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Contextual phonological errors and omission of obligatory liaison as a window into a reduced span of phonological encoding

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Abstract

Background: The question of how much speakers plan ahead before they start articulating their message is essential to understand how fluency is ensured during speech production. This question has been largely investigated in healthy speakers. Surprisingly, this remains unexplored for brain damaged speakers, even though a reduced span of encoding might account for the fact that those impaired speakers often produce scattered speech.

Aims: In this study, we examine whether the span of encoding is reduced in some left hemisphere brain damaged speakers by taking advantage of two linguistic phenomena which provide an insight into ahead phonological planning.

Methods and procedures: First, we elicit the production of French sequences involving obligatory *liaisons* (e.g., /mõ/ and /ami/ produced /mõ.**n**ami/), for which the correct production requires ahead planning, at least up to the first phoneme of the following word of the utterance. Second, we use tongue-twister-like sequences in order to elicit contextual phonological errors, as phoneme anticipation errors (e.g., bureau vert—*green desk*—produced /**v**yRo.vER/) suggest that the speaker has planned ahead before articulating. If brain damaged speakers do present a reduced span of encoding, they should both produce a high rate of liaison consonant omissions and a low rate of anticipation contextual phonological errors.

Outcome and results: The results on a group of 13 speakers with aphasia and/or apraxia of speech overall show few contextual (syntagmatic) errors despite a high rate of segmental errors, whereas the majority of phonological errors produced on the same utterances by healthy speakers were syntagmatic. The speech/language impaired participants also presented a high rate of obligatory liaison consonants omission. Crucially, a negative correlation was observed between the rate of phoneme anticipation errors and the rate of liaison consonant omission.

Conclusion: These results suggest that some brain damaged speakers present a span of phonological encoding limited to single words and that the use of inter-word sandhi phenomena, such as French liaison and the analysis of phoneme anticipation errors, are valid linguistic tools to inform on the span of encoding.

Keywords: speech production, encoding, resyllabification, liaison, tongue-twister.

Introduction

To ensure fluency in connected speech, speakers probably plan the surface form of the upcoming words while they are articulating the current part of speech. Although this seems a cognitively costly task, it is unlikely that speakers plan word by word, as this would result in influent speech (Jæger, Furth, & Hilliard, 2012; Smith & Wheeldon, 2004). It is also unlikely that the surface form of an entire message has been planned before articulation of a sentence, as this would result in a larger span and proportion of phonological errors than what is usually observed in healthy speakers. The question of which minimal unit of ahead planning is necessary to ensure fluency has been largely investigated and debated in the psycholinguistic literature. This question is virtually unexplored in brain damaged speakers, although it is possible that the span of ahead planning is reduced for some speakers with aphasia, in particular, when large planning units increase the probability of phonological errors. One can also argue that planning only one word at a time might significantly reduce the cognitive load associated with parallel encoding in running speech. Here we investigate whether brain damaged patients producing segmental errors present a reduced phonological planning scope. To this end, we take advantage of a French phonological sandhi phenomenon, the obligatory *liaison*, the correct production of which is assumed to involve ahead planning. Furthermore, we elicit the production of tongue-twister-like sequences as a means to elicit contextual phonological errors. We compare the performance of a group of left hemisphere brain-damaged participants producing segmental errors but with relatively unimpaired lexical processes to a group of healthy speakers. Therefore, the purpose of the study is two-fold. First, we investigate whether linguistic phenomena such as the French *liaison* and contextual phonological errors can be used as a means to explore speech planning. Second, we examine whether brain damaged patients might present a reduced span of encoding at the phonological level.

As we aim to examine the production of specific phonological errors in order to investigate the span of encoding in left-hemisphere damaged patients, we will give a short overview of some of the major theoretical frameworks of error production mechanisms with a focus on phonological errors. Then, we will expose some of the main findings in the literature on the span of encoding.

Speech production involves several processing stages from concept to articulation, through semantic, lexical, phonological and phonetic processes (Levelt, 1999). The process of interest here, phonological encoding, relates to the stage where the phonological form of the utterance to be produced is retrieved, reorganised and assembled before being translated into articulatory plans.

The fact that speech production is not error-free indicates that something can go wrong during speech encoding processes; on the other hand the study of errors has been widely used to understand the architecture of language production and has fed the different speech production models. Of particular interest here are contextual (syntagmatic) phonological errors and in particular those errors in which a phoneme coming later in the utterance is anticipated into an earlier position or in which two phonemes exchange their position as in “The nipper is zarrow” (for “the zipper is narrow”, taken from Fromkin, 1971). In such errors all the target phonemes are correctly retrieved but their position is twisted. According to most models of speech production, abstract phonemes are selected/activated during phonological encoding (but see Hickok, 2013) and their order is achieved by attributing to serial order (from the beginning to the end of the word, Levelt et al., 1999) or to syllabic positions (Dell, 1986; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997). In such models, mis-ordering of phonemes into the frames causes phoneme exchange errors (metatheses). In Dell's model (1986) a phoneme can be erroneously anticipated into a previous slot due to an error in the timing of the sequencing mechanism; as a consequence the phoneme which slot was taken is placed in the free slot of the anticipated phoneme.

Non-syntagmatic phonological errors also occur, especially in brain damaged speakers. In such errors (eg. "the fipper" instead of *zipper*) the source of the segmental substitution cannot be identified within the produced utterance. In Dell´s model, such errors occur when another phoneme receives more activation than the target phoneme. Different proposals provide an explanation for non-contextual segmental errors. In the context of connectionist models of language production it has been suggested that phoneme mis-selection is due to noise in the connection between lexical and phonological nodes or throughout the lexical-semantic and lexical-phonological connections (Dell et al., 1997; Foygel & Dell, 2000; Schwartz, Wilshire, Gagnon and Polansky, 2004). Alternatively, segmental errors are thought to arise because of a default mechanism attributing segments when phonological information is missing or cannot be completely retrieved (Butterworth, 1992; Kohn & Smith, 1995).

Finally, it should be mentioned that some errors perceived by the ear as phoneme substitutions might be phonetic distortions falling close to another phonemic category (Ziegler, 2008). Differently from segmental errors, which involve the substitution or exchange of abstract phonological units, phonetic errors are thought to arise during motor planning. The source of phonetic errors can be at the level of phonetic encoding as supposed in apraxia of speech for instance (Code, 1998; Darley, Aronson & Brown, 1975; Ziegler, 2008, 2009), but it has also been suggested that phonetic errors can arise because two abstract phonological plans compete during phonetic encoding (Goldrick & Blumstein, 2006; Laganaro 2012).

Hence, different frameworks provide different interpretations of non-contextual phonological errors both in healthy and brain-damaged speakers; by contrast most models converge on the mechanisms underlying phoneme exchange errors (metatheses) and in particular on the fact that such errors indicate some degree of phonological ahead planning.

The span of encoding at the phonological level

When examining how much speakers plan before they articulate their message, two related questions can be raised: 1) is there a fixed unit of encoding, and 2) if there is one, what is the size of this unit? The first studies investigating these questions with psycholinguistic paradigms and healthy speakers focussed on the second question. These studies, mostly based on the analysis of production latencies in picture naming tasks, tried to determine the size of the planning unit at the phonological level. Overall, diverging results were reported. While some authors claimed that the unit of encoding is limited to one word (Meyer, 1996), others argued that speakers plan the entire message before speaking (Schnur, 2011; Schnur, Costa, & Caramazza, 2006). A different set of studies focussed on which constraints might modulate phonological planning. The syntactic structure of the message was examined as a potential factor in different studies but, again, no coherence emerges from the literature. While Schriefers and Teruel (1999) observed a different span of encoding for different syntactic structures based on cross-linguistic studies (German and French), Michel Lange and Laganaro (2014) failed to report the same effect for similar syntactic structures within the same language (French). More recently, researchers focussed on the other question, namely whether the span of encoding is a fixed or a flexible unit. The results reported by these studies actually show that the planning unit is subject to inter-individual differences (Gillespie & Pearlmutter, 2011; Michel Lange & Laganaro, 2014; Wagner, Jescheniak, & Schriefers, 2010). Nevertheless, many investigations converge on the span of encoding extending over the initial word, at least in adjectival noun-phrases with pre-nominal adjectives (Costa & Caramazza, 2002; Damian & Dumay, 2007; Dumay, Damian, Stadthagen-Gonzalez, & Perez, 2009; Schnur et al., 2006). At the interface with the phonetic level, some studies reported syllabic length effect in picture naming tasks with longer naming latencies for words of two syllables relative to one (Santiago, MacKay, Palma & Rho, 2000) and frequency effects for both the first and second syllable of a bisyllabic word (Cholin, Dell & Levelt, 2011) which suggests a span of encoding extending the initial syllable.

Besides experimental paradigms based on reaction time measures, the production of errors can also represent a relevant source of information on advance planning. Of particular interest for our aim here are the errors with a syntagmatic origin, as some of them indicate that the speaker has planned ahead before articulating. For instance, a lexical exchange error such as "wash your food before you eat your hand" instead of "wash your hands before you eat your food" suggests that the speaker has planned both "food" and "hands" at least at the word level (the lemma) and exchanged his or her position while encoding the sentence. Specifically, phonological syntagmatic errors and metatheses in particular (see the example above, "The nipper is zarrow") provide an insight into phonological ahead planning (in the example above, the surface forms of both "zipper" and "narrow" have been planned before articulation and their onset is exchanged). Errors at the lexical level can occur in a fairly large span, while the span for errors at the phonological encoding level seem to be much smaller, thus indicating that the span of phonological planning can encompass single words but does not exceed three syllables on average (Rossi & Peter-Defare, 1998). Even though speech errors are a convenient insight into the span of encoding during speech planning, they are scarce in healthy speakers. Nevertheless, some researchers managed to study speech encoding processes through speech-error elicitation based on spoonerisms and tongue-twister production (Acheson & Hagoort, 2014; Acheson & MacDonald, 2009; Baars, 1992; Baars & Motley, 1974; Baars & Motley, 1976; Vitevitch, 2002; Goldrick & Blumstein, 2006). When it comes to the study of ahead planning in the brain damaged population, the data is rare, although the potential of error analysis is much larger than in healthy speakers.

Phonological Span of Encoding in Brain Damaged Speakers

As indicated in the previous section, experimental evidence and syntagmatic phonological errors in healthy speakers suggest a span of phonological encoding extending over the initial word, at least in adjectival noun-phrases with pre-nominal adjectives. While the span of phonological encoding has mainly been studied in healthy participants, very little is known about the span of encoding in brain damaged patients. It is well known that aphasic patients with impaired phonological encoding produce more errors on longer units (Kohn, 1989; Kohn & Smith, 1995; Pate, Saffran, & Martin, 1987). Hence, as larger utterances seem to be challenging, one may imagine that language and/or speech impaired speakers reduce their planning span to avoid the production of errors. The question then is whether their pattern of errors allows us to gain insight into their ahead planning. Some clinical observations suggest that this may be the case. For instance, whereas phonological errors often have a syntagmatic origin and involve more than one word in healthy speakers, phonological errors in aphasic speakers rarely have a syntagmatic origin. In other words, despite the fact that patients with phonological impairment produce high rates of phonological errors, the proportion of contextual errors (phoneme anticipation or metatheses) is often very low (see for instance Kohn & Smith, 1990; Wilshire, 2002). Hence, the very low rate of syntagmatic phonological errors in brain damaged patients strongly suggests that some of these patients might present a reduced span of encoding. Nevertheless, this conclusion is probably too simplistic, as no systematic studies have been carried out comparing healthy and aphasic speakers on the same task and stimuli. Here we introduce a task that can be used both with healthy speakers and brain damaged speakers and with very little adjustment on the procedure and instruction. First, we used a picture naming task to elicit syntagmatic phonological errors instead of the reading tasks typically used in spoonerisms and tongue-twister tasks. This allowed us to circumvent the problem of variability in reading processes following brain damage. Second, the introduction of sequences involving obligatory liaison in a picture naming task provides another cue to investigate ahead phonological planning, at least for the upcoming word onset.

Obligatory Liaison

Obligatory liaison is a common sandhi phenomenon in French that consists of the insertion of a consonant between a word ending with a vowel and a word also beginning with a vowel (e.g., /mõ/ and /ami/ produced /mõ.nami/). Only a few phonemes can perform the role of a liaison consonant: /z, n, t, ʀ, p, g/; among which, /z, n, t/ are the most frequently used (Durand & Lyche, 2008). This linguistic phenomenon is observed for Romance languages but not in the Germanic ones (Nespor & Vogel, 2007). Several factors determine whether the production of a liaison is obligatory or not. At the syntactic level, for instance, liaisons will only be obligatory for pre-nominal adjective noun-phrases (NPs) but not for post-nominal adjective NPs (Stark & Pomino, 2009). Similarly, syntactic cohesion (Bybee, 2001) and speech context (Encrevé, 1988) will condition the production of a liaison consonant. Many factors will influence the correct production of the liaison at the phonological level but the primer factor for the "silent" liaison consonant of a word 1 to be produced is the fact that the following word starts with a vowel. Even though most authors agree on the fact that liaison is a multifactorial phenomenon, there are mostly too competing accounts on the correct realisation of the liaison: a phonological one and a lexical one. Phonological accounts argue in favour of a floating consonant that attaches either the first or second word (Côté, 2005) while lexical accounts suggest two allomorphic forms stored in the lexicon for a liaison candidate. Several attempts have been made to explain the failure to produce the obligatory liaison. According to those two accounts mentioned different predictions are proposed. The phonological account would argue for a failure to select/produce the floating consonant while the lexical account would predict a breakdown occurring at the lexical stage and probably the retrieval of the wrong form (Bybee & Hopper, 2001; Chevrot, Dugua, & Fayol, 2005; Côté, 2005; Schane; 1967). Independently of which account one favors, phonological processing of the second word has to be partially operated in order to produce the liaison correctly. One proposal these accounts tend to overlook is that liaison omission can result from a reduced encoding span. Indeed, in order to correctly produce liaison consonants, speakers need to encode the second upcoming word or at least its first phoneme. The failure to plan ahead consequently leads to failure in correctly producing a liaison. Interestingly, even though liaison omission is considered a speech error in French, a study by Michel Lange and Laganaro (2014) suggested that speakers might reduce their span of encoding, even for liaison sequences, as a strategy in an experimental setting. In a picture naming task, the authors observed that the failure to produce the liaison was correlated with naming latencies. Speakers who presented short naming latencies failed to produce the liaison correctly, while speakers who presented longer naming latencies produced the liaison correctly. The authors concluded that the interpretation of their results was in agreement with studies suggesting that speech planning is under strategic control (Ferreira & Engelhardt, 2006; Ferreira & Swets, 2002; Konopka, 2012) and that the correct production of obligatory liaison is related to the ahead planning strategies. Longer production latencies associated with the production of liaison consonants strongly suggest that sequences are planned beyond the first word. On the other hand, short production latencies associated with the omission of obligatory liaison suggest a span of encoding limited to the first word. Hence, the failure to produce the liaison in brain damaged speakers might also be the result of a strategic reduction of the span of ahead planning.

In summary, different linguistic manipulations allow investigation of the span of ahead planning and speakers' strategies, but these have been seldom used with brain damaged patients. Between-word phonological errors indicate that the two interacting words have been planned before articulation, and the absence of syntagmatic errors in brain damaged patients who produce phonological errors on single words may suggest a limited encoding span. Similarly, failure to produce obligatory liaison consonants may also indicate a reduced encoding span. Hence, we suggest that the combined pattern of syntagmatic phonological errors and production of obligatory liaison will be informative on the span of ahead planning in brain damaged patients. We predict that patients who do not produce syntagmatic errors also omit the liaison consonants on obligatory sequences, pointing to a reduced encoding span in these patients.

Method

Participants

Brain damaged participants

Speech and/or language impaired patients following a left hemispheric stroke were recruited from rehabilitation hospital units in the French-speaking part of Switzerland. To be included in this study, patients had to be native French-speakers and present a moderate to mild phonological and/or phonetic impairment in the context of mild aphasia (or residual aphasia for patients in a chronic stage). Due to the specificity of the multi-word picture naming task used in the study, brain damaged patients had to have quasi-spared or only mildly impaired naming, preserved comprehension and spared production of monosyllabic words as assessed with a standard French aphasia assessment tool (MT86, Nespoulous et al., 1992). As a consequence of the inclusion of mildly impaired participants, from the initial pool of 19 participants, six were excluded because they produced low rates of segmental errors (less than 5%) in the experimental tasks (see below). This left a group of ten participants with mild aphasia, two with residual Broca aphasia and one with apraxia of speech (AoS) without aphasia aged between 31 and 87 (mean= 58 years old; SD= 17). Patients' demographic details are presented in Table 1.

[Table 1 about here]

Table 1. *Overview of the demographic and clinical details for the brain-damaged participants*

Participant	Age	Gender	Education*	Time Post Onset	Aphasia subtype (at testing)
P1	47	H	III	2 years	Conduction aphasia
P2	82	F	II	4 months	Conduction aphasia
P3	74	H	II	16 months	AoS
P4	71	H	II	2 months	Broca aphasia + AoS
P5	43	H	II	1 month	Anomic w/ occasional phon. Errors
P6	69	F	II	2 months	Conduction aphasia
P7	42	F	II	7 months	Conduction aphasia
P8	51	H	III	15 months	Broca aphasia
P9	64	H	II	6 years	Broca aphasia
P10	48	H	II	5 months	Mild AoS, residual Broca Aphasia

P11	29	H	II	2 years	Broca's aphasia
P12	87	H	II	4 months	Conduction aphasia
P13	51	H	II	3 years	Mainly AoS, residual Broca Aphasia

**Note: I : obligatory school (9 years); II: 10-13 years ; III : superior education*

Healthy Participants

The group of healthy participants was composed of 15 non-brain damaged volunteers recruited from the general public. All were French native speakers and aged between 21 to 55 years old (mean= 35 years old, SD =14).

All the participants signed a written informed consent to participate in the study, which were approved by the local ethics committees.

Materials

Production was elicited with a picture-naming task eliciting adjectival noun-phrases (NPs). Two-word (2W) sequences were composed of a pre-nominal adjective and a noun (e.g., “ancien champignon”—*old mushroom*), and three-word (3W) sequences were composed of a pre-nominal adjective, a noun, and post-nominal adjective (e.g., “ancien champignon jaune”—*old yellow mushroom*). The post-nominal adjectives were six colour adjectives (bleu—*blue*, brun—*brown*, gris—*grey*, jaune—*yellow*, rouge—*red*, vert—*green*) and the pre-nominal adjectives were four qualifying adjectives (ancien—*old*, brilliant—*shiny*, grand—*big*, trois—*three*).

Forty-eight black and white line drawings of common objects and their corresponding nouns were selected from the Alario and Ferrand (1999) database with the following characteristics: Object names were all of masculine gender, between one and three syllables long, and the drawings selected had a name agreement of over 80%. Sixteen nouns were selected for each of the three sentence-type conditions (*liaison, tongue-twister,* and *phonologically "neutral"*). Sixteen nouns beginning with a vowel (V-initial) were selected for the French *liaison* sequences and associated with V-final adjectives (e.g., "grand (/grã/) avion (/avjõ/)"—*big airplane*—, produced /gRã.tavjõ/). Thirty-two other nouns (with a consonant onset) were used for the *tongue-twister* and *phonologically neutral* condition. Sixteen of these nouns were associated with specific adjectives in order to form *tongue-twister*-like sequences. All the tongue-twister-like sequences had at least one repeated phoneme across the adjective and the noun and either a phoneme differing on a single feature on word onset (e.g. "grand crabe" – *big crab*-) or on syllable onset, (e.g., "ancien champignon" – *old mushroom*-) or twisted order of repeated phonemes across the adjective and the noun (eg. "trois tigres" – *three tigers*-). The nouns were matched across the three utterance-type conditions on length in syllables and did not differ significantly on the number of phonemes, lexical frequency, age of acquisition, name agreement, and familiarity (all p>.1). The list of stimuli is presented in Appendix 1.

The 48 corresponding object pictures were modified in colour or size to elicit two and three word noun-phrases as well as French obligatory liaisons or tongue-twister sequences.

To represent the different adjective conditions, the black and white drawings were coloured for the association with the colour adjectives. They were enlarged to illustrate the "grand"—*big* adjective. Two different types of filters were added for the adjectives "ancient"—*old* and "brilliant"—*shiny*. Finally, the "trois"—*three* adjective was pictured by a triple representation of the same item.

To further cue the production of two- or three-word sequences, two or three lines, symbolising the number of words, were added under the target picture. An example of stimuli is provided in Figure 1.

[Figure 1 about here]

Hence, the total set of stimuli consisted of 32 French liaison sequences (16 two-word and 16 three-word sequences), 32 tongue-twister-like sequences (16 two-word and 16 three-word sequences) and 32 neutral sequences (16 two-word and 16 three-word sequences). An example for each of the experimental conditions is provided in Table 2. Phonologically "neutral" sequences did not present any specific phonological difficulty.

[Table 2 about here]

Table 2

Example Stimuli for Each Sequence Condition

	Length of utterance	
Sequence type	***2 words (short)***	***3 words (long)***
Obligatory liaison	grand (t) avion	grand (t) avion bleu
Tongue-twister	trois tigres	trois tigres gris
Neutral	trois stylos	trois stylos bleus

Note: The (t) corresponds to the liaison consonant.

Procedure

All the participants underwent a familiarisation phase, followed by the experimental phase. They were first familiarised with the 48 nouns, 10 adjectives, and their corresponding pictorial representations, and five additional nouns were used for training in all adjective-noun associations. The pictures of the nouns and the symbolisation of the adjectives were initially presented to the participant on a booklet with the modal name in the left-hand column and the corresponding image in the right-hand column. The participants were asked to get acquainted with the nouns and adjectives without time pressure. They were then asked to name each object on the list out loud while the column with the labels was hidden to ensure that the corresponding names had been associated correctly. Extra time was taken with the brain damaged participants to ensure that the instructions had been understood and that the images and their corresponding names were produced correctly.

Participants then completed a short training session with five filler nouns associated with all the adjectives. They were asked to name the pictures out loud with sequences of two or three words. The experimenter reminded participants to speak as naturally and as quickly as possible. The training phase was repeated if necessary until the participants could accurately produce the expected practice utterances. They were not explicitly told to produce the liaison consonants between words. Nevertheless, in case of erroneous production (including failure to produce a liaison consonant), the experimenter produced the correct sequence before moving on to the next training item.

The procedure of the experimental phase was slightly different for healthy and impaired participants. The stimuli were presented by the experimenter on paper sheets, one image at a time, to speech/language impaired participants. The experimenter moved to the next trial after the correct response or after providing the correct answer to an error. There was no time constraint. The experiment was completed during two separate sessions for some participants.

For healthy participants, the stimuli were presented on an HP computer with a 17-inch monitor using the DMDX software (Forster & Forster, 2003). A fixation cross was presented for 500 ms, followed by the target object after a 200 ms blank screen. The picture remained on screen for 1200 ms, and the next trial started after 2000 ms. The time constraint to produce the sequence was used to maximise the production of errors.

Productions were recorded via a head-mounted microphone connected to the computer for healthy participants while the entire session was recorded on a high-quality hand-held recorder for brain damaged participants.

For all the participants, the experimental items were administered in a pseudo-random order, and four different pseudo-random orders were counterbalanced between participants.

Pre-Analyses

All the productions were scored off-line and transcribed by one judge for healthy speakers and by two independent judges for the group of left-hemisphere damaged participants. The transcribers were two experienced clinicians. They transcribed perceived segmental errors and identified phonetic distortions by ear. Both agreed about the way to transcribe segmental errors and adopted the same code to score phonetic distortions. In case of divergence between the two judges, they discussed in order to find a consensus and adopt the better transcription and/or error categorisation according to the participant production. If a final agreement could not be made, a third experienced clinician would decide which transcription she perceived more adequate. Out of a total of 491 sequences, judge 1 and 2 disagreed on 33 items (6,7%). An agreement was reached for 12 of them and 21 required a third judge (4,2%).

The errors were categorised as follows:

1. *Lexical error:* Included incorrect word order, or an incorrect word, as for example: “oeuf brillant” instead of “brillant oeuf”; “agenda marron” instead of “agenda brun”.
2. *Phonological (segmental) error*: Phoneme substitution (i.e., /brijɑ̃.grɑ̃.ruʒ/ for “brillant gland rouge”), addition (i.e., /brijɑ̃.kadnape.blø/ for “brillant canapé bleu”), omission

(i.e., /grɑ̃.kɔkɔdil/ for “grand crocodile”), metatheses (i.e., /grɑ̃.ɛgr.blœ/ for “grand aigle brun”).

3. *Phonetic error:* distorted substitution and any distortion of a phoneme qualifying as a phonetic error (i.e., /brijɑ̃.gnɑ̃.ru(ʒr)/ with (ʒz) being an approximation between two phonemes /z/ and / ʒ / for “brillant gland rouge”).
4. *Liaison consonant error*: The omission of the obligatory liaison consonant (liaison C) (i.e., /brijɑ̃.œf.blø/ for /brijɑ̃.tœf.blø/, “brillant oeuf bleu”) or a substitution of the liaison consonant (i.e., /brijɑ̃.nœf.blø/ for /brijɑ̃.tœf.blø/, “brillant oeuf bleu”).

Phonological errors were then scored as *contextual* when a syntagmatic origin of the error could be identified within the utterance (i.e., /trwa.kast/ for “trois casques”). Concerning contextual phonological errors, we further distinguished *anticipatory* and *perseverative* phonological errors. In anticipatory contextual errors, the erroneous phoneme is found in the following context (i.e., /ɛskaRbo.vɛʀ/ for “escabeau vert”), while in perseverative ones, the error follows a context with the same phoneme (i.e., /grɑ̃.eglefɑ̃/ for “grand éléphant”). We also scored between-word and intra-word contextual errors separately.

Lexical errors were excluded from the analyses as our working hypothesis focussed on segmental contextual errors and on the omission of obligatory liaison consonants. Furthermore, we decided to disregard phonetic errors as these specific errors are difficult to discriminate and transcribe by ear, and a contextual origin can be difficult to identify. We are aware that even a perceived segmental substitution or omission may potentially have a phonetic origin (see Buchwald and Miozzo, 2011), but our aim being the relationship between liaison consonant omissions and contextual substitution errors we included errors that can be clearly classified, independently of their possible underlying origin. Nevertheless, brain-damaged participants producing phonetic errors were not excluded if they also presented a minimum of 5% of perceived and classifiable segmental errors as the focus of our investigation of the relationship between liaison consonant omissions and contextual substitution errors.

Results

Healthy Participants

Healthy subjects produced 9% of utterances with a different lexical content than the expected one (errors where other words than the expected ones were produced and utterances produced with a determiner). These utterances were discarded from the following analyses. 21 phonological errors were observed on the remaining "lexically correct" sequences (1.6%, ranging from 0 to 3.8% across participants) with a higher error rate on three words (3W) than on two words (2W) (1%, vs. 3 %, $z = -2.37$, $p < .02$). The rate of phonological errors was larger on the tongue-twister-like sequences (2.4%) than on the neutral sequences (0.7%), but the difference did not reach significance on the Wilcoxon test ($z = -1.6$, $p = .1$). The majority of phonological errors (86%) were contextual errors, and most of them (78%) were phoneme anticipation (the number of anticipations was significantly larger than the number of perseverations across subjects: $z = -2.25$, $p = .024$). Among the contextual anticipation errors 9 (64 %) were within-word and 5 (36%) were between-word anticipations with no significant differences between them (Wilcoxon $z = -1.18$, $p = .24$).

The rate of liaison consonant omission was 10% (0–25%) with no significant difference between length conditions (Wilcoxon $z = -1.7$, $p = .09$).

Brain damaged Participants

Thanks to the systematic familiarisation in the procedure used with the brain-damaged participants, the rate of lexical errors was very low (2%, ranging from 0 to 11%). These errors were removed from the following analyses and error counts. A detailed overview of the participants´ individual error rates is presented in the Appendix 2.

The group of 13 patients produced 190 segmental errors (on 15% of the "lexically correct" phrases). There was neither an effect of sentence type on overall phonological errors (Friedman Chi square = 1.4, p = .5) nor an effect of number of words in the sequences (Wilcoxon z < 1). There were also 74 phonetic errors (on 6.1% of the utterances) in the corpus, but the number of segmental errors was higher than the number of phonetic errors in all but one participant with AoS (P10, see Apppendix 2). Phonetic errors were no further analysed except for verification in relationship with the results of our main analysis on contextual phonological errors and omission of obligatory liaisons.

The rate of *liaison* consonant omission on the 32 *liaison* sequences varied from 6% to 94% (mean: 56%) and was similar across short and long sequences (Wilcoxon z < 1).

Among the phonological errors, 84 (50%) were contextual errors (phoneme anticipation, perseveration, or metathesis). However, the proportion of contextual errors varied across patients from 29% to 80% of their phonological errors. The rate of contextual errors was slightly higher on 3W sequences than on 2W sequences (respectively, 50% and 35% of phonological errors in these sequences), but the difference did not reach significance (Wilcoxon z = -1.17, p = .24). Of the contextual errors, 49% were phoneme anticipations (including metatheses), 38% were phoneme perseverations, and 13% were ambiguous (could be both anticipation or perseveration errors).

To test our working hypothesis of a convergence between syntagmatic phonological errors and the correct production of obligatory liaisons, spearman correlation was calculated between the rate of *liaison* consonant omissions and the rate of contextual anticipation errors.

The correlation was negative in both the group of healthy participants (Rho=-.329, p= .15) and of speech/language impaired participants (Rho=-.598), but reached significance only in the latter (*p* =.030), indicating a higher rate of omission of obligatory liaisons with lower rates of phoneme anticipation errors. To test whether the correlation between the production of liaison consonants and errors is specific to phoneme anticipation or if it is rather related to overall error rates, we further checked correlations between omission of obligatory liaison consonants and overall phonological error rates as well as with phoneme perseveration errors. There were no significant correlations with overall phonological errors or with perseverations in either group (see Table 3). Notice that although not significant, the correlation between the omission of obligatory liaison consonants and perseveration errors in patients was positive (Rho = .478, *p* = .09).

Table 3. *Correlation between individual rates of Obligatory Liaison Consonant (C) Omission and subtypes of segmental errors for the group of healthy participants and of speech/language impaired participants.*

Correlation (Rho) with rates of Liaison C omission	Proportion of contextual anticipation (on contextual errors)	*Proportion of contextual perseveration errors (on contextual errors)*	*Overall rate of segmental errors*
Group of healthy participants	*-.329*	*.108*	*-.373*
Group of speech/language impaired participants	***-.598****	*.478*	*.070*

*significant at p<.05

Among the contextual phoneme anticipation errors 67% were within-word syntagmatic errors and 29% between-word errors. Further analyses on the between-word anticipations observed for the aphasic speakers revealed that these phoneme anticipations mostly concerned the first (33%) or the second (42%) phoneme of a consequent word.

Discussion

The aim of this study was to investigate whether advance planning might be reduced in left-hemisphere damaged speakers presenting with high rates of segmental errors and, more specifically, to examine whether the convergence of two specific types of errors provide an insight into ahead phonological planning. We analysed two different types of linguistic phenomena, which both inform the span of phonological encoding in a different way: (1) the production of liaison consonants, which requires advance planning up to at least the first phoneme of the following word in order to be produced correctly, and (2) the production of contextual (syntagmatic) phonological errors, which provides insight into the span of phonological planning. We predicted that if brain damaged speakers present a reduced span of encoding, as suggested by their pattern of errors, they should present a high rate of *liaison* consonant omissions in obligatory contexts, suggesting that they fail to plan up to the following word. Similarly, they should produce very few anticipatory errors, as the following words in an utterance should not affect the production of earlier words. Healthy speakers, for whom the span of phonological encoding is assumed to extend beyond the initial word, should, on the contrary, not fail to produce the liaison consonants and present a high rate of anticipatory errors.

We reported several observations. First, even though brain damaged participants produced a high rate of segmental errors, less than half of them had a probable syntagmatic (contextual) origin, whereas the majority of phonological errors produced on the same utterances by healthy speakers were syntagmatic. This observation is in line with previous reports in the literature pointing to a paradigmatic origin of aphasic phonological errors (Kohn & Smith, 1990; Wilshire, 2002). The reduced rate of contextual errors in spite of a high number of segmental errors coupled with the rate of liaison consonant omissions and the significant negative correlation between the two suggest a reduced span of encoding for some participants in the left-hemisphere damaged group. The observation that some brain damaged speakers might present a reduced span of encoding does not indicate per se that it is specifically at the phonological level as it is difficult to estimate the span of encoding at earlier stages. Nevertheless, when it comes to the production of adjective+noun phrases, it seems rather likely that the noun must be retrieved lexically before the adjective can be produced as the agreement between the two elements depends on the properties of the noun. The noun being the head of the adjective+noun phrase has indeed to be partially processed in order for the adjective to agree accordingly. Further support comes from psycholinguistic studies on adjective+noun production (Schriefers & Teruel, 1999; Dumay et al., 2009; Alario, Costa & Caramazza, 2002) in which the authors reported a lexical priming effect or an effect of variables related to the noun before articulation initiated. Hence, if we assume that the noun should be encoded lexically in a noun-phrase before the adjective, the reduced span of encoding can only take place at the word form level. The present results also indicate that advance planning is not reduced in all patients: Those participants who produced a higher rate of phoneme anticipation errors also produced the liaison consonants correctly; on the other hand, other participants produced low rates of phoneme anticipations and high rates of liaison consonant omission. It is therefore important to note that the results of this study do not allow us to demonstrate that speakers producing segmental errors will necessarily present a reduced span of encoding as can be observed when looking at individual data. We would rather argue that the joint investigation of liaison omissions and anticipation errors in a speech production paradigm can allow to investigate the span of phonological encoding in a population producing segmental errors. Overall, the convergence between reduced rates of syntagmatic phonological errors and the omission of obligatory liaisons suggests a reduced span of phonological encoding whereas the correct production of liaisons along with high rates of syntagmatic errors suggests a preserved encoding span. Additionally, we claim that these two linguistic phenomena are interesting tools to allow insight into the span of phonological encoding in brain damaged speakers.

Contextual Errors

As stated in the introduction, speakers presenting with impaired speech/language production following a left hemisphere brain damage produce far more phonological errors than healthy speakers. This was indeed the case in the current study, where patients produced 15% of phonological errors on the lexically correct sequences against 1.6% for healthy speakers. Among those phonological errors, 44% had a contextual origin, whereas most phonological errors were contextual in the group of healthy speakers. Overall, the results reported here are in line with the results reported in the literature. Previous studies that have examined the rate of contextual errors produced by aphasic brain damaged speakers compared to healthy speakers reported that contextual errors seem to account for approximately 70% of phonological errors in healthy speakers, while only 20% of phonological errors seem to have a contextual origin in aphasic speakers (Blumstein, 1973; Schwartz, Saffran, Bloch & Dell, 1994; Talo, 1980). The proportion of contextual errors is slightly higher in the present study in both patients (44%) and healthy participants (86%) than in the previously mentioned studies. This could be due to the specific eliciting material in the present study. The observation of a reduced rate of syntagmatic errors in the patient group could be interpreted as patients as a group not being affected by the phonological content coming later in a message compared to healthy speakers because they have not planned it. However, the rate of contextual errors varied across participants (from 14% to 80% in the present study). Before any further conclusions from this error data, we should consider the other phenomena, namely the production of correct liaison consonants and its relationship with the variability in the rate of contextual errors.

Liaison Consonant Production

As exposed in the introduction, there is fairly strong evidence that the span of phonological encoding in healthy speakers encompasses the initial word, especially in the production of adjective-noun phrases (Costa & Camarazza, 2002; Michel Lange & Laganaro, 2014). For French speakers, this claim is especially supported by the fact that, to be able to produce a liaison sequence, speakers need to have planned at least up to the first phoneme of the second word of a liaison sequence. We therefore expected to observe a correlation between the correct production of the liaison sequences and the rate of anticipatory phonological errors in healthy speakers. This was, however, not what we observed in the group of healthy participants, failing instead to report any significant correlation. A likely explanation for the lack of significant correlation is that the rate of phonological errors was very low for the healthy participant group (1.6%) and the high proportion of contextual anticipations involves very low between-participant variability (one to two errors per participant). This low rate of errors probably accounts for the lack of significance of the correlation between the liaison consonants production and the proportion of contextual anticipation errors.

In the patient group the rate of liaison consonant omissions was very large (56%), with huge variation across participants (from 6% to 94%). The omission of liaison consonants may constitute a specific phonological difficulty in some left-hemisphere damaged patients. However, the rate of omission of obligatory liaison does not correlate with the overall rates of phonological errors; it only correlates negatively with the proportion of phoneme anticipation errors. Alternatively, a high rate of omission of obligatory liaisons may be explained by impaired phonetic encoding, which also might reduce the size of encoded elements, likely to syllables. There was however no correlation between the number of phonetic errors and of liaison consonant omission (Rho = -.002, p = *.99*), nor between perceptually perceived pauses and omission of liaison consonant and pauses (Rho = .13, p = .65 with overall pause rates and Rho = .26, p = .27 with pauses occurring between the first and second word). Therefore, the absence of correlation between perceived phonetic errors and liaison omission does not seem to support a phonetic origin of the observed phenomena.

Hence, only a higher rate of phoneme anticipation errors was related to the correct production of liaison consonants, which rather suggests that liaison consonant omission is the result of a reduced encoding span. In sum, the current data suggest that the span of phonological encoding in brain damaged speakers tends to be reduced but is subject to variation and can, for some patients, extend the initial word.

Liaison and tongue-twister sequences as methodological tools

A second aim of this study was to assess whether the development of specific linguistic materials proved to be an efficient tool in order to investigate the span of encoding. Both liaison (Michel Lange & Laganaro, 2014) and tongue-twister sequences (Goldrick & Blumstein, 2006; Whilshire, 1999) have been successfully used in previous studies. The elicitation of liaison sequences in this study clearly showed variable performance across participants and allowed to infer on the span of encoding by showing a negative correlation between liaison omission and segmental anticipatory errors. The tongue twister sequences were aimed to increase the probability of phonological errors, but we failed to show significant results in terms of error rates with tongue-twister sequences. While healthy speakers did produce a higher rate of phonological errors in the tongue-twister condition, this difference did not reach significance and no difference across sentence type was observed in the brain damaged participants. This might be due to the material developed for the task: because of the constraints of a picture naming task and the matching required across the three sentence conditions the manipulations in the tongue twister sequences did not meet all the criteria usually required to properly elicit tongue-twister like effects (Whilshire, 1999). While the liaison sequences were clearly informative, it is difficult from this study to determine whether the tongue-twister sequences are a better tool than any other multiple word elicitation material to elicit segmental anticipation errors in order to investigate the span of encoding.

Conclusion

The aim of this study was to investigate the span of encoding in brain damaged speakers with phonological encoding impairment. Classical corpus or spontaneous patient production samples usually only highlight the fact that phonologically impaired patients produce many phonological errors, few of them with a contextual origin. We replicated this observation, but we also reported a negative correlation between the rate of phoneme anticipation errors and the rate of liaison consonant omissions thus suggesting reduction of the span of encoding for some of the brain damaged speakers. The present study also showed that the joint analysis of *liaison* and phoneme anticipation errors can be used to examine advance planning.

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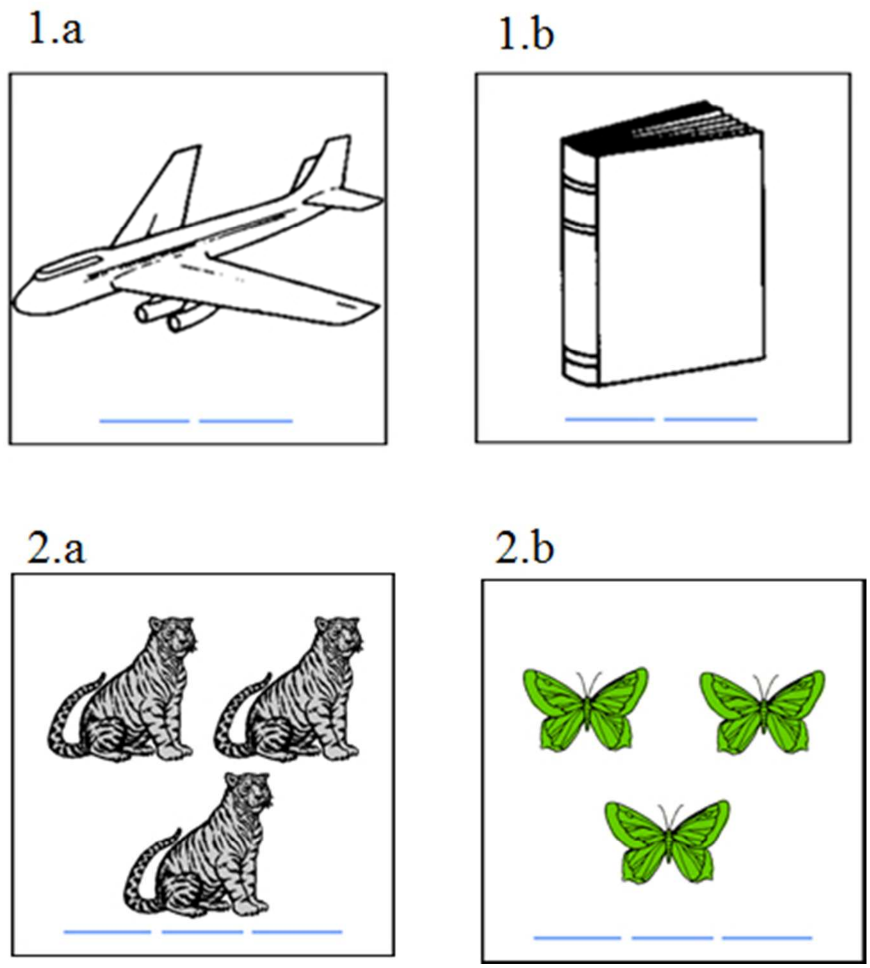
FIGURE CAPTION

Figure 1. Illustration of four examples of stimuli. The lines underneath the picture illustrate the number of words to be produced. For the first two pictures (1.a and 1.b), the participant has to produce two words, as indicated by the two blue lines underneath. Picture 1.a illustrates a liaison condition (grand avion—*big plane* where "grand" /gRã/ "avion" /avjõ/ is produced /grɑ̃.tavjɔ̃/) and picture 1.b illustrates a two-word phonologically neutral condition (grand livre—*big book*, /gRã.livR/). In the second picture, the participant is expected to produce three words. Picture 2.a illustrates a tongue-twister condition (trois tigres gris—*three grey tigers*, pronounced /tʀwɑ.tigʀ.gʀi/) and picture 2.b illustrates a three-word phonologically neutral condition (trois papillons verts—*three green butterflies*).



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114x129mm (96 x 96 DPI)

List of stimuli

Pre_Adj	Post_Adj	Length_seq	Cond_seq	Noun	Phono_N	English	Sequence	Phono_seq
ancien	-	2M	Liaison	agenda	aʒɛ̃da	diary	ancien agenda	ɑ̃.sjɛ̃. na.ʒɛ̃.da
ancien	-	2M	Liaison	escabeau	ɛskabo	stepladder	ancien escabeau	ɑ̃.sjɛ̃.nɛ.ska.bo
ancien	-	2M	Liaison	arrosoir	aʀozwaʀ	watering c.	ancien arrosoir	ɑ̃.sjɛ̃.na.ʀo.zwaʀ
ancien	-	2M	Liaison	escalier	ɛskalje	stairs	ancien escalier	ɑ̃.sjɛ̃.nɛ.ska.lje
brillant	-	2M	Liaison	igloo	iglu	igloo	brillant igloo	bʀi.jɑ̃.ti.glu
brillant	-	2M	Liaison	arbre	aʀbʀ	tree	brillant arbre	bʀi.jɑ̃.taʀbʀ
brillant	-	2M	Liaison	œuf	œf	egg	brillant œuf	bʀi.jɑ̃.tœf
brillant	-	2M	Liaison	ours	uʀs	bear	brillant ours	bʀi.jɑ̃.tuʀs
grand	-	2M	Liaison	elephant	elefɑ̃	elephant	grand éléphant	gʀɑ̃.te.le.fɑ̃
grand	-	2M	Liaison	avion	avjɔ̃	airplane	grand avion	gʀɑ̃.ta.vjɔ̃
grand	-	2M	Liaison	écureuil	ekyʀœj	squirrel	grand écureuil	gʀɑ̃.te.ky.ʀœj
grand	-	2M	Liaison	aigle	ɛgl	eagle	grand aigle	gʀɑ̃.tɛgl
trois	-	2M	Liaison	indien	ɛ̃djɛ̃	Indian	trois indiens	tʀwɑ.zɛ̃.djɛ̃
trois	-	2M	Liaison	ananas	ananas	pineapple	trois ananas	tʀwɑ.za.na.na
trois	-	2M	Liaison	oignon	ɔɲɔ̃	onion	trois oignons	tʀwɑ.zɔ.ɲɔ̃
trois	-	*2M*	Liaison	entonnoir	ɑ̃tɔnwaʀ	funnel	trois entonnoirs	tʀwɑ.zɑ̃.tɔ.nwaʀ
ancien	brun	3M	Liaison	agenda	aʒɛ̃da	diary	ancien agenda brun	ɑ̃.sjɛ̃.na.ʒɛ̃.da.bʀœ̃
ancien	vert	3M	Liaison	escabeau	ɛskabo	stepladder	ancien escabeau vert	ɑ̃.sjɛ̃.nɛs.ka.bo.vɛʀ
ancien	bleu	3M	Liaison	arrosoir	aʀozwaʀ	watering c.	ancien arrosoir bleu	ɑ̃.sjɛ̃.na.ʀo.zwaʀ.blø
ancien	brun	3M	Liaison	escalier	ɛskalje	stairs	ancien escalier brun	ɑ̃.sjɛ̃.nɛ.ska.lje.bʀœ̃
brillant	bleu	3M	Liaison	œuf	œf	egg	brillant œuf bleu	bʀi.jɑ̃.tœf.blø
brillant	jaune	3M	Liaison	arbre	aʀbʀ	tree	brillant arbre jaune	bʀi.jɑ̃.taʀbʀ.ʒon
brillant	brun	3M	Liaison	ours	uʀs	bear	brillant ours brun	bʀi.jɑ̃.tuʀs.bʀœ̃
brillant	rouge	3M	Liaison	igloo	iglu	igloo	brillant igloo rouge	bʀi.jɑ̃.ti.glu.ʀuʒ
grand	brun	3M	Liaison	aigle	ɛgl	eagle	grand aigle brun	gʀɑ̃.tɛgl.bʀœ̃

grand	bleu	3M	Liaison	avion	avjɔ̃	airplane	grand avion bleu	gʀɑ̃.ta.vjɔ̃.blø
grand	brun	3M	Liaison	ecureuil	ekyʀœj	squirrel	grand ecureuil brun	gʀɑ̃.te.ky.ʀœj.bʀœ̃
grand	gris	3M	Liaison	elephant	elefɑ̃	elephant	grand éléphant gris	gʀɑ̃.te.le.fɑ̃.gʀi
trois	jaune	3M	Liaison	indien	ɛ̃djɛ̃	Indian	trois indiens jaunes	tʀwɑ.zɛ̃.djɛ̃.ʒon
trois	brun	3M	Liaison	oignon	ɔɲɔ̃	onion	trois oignons bruns	tʀwɑ.zɔ.ɲɔ̃.bʀœ̃
trois	jaune	3M	Liaison	ananas	ananas	pineapple	trois ananas jaunes	tʀwɑ.za.na.na.ʒon
trois	*rouge*	*3M*	Liaison	entonnoir	ɑ̃tɔnwaʀ	funnel	trois entonnoirs rouges	tʀwɑ.zɑ̃.tɔ.nwaʀ.ʀuʒ
ancien	-	2M	Neutral	serpent	sɛʀpɑ̃	snake	ancien serpent	ɑ̃.sjɛ̃.sɛʀ.pɑ̃
ancien	-	2M	Neutral	robinet	ʀɔbinɛ	faucet	ancien robinet	ɑ̃.sjɛ̃.ʀɔ.bi.nɛ
ancien	-	2M	Neutral	marteau	maʀto	hammer	ancien marteau	ɑ̃.sjɛ̃.maʀ.to
ancien	-	2M	Neutral	labyrinthe	labiʀɛ̃t	maze	ancien labyrinthe	ɑ̃.sjɛ̃.la.bi.ʀɛ̃t
brillant	-	2M	Neutral	ski	ski	ski	brillant ski	bʀi.jɑ̃.ski
brillant	-	2M	Neutral	dinosaure	dinozɔʀ	dinosaur	brillant dinosaure	bʀi.jɑ̃.di.no.zɔʀ
brillant	-	2M	Neutral	gland	glɑ̃	acorn	brillant gland	bʀi.jɑ̃.glɑ̃
brillant	-	2M	Neutral	canape	kanape	couch	brillant canapé	bʀi.jɑ̃.ka.na.pe
grand	-	2M	Neutral	livre	livʀ	book	grand livre	gʀɑ̃.livʀ
grand	-	2M	Neutral	thermomètre	tɛʀmɔmɛtʀ	thermometer	grand thermomètre	gʀɑ̃.tɛʀ.mɔ.mɛtʀ
grand	-	2M	Neutral	stylo	stilɔ	pen	grand stylo	gʀɑ̃.sti.lɔ
grand	-	2M	Neutral	tournevis	tuʀnəvis	screwdriver	grand tournevis	gʀɑ̃.tuʀ.nə.vis
trois	-	2M	Neutral	palmier	palmje	palm tree	trois palmiers	tʀwɑ.pal.mje
trois	-	2M	Neutral	casque	kask	helmet	trois casques	tʀwɑ.kask
trois	-	2M	Neutral	sifflet	siflɛ	whistle	trois sifflets	tʀwɑ.si.flɛ
trois	-	*2M*	Neutral	papillon	papijɔ̃	butterfly	trois papillons	tʀwɑ.pa.pi.jɔ̃
ancien	vert	3M	Neutral	robinet	ʀɔbinɛ	faucet	ancien robinet vert	ɑ̃.sjɛ̃.ʀɔ.bi.nɛ.vɛʀ
ancien	vert	3M	Neutral	serpent	sɛʀpɑ̃	snake	ancien serpent vert	ɑ̃.sjɛ̃.sɛʀ.pɑ̃.vɛʀ
ancien	vert	3M	Neutral	labyrinthe	labiʀɛ̃t	maze	ancien labyrinthe vert	ɑ̃.sjɛ̃.la.bi.ʀɛ̃t.vɛʀ
ancien	jaune	3M	Neutral	marteau	maʀto	hammer	ancien marteau jaune	ɑ̃.sjɛ̃.maʀ.to.ʒon
brillant	vert	3M	Neutral	dinosaure	dinozɔʀ	dinosaur	brillant dinosaure vert	bʀi.jɑ̃.di.no.zɔʀ.vɛʀ
brillant	rouge	3M	Neutral	gland	glɑ̃	acorn	brillant gland rouge	bʀi.jɑ̃.glɑ̃.ʀuʒ
brillant	bleu	3M	Neutral	ski	ski	ski	brillant ski bleu	bʀi.jɑ̃.ski.blø

brillant	bleu	3M	Neutral	canape	kanape	couch	brillant canapé bleu	bʀi.jɑ̃.ka.na.pe.blø
grand	vert	3M	Neutral	stylo	stilɔ	pen	grand stylo vert	gʀɑ̃.sti.lɔ.vɛʀ
grand	jaune	3M	Neutral	livre	livʀ	book	grand livre jaune	gʀɑ̃.livʀ.ʒon
grand	jaune	3M	Neutral	tournevis	tuʀnəvis	screwdriver	grand tournevis jaune	gʀɑ̃.tuʀ.nə.vis.ʒon
grand	rouge	3M	Neutral	thermometre	tɛʀmɔmɛtʀ	thermometer	grand thermomètre rouge	gʀɑ̃.tɛʀ.mɔ.mɛtʀ.ʀuʒ
trois	bleu	3M	Neutral	casque	kask	helmet	trois casques bleus	tʀwɑ.kaskə.blø
trois	rouge	3M	Neutral	sifflet	siflɛ	whistle	trois sifflets rouges	tʀwɑ.si.flɛ.ʀuʒ
trois	*vert*	*3M*	Neutral	papillon	papijɔ̃	butterfly	trois papillons verts	tʀwɑ.pa.pi.jɔ̃.vɛʀ
trois	rouge	3M	Neutral	palmier	palmje	palm tree	trois palmiers rouges	tʀwɑ.pal.mje.ʀuʒ
ancien	-	2M	T-twister	chandelier	ʃɑ̃dəlje	candlestick	ancien chandelier	ɑ̃.sjɛ̃.ʃɑ̃.də.lje
ancien	-	2M	T-twister	champignon	ʃɑ̃piɲɔ̃	mushroom	ancien champignon	ɑ̃.sjɛ̃.ʃɑ̃.pi.ɲɔ̃
ancien	-	2M	T-twister	cendrier	sɑ̃dʀie	ashtray	ancien cendrier	ɑ̃.sjɛ̃.sɑ̃.dʀie
ancien	-	2M	T-twister	parachute	paʀaʃyt	parachute	ancien parachute	ɑ̃.sjɛ̃.pa.ʀa.ʃyt
brillant	-	2M	T-twister	puits	pɥi	well	brillant puits	bʀi.jɑ̃.pɥi
brillant	-	2M	T-twister	pneu	pnø	tire	brillant pneu	bʀi.jɑ̃.pnø
brillant	-	2M	T-twister	pantalon	pɑ̃talɔ̃	pants	brillant pantalon	bʀi.jɑ̃.pɑ̃.ta.lɔ̃
brillant	-	2M	T-twister	drapeau	dʀapo	flag	brillant drapeau	bʀi.jɑ̃.dʀa.po
grand	-	2M	T-twister	croissant	kʀwasɑ̃	croissant	grand croissant	gʀɑ̃.kʀwa.sɑ̃
grand	-	2M	T-twister	crabe	kʀab	crab	grand crabe	gʀɑ̃.kʀab
grand	-	2M	T-twister	crocodile	kʀɔkɔdil	alligator	grand crocodile	gʀɑ̃.kʀɔ.kɔ.dil
grand	-	2M	T-twister	tracteur	tʀaktœʀ	tractor	grand tracteur	gʀɑ̃.tʀak.tœʀ
trois	-	*2M*	T-twister	parapluie	paʀaplɥi	umbrella	trois parapluies	tʀwɑ.pa.ʀa.plɥi
trois	-	2M	T-twister	chronomètre	kʀɔnɔmɛtʀ	stop watch	trois chronomètres	tʀwɑ.kʀɔ.nɔ.mɛtʀ
trois	-	2M	T-twister	briquet	bʀikɛ	lighter	trois briquets	tʀwɑ.bʀi.kɛ
trois	-	2M	T-twister	tigre	tigʀ	tiger	trois tigres	tʀwɑ.tigʀ
ancien	rouge	3M	T-twister	parachute	paʀaʃyt	parachute	ancien parachute rouge	ɑ̃.sjɛ̃.pa.ʀa.ʃyt.ʀuʒ
ancien	jaune	3M	T-twister	chandelier	ʃɑ̃dəlje	candlestick	ancien chandelier jaune	ɑ̃.sjɛ̃.ʃɑ̃.də.lje.ʒon
ancien	rouge	3M	T-twister	cendrier	sɑ̃dʀie	ashtray	ancien cendrier rouge	ɑ̃.sjɛ̃.sɑ̃.dʀie.ʀuʒ
ancien	jaune	3M	T-twister	champignon	ʃɑ̃piɲɔ̃	mushroom	ancien champignon jaune	ɑ̃.sjɛ̃.ʃɑ̃.pi.ɲɔ̃.ʒon
brillant	bleu	3M	T-twister	pantalon	pɑ̃talɔ̃	pants	brillant pantalon bleu	bʀi.jɑ̃.pɑ̃.ta.lɔ̃.blø

brillant	bleu	3M	T-twister	pneu	pnø	tire	brillant pneu bleu	bʀi.jɑ̃.pnø.blø
brillant	brun	3M	T-twister	drapeau	dʀapo	flag	brillant drapeau brun	bʀi.jɑ̃.dʀa.po.bʀœ̃
brillant	gris	3M	T-twister	puits	pɥi	well	brillant puits gris	bʀi.jɑ̃.pɥi.gʀi
grand	gris	3M	T-twister	tracteur	tʀaktœʀ	tractor	grand tracteur gris	gʀɑ̃.tʀak.tœʀ.gʀi
grand	gris	3M	T-twister	crocodile	kʀɔkɔdil	alligator	grand crocodile gris	gʀɑ̃.kʀɔ.kɔ.dil.gʀi
grand	gris	3M	T-twister	croissant	kʀwasɑ̃	croissant	grand croissant gris	gʀɑ̃.kʀwa.sɑ̃.gʀi
grand	gris	3M	T-twister	crabe	kʀab	crab	grand crabe gris	gʀɑ̃.kʀab.gʀi
trois	gris	3M	T-twister	tigre	tigʀ	tiger	trois tigres gris	tʀwɑ.tigʀ.gʀi
trois	gris	3M	T-twister	briquet	bʀikɛ	lighter	trois briquets gris	tʀwɑ.bʀi.kɛ.gʀi
trois	gris	3M	T-twister	chronomètre	kʀɔnɔmɛtʀ	stop watch	trois chronomètres gris	tʀwɑ.kʀɔ.nɔ.mɛtʀ.gʀi
trois	*brun*	*3M*	T-twister	parapluie	paʀaplɥi	umbrella	trois parapluies bruns	tʀwɑ.pa.ʀa.plɥi.bʀœ̃

Note: Pre_adj stands for pre-nominal adjectives; Post_adj for post-nominal adjectives; Length_seq for the length of the sequence in number of words; Cond_seq for the sequence condition; Noun for the main nouns used in a given sequence; Phono_N for the phonological transcription of the main noun in a given sequence; English for the English transcription of the main noun in a given sequence; Sequence for the entire sequence in French and Phono_seq for the phonological transcription of the entire sequence.

Individual data

Part.	Tot. N. Lex. Cor. Seq.	N. Lex. Cor. Liaison Seq.	N. Liaison Omission	Prop. Liaison Omission	Tot. N. Phonetic Errors	N. Phono Errors	Prop. Cont. Phono. Errors	N. Cont. Errors	Prop. Cont. Pers.	Prop. Cont. Ant.	N. Ant.	N. Inter-W. Ant.	N. Intra-W. Ant.
P1	*96*	*32*	*11*	*34%*	*6*	21	62%	13	62%	46%	6	2	4
P2	*95*	*32*	*12*	*38%*	*0*	12	42%	5	80%	60%	3	0	3
P3	*95*	*32*	*10*	*31%*	*3*	14	64%	9	0%	100%	9	2	7
P4	*94*	*32*	*23*	*72%*	*20*	45	29%	13	46%	85%	11	5	5
P5	*95*	*32*	*2*	*6%*	*1*	5	60%	3	0%	100%	3	0	3
P6	*96*	*32*	*23*	*72%*	*2*	27	33%	9	33%	78%	7	3	4
P7	*93*	*31*	*23*	*74%*	*0*	7	57%	4	75%	50%	2	0	2
P8	*96*	*32*	*30*	*94%*	*1*	10	50%	5	80%	20%	1	1	0
P9	*85*	*29*	*12*	*41%*	*6*	10	80%	8	38%	75%	6	1	5
P10	*90*	*30*	*19*	*63%*	*19*	6	50%	3	100%	33%	1	0	0
P11	*94*	*30*	*25*	*83%*	*1*	6	50%	3	100%	0%	0	0	0
P12	*94*	*31*	*10*	*32%*	*3*	7	43%	3	67%	33%	1	0	1
P13	*95*	*31*	*27*	*87%*	*12*	20	30%	6	67%	33%	2	1	1
Tot.	**1218**	**406**	**227**	**56%**	**74**	**190**	**50%**	**84**	**57%***	**55%***	**52**	**15**	**35**

Note: Part.= Participants; Tot. N. Lex. Cor. Seq= Total number of lexically correct sequences; N. Lex. Cor. Liaison Seq.= Number of lexically correct sequences; N. Liaison Omission= Number of liaison omissions; Prop. Liaison Omission= Proportion of liaison omissions; Tot. N. Phonetic Errors= Total number of phonetic errors; N. Phono Errors= Number of phonological errors; Prop. Cont. Phono. Errors= Proportion of contextual phonological errors; N. Cont. Errors= Number of contextual errors; Prop. Cont. Pers.= Proportion of contextual perseverations; Prop. Cont. Ant.= Proportion of contextual anticipations; N. Ant.= Number of anticipations; N. Inter-W. Ant.= Number of inter-word anticipations; N. Intra-W. Ant.= Number of intra-word anticipations.

**The proportion of perseveration added to anticipation is above 100% considering cases were anticipation and perseveration happen together (ie. metathesis)*