/1092-4388(2012/11-0316)

Lashley, K. S. (1951). The problem of serial order in behavior. In L. A. Jeffress (Ed.), *Cerebral mechanisms in behavior* (pp. 112–131). Wiley.

Lecours, A., & Lhermitte, F. (1976). Pure form of phonetic disintegration syndrome (pure Anarthria)—Anatomo—Clinical report of a historical case. *Brain and Language*, *3*(1), 88–113. https://doi.org/10.1016/0093-934X(76)90008-0

Levelt, W. J., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *The Behavioral and Brain Sciences*, *22*(1), 1–38. discussion 38–75 https://doi.org/10.1017/S0140525X99001776

Liss, J. M. (1998). Error-revision in the spontaneous speech of apraxic speakers. *Brain and Language*, *62*(3), 342–360. https://doi.org/10.1006/brln.1997.1907

Maas, E., & Mailend, M.-L. (2012). Speech planning happens before speech execution: Online reaction time methods in the study of apraxia of speech. *Journal of Speech, Language, and Hearing Research,55*(5), S1523-34. https://doi.org/10.1044/1092-4388(2012/11-0311)

Maas, E., Mailend, M.-L., & Guenther, F. H. (2015). Feedforward and feedback control in Apraxia of speech: Effects of noise masking on vowel production. *Journal of Speech Language and Hearing Research*, *58*(2), 185–200. https://doi.org/10.1044/2014_JSLHR-S-13-0300

Mackay, D. (1982). The problems of flexibility, fluency, and speed-accuracy trade-off in skilled behavior. *Psychological Review*, *89*(5), 483–506. https://doi.org/10.1037/0033-295X.89.5.483

Mailend, M.-L., Maas, E., Beeson, P. M., Story, B. H., & Forster, K. I. (2019). Speech motor planning in the context of phonetically similar words: Evidence from apraxia of speech and aphasia. *Neuropsychologia*, *127*(4), 171–184. https://doi.org/10.1016/j.neuropsychologia.2019.02.018

Marshall, R., & Tompkins, C. (1982). Verbal self-correction behaviors of fluent and non-fluent aphasic subjects. *Brain and Language*, *15*(2), 292–306. https://doi.org/10.1016/0093-934X(82)90061-X

McNeil, M., Liss, J. M., Tseng, C. H., & Kent, R. D. (1990). Effects of speech rate on the absolute and relative timing of apraxic and conduction aphasic sentence production. *Brain and Language*, *38* (1), 135–158. https://doi.org/10.1016/0093-934X(90)90106-Q

McNeil, M. R., Odell, K. H., Miller, S. B., & Hunter, L. (1995). Consistency, variability, and target approximation for successive speech repetitions among apraxic, conduction aphasic, and ataxic dysarthric speakers. In M. L. Lemme (Ed.), *Clinical aphasiology, vol 23* (pp. 39–55). Pro-Ed Inc.

McNeil, M. R., Ballard, K. J., Duffy, J. R., & Wambaugh, J. (2016). Apraxia of speech theory, assessment, differential diagnosis, and treatment: Past, present, and future. In P. van Lieshout, B. Maassen, & H. Terband (Eds.), *Speech Motor Control in Normal and Disordered Speech: Future Developments in Theory and Methodology (pp. 195–221)*. Rockville, MD: ASHA Press.

Meyer, A. S. (1991). The time course of phonological encoding in language production—Phonological encoding inside a syllable. *Journal of Memory and Language*, *30*(1), 69–89. https://doi.org/10.1016/0749-596X(91)90011-8

Miller, H. E., & Guenther, F. H. (2020). Modelling speech motor programming and apraxia of speech in the DIVA/GODIVA neurocomputational framework. *Aphasiology*, 1–18. https://doi.org/10.1080/02687038.2020.1765307

Molloy, J., & Jagoe, C. (2019). Use of diverse diagnostic criteria for acquired apraxia of speech: A scoping review. *International Journal of Language & Communication Disorders*, *54*(6), 875–893. https://doi.org/10.1111/1460-6984.12494

Nespoulous, J.-L., Joanette, Y., Béland, R., Caplan, D., & Lecours, A. R. (1984). Phonologic disturbances in aphasia: Is there a 'markedness effect' in aphasic phonetic errors? *Advances in Neurology*, *42*, 203-14. PMID: 6209957

Nespoulous, J.-L., Joanette, Y., Ska, B., Caplan, D., & Lecours, A. (1987). Production deficits in Broca's and conduction aphasia: Repetition vs. reading.

Odell, K., Mcneil, M., Rosenbek, J., & Hunter, L. (1990). Perceptual characteristics of consonant production by Apraxic Speakers. *The Journal of speech and hearing disorders*, 55, 345–59. doi:10.1044/jshd.5502.345

Ogar, J., Slama, H., Dronkers, N., Amici, S., & Luisa Gorno-Tempini, M. (2005). Apraxia of speech: An overview. *Neurocase*, *11*(6), 427–432. https://doi.org/10.1080/13554790500263529

Olson, A., Romani, C., & Caramazza, A. (2010). Analysis and interpretation of serial position data. *Cognitive Neuropsychology*, *27*(2), 134–151. https://doi.org/10.1080/02643294.2010.504580

Postma, A. (2000). Detection of errors during speech production: A review of speech monitoring models. *Cognition*, *77*(2), 97–132. https://doi.org/10.1016/S0010-0277(00)00090-1

Ripamonti, E., Frustaci, M., Zonca, G., Aggujaro, S., Molteni, F., & Luzzatti, C. (2018). Disentangling phonological and articulatory processing: A neuroanatomical study in aphasia. *Neuropsychologia,121(12)*, 175–185. https://doi.org/10.1016/j.neuropsychologia.2018.10.015

Roelofs, A. (1996). Serial order in planning the production of successive morphemes of a word. *Journal of Memory and Language*, *35*(6), 854–876. https://doi.org/10.1006/jmla.1996.0044

Roelofs, A. (1997). The WEAVER model of word-form encoding in speech production. *Cognition*, *64* (3), 249–284. https://doi.org/10.1016/S0010-0277(97)00027-9

Rogers, M. A., & Storkel, H. L. (1999). Planning speech one syllable at a time: The reduced buffer capacity hypothesis in apraxia of speech. *Aphasiology*, *13*(9–11), 793–805. https://doi.org/10.1080/026870399401885

Romani, C., & Galluzzi, C. (2005). Effects of syllabic complexity in predicting accuracy of repetition and direction of errors in patients with articulatory and phonological difficulties. *Cognitive Neuropsychology*, *22*(7), 817–850. https://doi.org/10.1080/02643290442000365

Romani, C., Galluzzi, C., Bureca, I., & Olson, A. (2011). Effects of syllable structure in aphasic errors: Implications for a new model of speech production. *Cognitive Psychology*, *62*(2), 151–192. https://doi.org/10.1016/j.cogpsych.2010.08.001

Romani, C., Galluzzi, C., & Olson, A. (2011b). Phonological-lexical activation: A lexical component or an output buffer? Evidence from aphasic errors. *Cortex*, *47*(2), 217–235. https://doi.org/10.1016/j.cortex.2009.11.004

Romani, C., Galuzzi, C., Guariglia, C., & Goslin, J. (2017). Comparing phoneme frequency, age of acquisition, and loss in aphasia: Implications for phonological universals. *Cognitive Neuropsychology*, *34*(7–8), 449–471. https://doi.org/10.1080/02643294.2017.1369942

Romani, C., Olson, A., Semenza, C., & Granà, A. (2002). Patterns of phonological errors as a function of a phonological versus an articulatory locus of impairment. *Cortex*, *38*(4), 541–567. https://doi.org/10.1016/S0010-9452(08)70022-4

Romani, C., Silverstein, P., Ramoo, D., & Olson, A. (in preparation). *Effects of length, frequency and preparation on onset RTs and word durations: Articulation cannot be buffered and prepared*.

Rosenbek, J. C., Kent, R. D., & LaPointe, L. L. (1984). Apraxia of speech: An overview and some perspectives. In M. R. Rosenbek, M. R. McNeil, & A. E. Aronson (Eds.), *Apraxia of speech: Physiology, acoustics, linguistics, management* (pp. 1–72). College-Hill Press.

Sakai, Y., Nakamura, T., Sakurai, A., Yamaguchi, H., & Hirai, S. (2000). Right frontal areas 6 and 8 are associated with simultanapraxia, a subset of motor impersistence. *Neurology*, *54*(2), 522–524. https://doi.org/10.1212/WNL.54.2.522

Saltzman, E., & Kelso, J. A. (1987). Skilled actions: A task-dynamic approach. *Psychological Review*, *94*(1), 84–106. https://doi.org/10.1037/0033-295X.94.1.84

Schiller, N. O., Greenhall, J. A., Shelton, J. R., & Caramazza, A. (2001). Serial order effects in spelling errors: Evidence from two dysgraphic patients. *Neurocase*, *7*(1), 1–14. https://doi.org/10.1093/neucas/7.1.1

Shallice, T., Rumiati, R. I., & Zadini, A. (2000). The selective impairment of the phonological output buffer. *Cognitive Neuropsychology*, *17*(6), 517–546. https://doi.org/10.1080/02643290050110638

Shallice, T., & Warrington, E. K. (1977). Auditory-verbal short-term memory impairment and conduction aphasia. *Brain and Language*, *4*(4), 479–491. https://doi.org/10.1016/0093-934X(77)90040-2

Staiger, A., & Ziegler, W. (2008). Syllable frequency and syllable structure in the spontaneous speech production of patients with apraxia of speech. *Aphasiology*, *22*(11), 1201–1215. https://doi.org/10.1080/02687030701820584

Tilsen, S. (2013). A dynamical model of hierarchical selection and coordination in speech planning. *PLoS One*, *8*(4), e62800. https://doi.org/10.1371/journal.pone.0062800

Tilsen, S. (2016). Selection and coordination: The articulatory basis for the emergence of phonological structure. *Journal of Phonetics*, *55*, 53–77. https://doi.org/10.1016/j.wocn.2015.11.005

Trost, J. E. (1970). *A descriptive study of verbal apraxia in patients with Broca's aphasia* [Doctoral dissertation]. Northwestern University.

Utianski, R. L., Duffy, J. R., Clark, H. M., Strand, E. A., Botha, H., Schwarz, C. G., Machulda, M. M., Senjem, M. L., Spychalla, A. J., Jack, C. R., Petersen, R. C., Lowe, V. J., Whitwell, J. L., & Josephs, K. A. (2018). Prosodic and phonetic subtypes of primary progressive apraxia of speech. *Brain and Language*, *184*(9), 54–65. https://doi.org/10.1016/j.bandl.2018.06.004

Valdois, S., Joanette, Y., & Nespoulous, J. (1989). Intrinsic organization of sequences of phonemic approximations—A preliminary-study. *Aphasiology*, *3*(1), 55–73. https://doi.org/10.1080/02687038908248976

Van Der Merwe, A. (2020). New perspectives on speech motor planning and programming in the context of the four-level model and its implications for understanding the pathophysiology underlying apraxia of speech and other motor speech disorders. *Aphasiology*, 1–27. https://doi.org/10.1080/02687038.2020.1765306

Varley, R., & Whiteside, S. P. (2001). What is the underlying impairment in acquired apraxia of speech? *Aphasiology*, *15*(1), 39–49. https://doi.org/10.1080/02687040042000115

Wambaugh, J., Shuster, L., Bailey, D. J., Mauszycki, S., Kean, J., Nessler, C., Wright, S., & Brunsvold, J. (2016). Self-judgments of word production accuracy in acquired Apraxia of speech. *American Journal of Speech-Language Pathology*, *25*(4S), S716–S728. https://doi.org/10.1044/2016_AJSLP-15-0139

Ward, J., & Romani, C. (1998). Serial position effects and lexical activation in spelling: Evidence from a single case study. *Neurocase*, *4*(3), 189–206. https://doi.org/10.1080/13554799808410621

Wilshire, C. E. (1999). The ‘tongue twister’ paradigm as a technique for studying phonological encoding. *Language and Speech*, *42*(1), 57–82. https://doi.org/10.1177/00238309990420010301
Wilshire, C. E. (2002). Where do aphasic phonological errors come from? Evidence from phoneme movement errors in picture naming. *Aphasiology*, *16*(1–2), 169–197. https://doi.org/10.1080/02687040143000528
Ziegler, W. (2009). Modelling the architecture of phonetic plans: Evidence from apraxia of speech. *Language and Cognitive Processes*, *24*(5), 631–661. https://doi.org/10.1080/01690960802327989