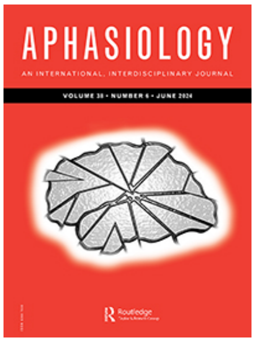

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How dual-task interference on word production is modulated by the timing of the secondary task: evidence from errors in people with aphasia

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ABSTRACT

Background: Utterance production is affected under dual-task conditions, but so far studies have shown an impact either on lexical or on phonological processes, but not on both simultaneously.

Aims: In the present study, we aimed at investigating how interference on lexical and phonological encoding is modulated by the timing of the concurrent task and by the attentional requirement (divided vs focused attention).

Methods: Participants with aphasia (PWA) underwent a picture naming task and an auditory detection task, with auditory stimuli presented at different stimulus onset asynchronies (SOAs). The dual-task was performed under divided (Experiment 1) and focused attention (Experiment 2).

Outcome & Results: Omission errors increased under dual-task at early SOA only in Experiment 1 while phonological errors increased at later SOAs in both experiments.

Conclusion: These patterns of errors indicate that lexical and phonological processes are impacted under dual-task conditions, giving rise to an increase of specific types of errors at specific SOAs. They also show that very mild anomia may be more severe when assessed under dual-task conditions.

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Dual-task; word production; interference; attention; aphasia

Introduction

Language is usually fast, automatic and precise, but we all experience situations in which speaking is less easy. In our everyday life, we may be playing with a child, cooking or driving while talking to someone else. When dual-task conditions are studied experimentally, utterance production is usually affected at least in terms of speech rate (Caramazza, 1997, Kemper et al., 2011), naming latencies (Fargier & Laganaro, 2019) and accuracy (Laganaro et al., 2019). In such conditions, the attention of the speaker is divided between two tasks that have to be performed actively and any detrimental effect on speaking is interpreted as evidence that some attentional control is necessary to speak. Speaking may however also become more difficult in focused attention conditions when interference

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comes from a “passive” second task, for instance when stimuli (e.g., syllables, tones) are heard while speaking (Fargier & Laganaro, 2019), a condition that seems to particularly affect people with aphasia (PWA) (Laganaro et al., 2019).

As speaking is a complex cognitive task relying on several encoding processes, a core question is whether all processes are equally impacted by dual-tasks, or if only specific encoding processes require attention and become more sensitive to the interference under dual-task conditions. In particular, whereas all word planning processes seem to require attention, the impact on each word planning process seems to depend on specific experimental manipulations (delay between the tasks, type of stimuli, attentional demand). Here we investigate whether interference on lexical selection and phonological encoding is modulated by the timing of the concurrent task and by the attentional requirement.

In the following, we will first review the dual-task paradigms that have been used to investigate attentional requirement in speaking, before reviewing the evidence on the processing levels that seem to require attention. Finally, we will review the incongruent results found in clinical studies under dual-task conditions and the questions raised by these studies.

Dual-task interference in speech production has been explored experimentally by asking participants to perform a verbal task (e.g., picture naming, sentence completion) while performing a concurrent non-verbal task (e.g., visual or auditory detection requiring a motor response, but also ecologically tasks such as driving). Dual-task paradigms have been used in studies to investigate specific word production processes such as lexical selection (Ferreira & Pashler, 2002); phonological encoding (Fargier & Laganaro, 2016), or more complex production tasks such as conversation (Boiteau et al., 2014), or narration (Kemper et al., 2009) and have also been used with auditory comprehension tasks (Celsi & Olson, 1988) and word reading (Reynolds & Besner, 2006). In neurotypical speakers, studies on speech production have shown shorter and less complex sentences when simultaneously performing a non-linguistic task such as walking (Kemper et al., 2005).

Based on the observations on speech production, it has been argued that utterance planning is not entirely automatic and requires some attentional resources (Garrod & Pickering, 2007; Roelofs, 2008). The interference in dual-task conditions (longer reaction times and/or decreased accuracy) as compared to performance while executing the same activity in isolation is taken as an indicator of attentional demand in the processes involved. The idea is that attentional capacity is limited and must be shared between two tasks that are both demanding some attentional resources. Given that utterance planning involves several encoding processes from conceptualisation to motor speech, a key issue is whether all or only some processes require attention, a question that may best be addressed with specific experimental approaches.

For single word production the main processes acknowledged by most models (Caramazza, 1997; Dell, 1986; Levelt et al., 1999) are conceptualisation or semantic processes, lexical selection (lemma retrieval in some models), phonological encoding (retrieving the phonological form of the target word), phonetic (or motor speech) encoding and articulation. To determine which word planning processes require attention, previous studies typically used the Psychological Refractory Period paradigm (PRP paradigm, Welford, 1952) in which two tasks (verbal and non-verbal) are performed with a variable interval between their onset (Stimulus Onset Asynchrony; SOA). Various lengths of SOA have been used and have allowed to determine the temporal dynamic of word production. Based on behavioural/chronometric and electro- and magnetoencephalographic event related studies (Indefrey & Levelt, 2004; Indefrey, 2011) semantic to lexical processes are estimated to occur from about 150 to 250 ms after picture presentation, phonological encoding after about 300 ms followed by phonetic encoding processes to be engaged at about 450 ms. These estimations are based on neurotypical individuals with production latencies around 600 ms, but have also been confirmed on participants with aphasia and longer production latencies (Laganaro et al., 2009). The idea that lexical selection is the main word encoding process under attentional demand has dominated for a while, until some studies provided evidence that post-lexical phonological processes (Cook & Meyer, 2008; Fargier & Laganaro, 2016) and even motor speech encoding or articulation (Bailey & Dromey, 2015; Fournet et al., 2021) also require attentional resources. It has also been suggested that in case of language impairment the attentional demand of utterance encoding is larger than in neurotypical speakers.

Dual-task paradigms have also been used to assess some components of the psychological concept of attention, which is not unified. In the model proposed by Van Zomeren and Brouwer (1994), the different components of attention have been separated into two categories: intensity (alertness and sustained attention) and selectivity (focused attention and divided attention). Divided attention is defined as the capacity to decide or share attention between different tasks whereas focused attention is the ability to focus on a task or as a part of the environment and to ignore distractors. These two components of selectivity have been studied in PWA, as attentional impairment could co-occur with language impairment (Erickson et al., 1996). Very few studies have investigated how interference on word production is modulated by the attentional requirement using the dual-task paradigm in this population.

Dual-task paradigms have been used in PWA in two clinical studies on word production (Murray, 2000; Laganaro et al., 2019), leading to somewhat different results. In Murray's study (2000), participants with brain-damage (right or left-hemisphere), performed a one-word sentence completion and a tone discrimination task presented simultaneously (SOA = 0). The dual-tasks were performed under focused and divided attention condition, in two different blocks. Results in PWA showed longer reaction times and lower accuracy with an increase of semantic, unrelated and perseverative errors as compared to neurotypical individuals. Different results have been reported in a group of PWA by Laganaro et al. (2019). PWA performed a dual-task composed of a picture naming task and a syllable detection (participants had to press a key on the keyboard when hearing the target syllable), appearing at SOA +300 ms, likely targeting phonological processes based on previous estimates of the timing of utterance processes (Indefrey, 2011). The dual-tasks were performed under different attentional requirement (focused and divided attention), in two different blocks, as in Murray's study (2000). A decrease of accuracy and in particular an increase of phonological errors was observed, suggesting that phonological and phonetic encoding also require attention.

Despite the apparent contradiction in the reported errors (lexical versus phonological) observed under dual-task conditions, the different results could be explained by different methodological aspects. First, these results might originate from different SOAs across the two studies. In Murray (2000), both tasks were presented simultaneously, meaning that SOA was 0 ms, whereas the second task appeared at SOA +300 ms in Laganaro et al. (2019), likely targeting phonological encoding processes. This leads to the question of whether lexical and phonological processing require equal attentional resources i.e whether lexical and phonological errors can be observed within a single study at different SOAs. Second, the two clinical studies also differed by the type of second task. In Murray's study (2000), participants performed a tone discrimination task (non-verbal stimuli) whereas in Laganaro et al. (2019), a syllable detection task was administered (verbal stimuli). Third, in both studies, the attentional requirement by the task under dual-task conditions was also manipulated (focused vs divided attention). In Murray (2000), the increase of lexical errors was observed under both attentional requirement whereas in Laganaro et al. (2019), phonological errors increased only under divided attention. Results in both studies (Laganaro et al., 2019; Murray, 2000) seem to suggest that interference was larger under divided attention than under focused attention, meaning that the degree of interference on word planning processes is modulated by the attentional requirement.

In sum, the incongruent results on the type of errors under dual-task conditions in PWA may be related to methodological differences between the studies in terms of SOA, stimulus type and attentional requirement.

In the present study, we aim at investigating whether dual-task interference on lexical processes and on phonological encoding can be found within the same study and if this interference is modulated (i) by the timing of the concurrent task (SOA) and (ii) by the attentional requirement (divided vs focused attention).

As detailed above, previous studies have reported either an increase of lexical errors (Murray, 2000) or an increase of phonological errors (Laganaro et al., 2019) in PWA, but with different timing between the language and the auditory detection tasks. Here, we will therefore use different SOAs of the concurrent auditory syllable detection task based on previous estimates of the timing of lexical-semantic and of phonological processes (Indefrey & Levelt, 2004; Indefrey, 2011). If the word encoding processes affected by dual-task depend on the timing of the concurrent task, we expected lexical-semantic processes to be impacted at SOA +150 ms and post-lexical processes at SOA +300 and +450 ms respectively for phonological and phonetic encoding. In PWA, an insight into the encoding processes that are affected at each SOA can be found in the type of errors produced in each condition. For the second aim, namely whether effects at different timings are modulated by the attentional requirement, the dual-task paradigm will be performed under divided (Experiment 1) and focused attention (Experiment 2).

We expected that lexical processes should be impacted under both attentional requirements, as they seem to be more sensitive to the interference, as lexical errors were observed in both attentional requirements in Murray (2000). By contrast, phonological processes should be impacted only under divided attention conditions, as phonological errors in Laganaro et al. (2019) were observed only under divided attention condition.

Experiment 1

The aim of the first experiment was to investigate whether different word encoding processes are interfered under a dual-task requiring divided attention, with stimuli of the secondary task (syllables) presented at three different SOAs (+150, +300, +450), likely targeting the timing of different word planning processes according to current estimates of the time-course of word encoding (Indefrey, 2011).

Participants

A group of twenty-two PWA took part in this experiment and were recruited from the rehabilitation unit at Bordeaux University Hospital and at the Consultation en Logopédie at the Faculty of Psychology and Educational Sciences, in Geneva University. The inclusion criteria were: native French speaker, suffering from aphasia after a first left-hemispheric stroke (ischemic or hemorrhagic, range months post-onset: 3-204), mild to moderate anomia, minor or no comprehension deficit according to the clinical assessment (see below). Among the twenty-two participants who met the criteria, one was excluded because he produced a majority of omission errors (>50%) in the experimental picture naming task in the "naming alone condition" (see below). Twenty-one participants were retained in the final group (9 men, 12 women, mean age: 59.52, SD: 15.05, see Appendix 1).[1] Four participants (P19, P20, P21 and P22) presented apraxia of speech associated with mild aphasia. The clinical language assessment was done with some subtests (picture naming, repetition of words and pseudo-words, semantic and oral comprehension) of the "Batterie d'Evaluation Cognitive du Langage" (BECLA, Macoir et al., 2016) and the results are presented in Appendix 1. The language tests were administered at the end of the experimental sessions (see below).

In addition to language assessment, participants performed a visual detection task to exclude severe attentional impairment. The visual detection task was elaborated to mirror the auditory syllable detection task used in the experiment (see below), but with non-verbal stimuli. The stimuli (N = 30) were four different symbols ("+"; "-"; "~"; "#") and appeared pseudo randomly on screen for 2000 ms. PWA had to press a key on the keyboard as quickly as possible when they identified the target symbol "+" (1/3 of the stimuli). Results are also presented in Appendix 1.

All the participants gave their informed written consent for their participation in this experiment, which was approved by the corresponding local ethics committees.

Material

Picture naming task

One hundred and eight colour photographs and their corresponding names were selected from a standardized database (Brodeur et al., 2010; Brodeur et al., 2014). All pictures corresponded to common objects and had a high name agreement in French (above 70%), except twelve photographs for which this data was not available. They were split into three lists of thirty items each, matched on variables associated with the pictures and to their corresponding words: image agreement, image familiarity, image manipulability, subjective image visual complexity, lexical frequency in film subtitles, word length in phonemes and in syllables and syllabic structure according to lexique.org (New et al., 2004). Ninety pictures corresponded to the experimental analysed items (three lists of

[1]In the Appendix 1, the PWA from both experiments are presented (experiment 1 and 2). The last two columns indicate which experiments have been performed by the participants, as some of them didn't perform both.

thirty items), and eighteen pictures (six per list) served as fillers in the "naming and hearing" (called dual-task condition for the remainder of the manuscript) and were associated with the target syllable to detect (always the syllable "fo", see below) and not analysed.

Auditory detection task

Four different syllables (/mi/, /na/, /ri/ and /fo/) constituted the stimuli for the auditory detection task. The target syllable was /fo/. The auditory stimuli were recorded in Audacity® software by a female speaker and lasted 280 ms.

Dual-task condition

The dual-task paradigm consisted of picture naming and auditory syllable detection. Each experimental picture was associated with one of the three non-target syllables that occurred the same number of times (30x /mi/, 30x /na/, 30x /ri/). Syllables were matched to target pictures pseudo randomly, in order to avoid phonological overlaps with the syllables of the word corresponding to the picture to name at the syllabic level and at the segmental level for the first syllable of the word. Filler pictures were always associated with the target syllable /fo/. Each list of thirty items was associated with one SOA (+150, +300 or +450), meaning that the auditory syllable was presented either 150, 300 or 450 ms after the onset of the picture and counter-balanced across participants. The three SOAs were chosen because they likely correspond to different word planning processes in the dynamics of word production (Indefrey, 2011).

Procedure

Participants were tested individually in a quiet room, in front of the computer (approximately 50 cm from their chest). The presentation of trials was controlled by the E-Prime software (E-Studio), which also recorded the vocal responses through a headset and the manual responses (button press). The intensity of the auditory stimuli was adjusted according to each subject's preference during practice trials.

PWA started with a familiarisation phase where all the one hundred and eight stimuli of the picture naming task were presented in alphabetical order. Participants were asked to name them aloud once. The experimenter gave feedback after each production. If the picture name was incorrect, the experimenter gave the correct answer, and the participant was asked to repeat it.

The picture naming and the auditory detection task were completed alone and then simultaneously. In the dual-task condition, participants had to name pictures while detecting the target syllable /fo/. Importantly, naming latencies were not analysed for the pictures appearing alongside the target syllable. The experimental session lasted about thirty-five minutes.

Auditory detection performed alone and under dual-task condition

In the auditory detection task, participants had to press a key on the keyboard with their dominant hand (except for PWA with hemiplegia who responded with their non-dominant hand) as quickly and accurately as possible when they heard the target syllable /fo/. In the auditory detection performed alone, each stimulus was played after a fixation cross lasting 500 ms. Participants were trained to the detection task with ten practice stimuli including three targets. The auditory detection performed alone included thirty trials including twelve target syllables. Under dual-task condition (naming and hearing), participants also had to press a key on the keyboard with their dominant hand as quickly and accurately as possible when they heard the target syllable /fo/, but the syllables were played at three different SOAs: +150, +300 and +450 ms after the picture to name which was displayed on the screen (see hereafter).

Picture naming performed in naming alone and under dual-task condition

The picture naming task started with ten training items. Participants had to name the pictures presented on the screen as quickly and accurately as possible. Pictures were presented on a black screen at a constant size of 300 x 300 pixels. Each trial started with a fixation cross presented for 500 ms, followed by a picture, which remained on screen for a maximum of 5000 ms. The following trial was launched manually by a mouse click from the experimenter. To avoid response strategies (e.g., waiting for the syllable to be played before naming the picture), the two conditions (naming alone, dual-task conditions) were mixed up and randomly presented. This means that the participants were instructed to name pictures and detect the syllable /fo/ while auditory stimuli did not appear on all trials. Instructions also indicated that both tasks had to be performed simultaneously. Each picture appeared twice, once without a concurrent syllable (naming alone condition) and once with a non-target syllable (naming and hearing, dual-task conditions). Filler items (pictures always associated with the target syllable "fo") were also presented once without a concurrent syllable and once with the target syllable. A total of two hundred and sixteen trials were presented pseudo-randomly (ninety items and eighteen fillers presented in the "naming alone" and under dual-task conditions). The order of the items was pseudo-randomized, so that items from the same semantic category and/or starting with the same first phoneme were not presented consecutively and the two presentations of the same stimuli (naming alone versus dual-task conditions) were separate by at least twenty other items.

PWA started with the auditory detection task alone and then continued with the picture naming task mixing naming alone (no concomitant auditory stimuli) and dual-task (auditory detection in addition) conditions.

Data pre-treatment and analyses

All recorded productions were inspected through the software Check Vocal (CheckVocal 2.2.6; Protopapas, 2007) for accuracy and naming latencies/reaction times (RTs). Correct responses were productions that corresponded to the expected name within five seconds. Expected names preceded by determiners (e.g., "a", "the") or hesitations (e.g., "hum", "uh"), as well as acceptable synonyms, were considered as correct responses, but were excluded from the RTs analyses. All erroneous responses were coded using four categories: lexical errors, phonological errors, phonetic errors and omission errors (no response given within the time interval). Lexical errors included semantically related substitutions (e.g., spider for ant), lexical substitutions without semantic or phonological relationship with the target (e.g., match for windmill), verbal perseverations of a previous item and mixed errors, defined as semantically related words sharing at least half of the phonemes with the target (e.g., "chausson" -slipper- for "chaussette" -socks-). Phonological errors included neologisms (e.g., /nylt/ for watch-montre), phonological substitutions (eg., /DaRot/ for /kaRot/), successive approximations (e.g., "cravate"- tie- produced /akRa/ /adRa/ /kRavat/) and single phoneme substitution generating a semantically unrelated lexical entry (e.g., "bouton" /butɔ̃/ -button- produced /mutɔ̃/ -sheep-). Distorted phonemes and alteration of interphoneme transitions were scored as phonetic errors. Some productions of the patients with apraxia of speech were consistent in the type of transformation (e.g., voicing errors), independently of the condition, these productions were scored as correct. The classification of errors has been verified by a second speech and language therapist.

In order to ensure that all analysed errors corresponded to responses without button press, filler items as well as error trials corresponding to false-positive responses in the auditory detection task were removed from the analyses. For RTs analyses, the naming latencies beyond 3 standard deviations of the participant mean were removed (34 trials out of 3780; 0.90%).

In the picture naming task, naming latencies, overall accuracy and occurrence of each type of error were analysed. Analyses were performed through linear and generalized mixed-effects models respectively (Baayen et al., 2008; Jaeger, 2008), computed with the software RStudio (version 4.0.2) and the packages lme4 version 1.1–13 (Bates et al., 2015), lmerTest (version 2.0–33), languageR (version 1.4.1) using Satterthwaite approximation for degrees of freedom for the F and t statistics, car package for Wald chi-square and the NPL package (Ménétré, 2020). All RTs were log-transformed for the statistical analyses. Mixed-effect models were run with naming latencies (linear mixed-effects model) and on each type of error (generalized mixed-effects model) as dependent variables, and task condition (naming only, SOA +150, SOA +300 and SOA +450) as fixed factors. Items and participants were entered as random factors. For the generalized mixed-effects model, only one model was performed for each type of error. The reference was always the naming only condition and was compared to each SOA.

For the auditory detection task, reaction times were analysed with linear mixed-effects model with task condition (naming alone, +150, +300 and +450) as fixed factors and participants as random factor. Mixed-models with random slopes by participants and by items failed to converge.

For the analyses by type of errors, when two models were performed on the same data, the Bonferroni correction was applied, leading to a lower alpha-level threshold of .025.

Results

Auditory detection task

Under dual-task condition, button press reaction time data for one participant was not recorded due to a technical problem, therefore only twenty PWA were included in the analyses of the auditory detection task. Accuracy and RTs in the auditory detection task were calculated by removing false alarms (button press for non-target syllables) and omission errors (no reaction for target syllables) from the total number of trials (40 trials out of 4920 items). Accuracy was also close to ceiling for all PWA in the auditory detection task performed alone and under dual-task condition (see Table 1). There was a main effect

Table 1. Performance in the auditory detection tasks – RTs (in ms) and accuracy (in % correct).

			Type of error	
	RT	Accuracy	Omission	False alarm
Detection alone	827.18 (44.74)	97.17 (0.05)	0 (0)	2.83 (0.05)
SOA +150	1703.20 (873.92)	99.17 (0.02)	0.42 (0.01)	0.42 (0.01)
SOA +300	1770.64 (504.56)	98.75 (0.04)	0.28 (0.01)	0.97 (0.03)
SOA +450	1885.92 (511.21)	98.89 (0.03)	0.56 (0.02)	0.56 (0.02)

of the condition on RTs, $F(3, 538.94) = 577.48$, $p < .001$. Participants were longer under dual-task condition as compared to the auditory detection performed alone at each SOA, SOA +150 vs detection alone, $t = 28.62$, $\beta = 0.68$, $SE = 0.02$, $p < .001$; SOA +300 vs detection alone, $t = 31.65$, $\beta = 0.75$, $SE = 0.02$, $p < .001$; SOA +450 vs detection alone, $t = 34.30$, $\beta = 0.82$, $SE = 0.02$, $p < .001$. RTs increased with the lengthening of the SOA. As compared to SOA +150, RTs were longer at SOA +300, $t = 2.65$, $\beta = 0.07$, $SE = 0.03$, $p = .008$, and SOA +450, $t = 5.14$, $\beta = 0.14$, $SE = 0.03$, $p < .001$. RTs were also longer at SOA +450 as compared to SOA +300, $t = 2.50$, $\beta = 0.07$, $SE = 0.03$, $p = .013$.

Picture naming

For the picture naming task,[2] trials associated with a button press response were removed from the analyses (407 out of 4536 trials). Naming latencies were longer and accuracy was lower in dual-task conditions as compared to naming alone condition (see Table 2). There was a main effect of condition on RTs, $F(3,2657.5) = 269.68$, $p < .001$. Naming latencies were longer in dual-task condition as compared to the naming alone condition at all SOAs, SOA +150, $t = 19.78$, $\beta = 0.30$, $SE = 0.02$, $p < .001$; SOA +300, $t = 18.95$, $\beta = 0.29$, $SE = 0.02$, $p < .001$, and SOA +450, $t = 20.20$, $\beta = 0.30$, $SE = 0.01$, $p < .001$, without significant difference across SOAs.

The distribution of errors by type of errors for each condition is presented in Table 2 and significant statistical results are presented in Table 3 (see Appendix 2 for the complete results). On phonological errors, the main effect of condition was significant, $X^2(3, N = 21) = 8.40$, $p = .038$. There were significantly more phonological errors at SOA +300 and +450 relative to the naming alone condition, but not at SOA +150. Phonological errors were further analysed to test if there were intrusions of the

Table 2. Performance in the picture naming task – RTs (in ms), accuracy (in % correct) and rate of errors (in %).

	Picture naming		Type of error			
Condition	RT	Accuracy	Phonological errors	Lexical errors	Omission errors	Phonetic errors
Naming alone	1229.13 (630.59)	86.84 (0.34)	7.85 (0.27)	1.54 (0.12)	2.07 (0.14)	1.59 (0.13)
SOA +150	1654.31 (693.05)	83.92 (0.37)	8.60 (0.28)	2.23 (0.15)	3.66 (0.19)	0.96 (0.10)
SOA +300	1647.96 (713.18)	83.23 (0.37)	10.53 (0.31)	1.28 (0.11)	3.19 (0.18)	1.44 (0.12)
SOA +450	1653.74 (736.89)	84.16 (0.37)	10.37 (0.31)	1.75 (0.13)	2.23 (0.15)	1.12 (0.11)

[2]As mixed errors and neologisms could have different origins (Friedmann et al., 2013), analyses were also performed without neologisms and mixed errors. As the results were unchanged, we kept them in the analyses.

Table 3. Results of the generalized mixed-effects model with the type of error as dependent variables, and task condition (naming alone, +150 ms, +300 ms and +450 ms) as fixed factors.

Model on	Contrast	z	β	SE	P-value
Phonological errors (1)	Naming alone vs SOA +150	0.64	0.11	0.18	.525
	Naming alone vs SOA +300	2.37	0.40	0.17	**.018**
	Naming alone vs SOA +450	2.25	0.38	0.17	**.024**
Omission errors (2)	Naming alone vs SOA +150	2.32	0.68	0.29	**.020**
	Naming alone vs SOA +300	1.68	0.51	0.30	.094
	Naming alone vs SOA +450	0.32	0.11	0.34	.748

(1) glmer(PhonologicalErrors~taskcondition+(1|Subjects)+(1|Items)).
(2) glmer(OmissionErrors~taskcondition+(1|Subjects)+(1|Items)).

phonemes that composed the concurrent auditory syllable. Only 0.42% of the total phonological errors comported a phoneme that may be due to an intrusion from the auditory syllable. On omission errors, the overall main effect of condition was not significant, $X^2(3, N = 21) = 6.59$, $p = .086$, but the contrasts indicate an increase of omission errors at SOA +150 as compared to naming alone condition. No effect was observed at SOA +300 and +450. The main effect of condition was not significant for phonetic errors, $X^2(3, N = 21) = 2.12$, $p = .548$, nor for lexical errors, $X^2(3, N = 21) = 2.16$, $p = .539$.

Discussion

The purpose of this experiment was to test whether lexical selection and phonological encoding in picture naming were both impacted by a dual-task performed under divided attention with interfering auditory syllables appearing at different SOAs, likely targeting the timing of different word planning processes. Naming latencies increased under dual-task condition relative to naming alone at each SOA. Phonological errors increased at late SOAs (+300 and +450) while omission errors increased at SOA +150. In the auditory detection task, reaction times were longer under dual-task condition and no effect on accuracy was found.

In the auditory detection task, PWA displayed high accuracy and longer reaction times under dual-task condition, approximately twice as long as in performing the task alone. Given the high accuracy, it seems that the group of PWA did not display specific attentional impairment hindering the detection of auditory stimuli. This assumption is also congruent with the results close to ceiling obtained in the visual detection task in the clinical assessment (see Appendix 1). A larger increase of RTs is observed under dual-task condition in the auditory detection than in the picture naming task. This difference in slowing across tasks suggest that PWA prioritized the picture naming task in the dual-task condition, even if the participants were instructed to perform both tasks simultaneously.

In the picture naming task, an increase in naming latencies was found at each SOA relative to naming alone with no significant difference across SOAs. These results replicate those of a previous study with neurotypical individuals with different SOAs by Fargier and Laganaro (2019). The pattern of reaction times in PWA indicate that they are similarly interfered in terms of processing speed under dual-task condition at each SOA. The crucial result here then is the differential impact of each SOA on type of error, which we will discuss in more depth.

Under dual-task conditions, phonological errors increased at SOA +300 and +450. The result at SOA +300 confirms an impact of dual-task on phonological processes when concurrent syllables are presented at SOA +300, as already reported for PWA in Laganaro et al. (2019). The increase of phonological errors observed at SOA +450 is also in line with the temporal estimates by Indefrey and Levelt (2004), with these two late SOAs being associated with phonological and phonetic encoding. Therefore, the increase of phonological errors at these two late SOAs further suggests (1) that post-lexical processes require attentional resources and (2) that phonological processes occur at these later time-windows.

An increase of omission errors was found at SOA +150. This category of errors includes two types of responses: utterance produced after five seconds or no utterance produced at all. In the absence of any attempt to produce, it is difficult to identify the origin of this type of error. Omission errors have been previously associated with lexical-semantic deficits (Bormann et al., 2008; Chen et al., 2019; Dell et al.,2004). Under this type of interpretation of the origin of omission errors, the overall pattern of results of PWA seems in line with the time-course of word encoding processes as suggested by psycholinguistic studies (Indefrey & Levelt, 2004; Indefrey, 2011), with a shift from omission errors to phonological errors with increasing SOAs. However, other authors (Dell, 1986; Schwartz & Brecher, 2000) suggested that omission errors could originate from impaired phonological encoding, i.e., difficulties to retrieve or assemble the target-phonemes, which are suppressed by monitoring processes. Given the different timing of omission errors and of phonological errors in the present study, this latter interpretation seems less likely and we assume that omission errors -at least in this specific paradigm – primarily have a lexical origin.

It might seem surprising that only omission errors increased at SOA+150 but not lexical errors, especially as this pattern is not consistent with the results of Murray (2000) who found an increase of semantic errors when both tasks were presented simultaneously. There are two possible explanations to this discrepancy: the tasks and the profile of PWA. Our task differs from Murray's study (2000), in which participants had to complete a sentence with one word while in the present experiment they performed a picture naming task. In addition, in Murray's study, the second task (tone discrimination) was presented at the same time as the first task (SOA = 0 ms). Although lexical selection is performed around 150 ms in the estimated time-course used to determine the SOAs in the present experiment, it is possible that an SOA of 0 ms would also have an impact on lexical selection, given that the auditory syllables last 280 ms. However, the absence of lexical errors could also be due to the anomic profile of the PWA. In the present study, PWA suffered from mild aphasia and produced a minority of lexical errors as compared to phonological errors both in the picture naming task in the naming alone condition (see Table 3) and in the clinical assessment (see Appendix 1); they also overall displayed lower accuracy in tasks targeting phonological processes (for instance words and pseudowords repetition) than in lexical-semantic tasks (such as picture-word matching), see Appendix 1.

Provided that omission errors have a lexical origin as suggested by most authors, the present results on omission and phonological errors suggest that both lexical and phonological encoding processes are impacted under dual-task conditions and require attention. Before any further interpretation about the attentional demand on word planning processes, we turn to Experiment 2, where PWA underwent the same dual-task but under focused attention rather than under divided attention.

Experiment 2

Method

Population

Nineteen PWA (10 women, 9 men; mean age: 59.58; SD: 14.91; see Appendix 1) from Experiment 1 also underwent Experiment 2.

Material

The same material was used as in Experiment 1.

Procedure

PWA underwent Experiment 2 after Experiment 1 with a short break (5-10 minutes) between the two experiments. Experiment 2 was performed under the same conditions as Experiment 1, except that the dual-task was performed under focused attention, meaning that the participants were asked to name the pictures while passively hearing the auditory stimuli. Each list of stimuli was presented in a different order than in Experiment 1. The experimental session lasted about thirty-five minutes.

Data pre-processing and analyses

Same data pre-processing and analyses[3] were done as in Experiment 1, except that there are no analyses of the syllable detection task in the focused dual-task. Following the procedure, 48 trials out of 3420 items (1.40%) were removed.

Results (picture naming)

Table 4. Performance in the picture naming task – RTs (in ms), accuracy (in % correct) and rate of errors (in %).

	Picture naming		Type of error			
Condition	RT	Accuracy	Phonological errors	Lexical errors	Omission errors	Phonetic errors
Naming alone	1093.46 (540.09)	88.41 (0.32)	7.35 (0.26)	1.41 (0.12)	1.29 (0.11)	1.41(0.12)
SOA +150	1227.26 (650.02)	85.51 (0.35)	8.64 (0.28)	1.94 (0.14)	2.65 (0.16)	1.23 (0.11)
SOA +300	1294.91 (714.83)	81.51 (0.39)	13.03 (0.34)	0.70 (0.08)	3.17 (0.18)	1.23 (0.11)
SOA +450	1281.22 (704.24)	83.77 (0.37)	10.76 (0.31)	1.59 (0.13)	3.17 (0.18)	0.71 (0.08)

[3]The experiments were not designed to be analysed together but an analysis was run on the merged data from the two experiments. The interaction between conditions and experiment on RTs was significant. $F(3,5256.2)=31.745$, $p<.001$, thus further motivating the separate analysis of Experiment 1 and Experiment 2.

Table 5. Results of the generalized mixed-effects model with the type of error as dependent variables, and task condition (naming alone, +150 ms, +300 ms and +450 ms) as fixed factors.

Model on	Contrast	z	β	SE	P-value
Phonological errors (1)	Naming alone vs SOA +150	1.10	0.20	0.18	.269
	Naming alone vs SOA +300	4.46	0.74	0.17	**<.001**
	Naming alone vs SOA +450	2.81	0.48	0.17	**.005**
Omission errors (2)	Naming alone vs SOA +150	2.21	0.80	0.36	.027
	Naming alone vs SOA +300	2.99	1.04	0.35	**.003**
	Naming alone vs SOA +450	3.00	1.04	0.35	**.003**

(1) glmer(PhonologicalErrors~taskcondition+(1|Subjects)+(1|Items).
(2) glmer(OmissionErrors~taskcondition+(1|Subjects)+(1|Items).

Naming latencies increased and accuracy[4] decreased in picture naming task under dual-task condition relative to naming alone (see results in Table 4). A main effect of condition was observed on RTs, $F(3, 2523.9) = 87.12$, $p < .001$.

Naming latencies were longer under dual-task condition at all SOAs, naming alone vs SOA +150: t = 8.61, β = 0.11, SE = 0.01, $p < .001$; naming alone vs SOA +300: t = 10.88, β = 0.15, SE = 0.01, $p < .001$ and naming alone vs SOA +450: t = 13.37, β = 0.18; SE = 0.01, $p < .001$. Across SOAs, naming latencies were longer at SOA +300, t = 2.04, β = 0.03, SE = 0.02, $p = .044$, and +450, t = 3.91, β = 0.06, SE = 0.02, $p < .001$, as compared to SOA +150. Naming latencies did not differ between SOA +300 and SOA +450, t = 1.82, β = 0.03, SE = 0.02, $p = .068$.

The distribution of errors by type of error for each condition is presented in Table 4 and significant statistical results in Table 5 (see Appendix 3 for the complete results). No main effect of condition appeared on lexical errors nor on phonetic errors, $X^2(3, N = 19) = 3.49$, $p = .322$, and, $X^2(3, N = 19) = 1.81$, $p = .613$, respectively. For omission errors, the main effect of condition was significant, $X^2(3, N = 19) = 13.06$, $p = .004$. Omission errors increased at all SOAs relative to naming alone, but this effect was marginal at SOA +150 under Bonferroni correction (see Table 5). On phonological errors a main effect of condition was found, $X^2(3, N = 19) = 22.24$, $p < .001$. The increase of phonological errors was observed at SOA +300 and +450, but not at SOA +150 (see Table 5). As in Experiment 1, phonological errors were analysed for intrusions of the phoneme that composed the concurrent auditory syllables. Only 0.44% of the total phonological errors comported an error that may be attributed to intrusion of a phoneme from the auditory syllable.

Discussion

In the Experiment 2, the dual-task was performed under focused attention, i.e., pictures were named while passively hearing auditory syllables. Naming latencies increased under dual-task at each SOA as compared to the naming alone condition. An increase of phonological errors was observed at late SOAs (+300 and +450), but omission errors increased at each SOA (although marginally at SOA +150). The present pattern of results with regard to phonological errors is thus similar to the first experiment under divided attention, whereas increased omission errors are observed also at late SOAs only under focused attention. As the results on errors will be further discussed by integrating the

[4]As mixed errors and neologisms could have different origins (Friedmann et al., 2013), analyses were also performed without neologisms and mixed errors: the results were unchanged and we kept these errors in the analyses.

results of the two experiments in the General Discussion, we discuss here only the results on naming latencies.

A dual-task interference was observed in terms of naming latencies increasing at each SOA as compared to picture naming without concurrent auditory syllables. These results are only partially in line with previous research conducted under focused attention. Three decades ago, Schriefers et al. (1990) investigated the picture-word interference paradigm with different types of auditory distractors presented at different SOAs (0, +150 and +300) in neurotypical individuals. Unrelated words delayed naming latencies relative to silence at SOA 0 and SOA +150, but no effect on RTs was observed at SOA +300. Whereas picture word interference tasks are usually aimed at investigating the effect of semantic and/or phonological relationship between the target word and the distractor, the task is also a condition of focused attention and the results on unrelated words relative to silence reported by Schriefers et al. (1990) indicate that any auditory stimulus interferes with picture naming. Although null results have been reported at SOA +300 in Schriefers et al. (1990), in recent studies (Fargier & Laganaro, 2016, 2019) using a dual-task paradigm performed under focused attention condition, naming latencies increased at SOA +300, as in the present study. Finally, naming latencies increased in dual-task condition under focused attention, but the average increase was 249 ms less than in Experiment 1 under divided attention, suggesting participants were less interfered under focused attention, than under divided attention. This issue will be discussed in detail in the General discussion.

The pattern of errors (phonological and omission errors) appearing at specific SOAs and increased naming latencies at all SOAs under focused attention condition speak in favour of attentional control involved both in lexical and phonological encoding processes, similar to what was observed under divided attention (Experiment 1), although with some differences in the results, that will be discussed in the next section.

General discussion

The aims of the study were to determine whether dual-task interference on lexical processes and phonological encoding can be found within the same study but is modulated (i) by the timing of the concurrent task (SOA) that target the timing of the word planning processes and (ii) by the attentional requirement (divided vs focused attention).

To address the two aims, PWA performed a picture naming task while detecting a target auditory syllable (divided attention, Experiment 1), with syllables presented at three different SOAs (+150, +300, +450), that have been chosen to match the estimated time-course of different processes underlying word production. In Experiment 2 the same task was performed under focused attention, i.e., auditory syllables could be ignored.

In the two experiments, an impact of the dual-task condition was found with longer naming latencies at each SOA as compared to the naming alone condition. Phonological errors increased at late SOAs (+300 and +450) in both experiments, while the increase of omission errors under dual-task condition differed across Experiment 1 and 2. Omission errors increased only at SOA +150 under divided attention whereas they increased at each SOA under focused attention (although marginally at SOA +150).

Overall, the results confirm that both lexical and phonological errors arise under dual-task conditions within a single experiment. They also indicate that the impact of dual-task conditions on lexical and phonological encoding is modulated by the SOA and some aspects by the attentional requirement of the task. An increase in naming latencies was observed in all dual-task conditions and has been already discussed above, here we will rather focus on the results by type of errors that were more specifically modulated by the dual-task conditions. In the following, we will first discuss the attentional demand on lexical selection and post-lexical processes by considering the results by type of errors before discussing the temporal dynamic in word planning processes.

Lexical processes

Whereas the rate of lexical or semantic errors was not modulated by the dual-task, omission errors increased specifically at SOA +150 under divided attention and at each SOA (mainly at SOA +300 and +450) under focused attention. The increase of omission errors at SOA +150 in Experiment 1 is consistent with a lexical-semantic origin of this type of error (see Discussion of Experiment 1), but the increase of omission errors at each SOA in Experiment 2 was unexpected. As a reminder, omission errors included no answers and responses produced after five seconds. Even if RTs were qualitatively shorter in Experiment 2 relative to Experiment 1, PWA may have used the strategy of waiting the auditory stimuli to be played before naming the picture in order to be less interfered, which would involve that they produced the response out of time. Tiredness of PWA in the second experiment, along with intra-individual variations in attention or the repetition effect (Shields & Balota, 1991) could also have an impact on the increase of omission errors. Finally, due to the repeated activation of the items across experiments, the increase of omission errors could also be explained by the refractory inhibition hypothesis (McCarthy & Kartsounis, 2006; Schnur et al., 2005). According to this hypothesis, the post-selection inhibition of lexical nodes is pathologically longer in PWA, resulting in increasing omission errors when they have to be produced again. The observation that omission errors increase in Experiment 2 as compared to Experiment 1 while other errors do not increase with repetition is in line with the predictions of the refractory inhibition hypothesis. However, this hypothesis could not explain the increase of omission error in dual-task (and mainly at SOA +300 and +450) relative to naming in single task. These results are quite complex to interpret as there was no statistical comparison between the experiments, the order of the experiment was not counter-balanced and participants were not exactly the same across experiments.

In divided attention, the increase of omission errors at SOA +150, likely targeting lexical selection, suggests that lexical processes require some attentional resources as already claimed in previous studies (Garrod & Pickering, 2007; Roelofs, 2008). However, the increase of omission errors at SOA +150 was observed only in divided attention, but not in focused attention, suggesting that lexical processes are sensitive to the kind of attention involved, this point will be further discussed below.

Post-lexical processes

The results by type of error indicated an increase of phonological errors at late SOAs (+300 & +450) in both experiments. These results replicate those of a previous study in PWA using an SOA of +300 (Laganaro et al., 2019), but also show that interference with regard to phonological errors can be observed at later SOA, namely +450. Very few phonological errors (less than 0.5%) may be attributed to an intrusion of a phoneme from the concurrent auditory syllable, meaning that the interference impacts the word encoding processes themselves.

Besides replicating previous results at SOA+300, the present study also confirms empirically that phonological errors do not increase at earlier SOAs (here +150) and may therefore explain the absence of phonological errors in the study by Murray (2000), where the concurrent stimuli were presented simultaneously with the word production task. Although error rates are quite small, which is in line with the mild impairment of the included patients, they increase of at least +3% at SOA +300 and +450 in both experiments: the results on the increase of phonological errors are thus quite consistent across experiments and further corroborate that phonological encoding processes require attention and are impacted only at SOA > +300 ms.

Attention and its relation to word production

The attentional requirement of the dual-task differed across experiment: Experiment 1 was performed under divided attention condition and Experiment 2 under focused attention. In the study by Murray (2000), the increase of lexical errors was observed in both attentional requirement conditions. Here, as discussed in the previous section, the effect of dual-task on lexical processes was observed in both experiments, but the increase of omission errors was marginal at SOA +150 in Experiment 2, suggesting that lexical processes were not impacted in the same way depending on the type of attentional requirement. Also, while in Laganaro et al. (2019), the increase of phonological errors was observed only under divided attention, in the present study phonological errors increased in both experiments. As the results do not converge across studies on the effect of the type of attention and in particular on the impact of a passive dual-task (focused attention), it is difficult to conclude on the type of attentional requirement on word planning processes, and further investigations are needed to shed light on this issue.

Temporal dynamics in word production

One key point of the methodology used in the present study was to manipulate the SOAs based on the temporal estimates by Indefrey and Levelt (2004, Indefrey, 2011). However, such estimates are based on production latencies of around 600 ms and on groups of (young) neurotypical speakers, while here, word production in naming alone was around 1150 ms. Given this difference, one may wonder whether the SOAs tapped into the same processes in the PWA. However, the increase of phonological errors replicates the previous finding of Laganaro et al. (2019) at the same SOA (+300) and is consistent with the temporal estimations of Indefrey (2011). The increase of omission errors at SOA +150 in divided attention is also consistent with the temporal dynamic, as omission errors can be interpreted with a lexical-semantic origin. By contrast, under focused attention condition, omission errors increased at each SOA (weakly at SOA +150), which is not congruent with the estimate timing of lexical selection and/or with the interpretation of omission errors as arising during lexical selection. The increase of phonological errors at SOA +450 also seems to occur a bit later than expected from those temporals estimates, a result that could be linked to a shift or to a lengthening of post-lexical processes in PWA.

Conclusion

The present study clearly showed that lexical and phonological processes were impacted under focused and divided attention, giving rise to an increase of specific types of errors (relative to production under single/standard task) at specific SOAs, thus indicating that interference in lexical and phonological encoding depends on the timing of the concurrent task. Such results allowed to reconcile some previous contradictory reports about the attentional demand involved in lexical and post-lexical processes. Further studies are needed to identify the effect of other factors such as stimulus type on the interference on lexical and phonological processes.

Clinical implications

The examination of how the interference in word production under dual-task condition is modulated by different parameters has potential implications for clinical practice. Indeed, several patients suffered from very mild anomia when assessed with the standard single task procedure, but increased their errors up to 14% under dual-task conditions. As word planning processes are sensitive to interference and speaking in everyday life is mostly done under dual-task conditions, developing assessment tasks performed under dual-task conditions may be pertinent to highlight anomia under quasi real-life conditions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Declaration of interest statement

The authors confirm the absence of any conflict of interest.

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Appendix 1. Overview of the demographic and clinical assessments for PWA. Clinical assessment was done with the French screening battery BECLA, (Macoir et al., 2016), with the experimental tasks described in the method section. For each BECLA's subtest, accuracy is reported in percentage, and scores beyond the percentile 5 are emboldened.

					Clinical assessment (BECLA, Macoir et al., 2016)						Experimental tasks				
						Repetition		Oral comprehension	Semantic		Visual detection		Familiarisation	Experiment performed	
Participant	Age	Sex	Type of stroke	MPO	Naming /20	Words /15	Pseudo-words /10	Words /20	Pictures /20	Words /20	Accuracy	Reaction times	Accuracy	1	2
P1	43	F	Ischemic	51	100%	**93**%	100%	100%	100%	100%	97%	521.58	93% (L : 4.4% ; P : 1.1% ; O :1.1%)	X	X
P2	73	H	Ischemic	6	90%	**67**%	**50**%	100%	100%	100%	100%	384.83	82% (L :3.3% ; P :14.4% ; O :0%)		X
P3	46	F	hemorrhagic	59	85%	100%	90%	100%	**90**%	95%	100%	533.58	63% (L :8.9% ; P :8.9% ; O :18.9%)	X	X
P4	53	F	hemorrhagic	72	95%	100%	**70**%	100%	95%	100%	100%	1052.50	72% (L :0% ; P :0% ; O :27.8%)	X	X
P5	73	H	hemorrhagic	6	95%	100%	**60**%	**95**%	95%	100%	97%	594.18	74% (L :5.6% ; P :10% ; O :8.9%)	X	X
P6	72	H	Ischemic	11	95%	**87**%	**70**%	100%	95%	95%	100%	1139.67	60% (L :8.9% ; P :16.7% ; O :13.3%)	X	X
P7	58	H	Ischemic	4	100%	100%	100%	100%	100%	100%	100%	571.50	87% (L :4.4% ; P :6.7% ; O :2.2%)	X	X
P8	71	H	Ischemic	9	**85%**	100%	90%	100%	95%	100%	100%	683.75	74% (L :5.6% ; P :12.2% ; O :5.6%)	X	
P9	61	F	Ischemic	146	90%	100%	100%	**90**%	95%	**85**%	100%	588.58	69% (L :6.7% ; P :2.2% ; O :22.2%)	X	X

(*Continued*)

Appendix 1. (Continued).

					Clinical assessment (BECLA, Macoir et al., 2016)						Experimental tasks				
						Repetition		Oral comprehension	Semantic		Visual detection		Familiarisation	Experiment performed	
Participant	Age	Sex	Type of stroke	MPO	Naming /20	Words /15	Pseudo-words /10	Words /20	Pictures /20	Words /20	Accuracy	Reaction times	Accuracy	1	2
P10	60	H	Ischemic	4	90%	**73**%	90%	**95**%	100%	100%	100%	630.92	50% (L :3.3% ; P :41.1% ; O :4.4%)	X	X
P11	43	F	hemorrhagic	23	**80**%	100%	**80**%	100%	100%	100%	100%	1074.75	83% (L :2.2% ; P :5.6% ; O :1.1%)	X	
P12	66	H	Ischemic	22	90%	**80**%	**40**%	100%	100%	100%	100%	592.33	74% (L :5.6% ; P :11.1% ; O :8.9%)	X	X
P13	70	H	Ischemic	7	**85**%	100%	100%	**95**%	95%	**90**%	100%	480.58	77% (L :11.1% ; P :5.6% ; O :6.7%)	X	X
P14	78	F	Ischemic	21	90%	93%	**70**%	100%	100%	100%	97%	1042.00	86% (L :4.4% ; P :7.8% ; O :2.2%)	X	X
P15	77	F	hemorrhagic	4	90%	**87**%	**60**%	100%	100%	100%	100%	627.42	80% (L :11.1% ; P :6.7% ; O :2.2%)	X	
P16	85	F	Ischemic	3	**65**%	NA	NA	**92**%	**85**%	NA	100%	1183.08	66% (L :14.4% ; P :6.7% ; O :13.3%)	X	X
P17	66	H	Ischemic	32	90%	100%	100%	100%	**90**%	100%	90%	654.55	91% (L :4.4% ; P :1.1% ; O :2.2%)	X	X
P18	52	F	Ischemic	30	**85**%	100%	100%	100%	100%	**85**%	100%	569.83	84% (L :1.1% ; P :11.1% ; O :3.3%)	X	X

(Continued)

Appendix 1. (Continued).

					Clinical assessment (BECLA, Macoir et al., 2016)						Experimental tasks				
						Repetition		Oral comprehension	Semantic		Visual detection		Familiarisation	Experiment performed	
Participant	Age	Sex	Type of stroke	MPO	Naming /20	Words /15	Pseudo-words /10	Words /20	Pictures /20	Words /20	Accuracy	Reaction times	Accuracy	1	2
P19	32	F	Ischemic	204	90%	**87**%	90%	100%	100%	100%	100%	593.50	91% (L :1.1% ; P :2.2% ; O :5.6%)	X	X
P20	53	H	Ischemic	16	95%	**87**%	**80**%	100%	100%	95%	100%	359.42	96% (L :3.3% ; P :0% ; O :1.1%)	X	X
P21	29	F	Ischemic	14	100%	100%	**80**%	**95**%	95%	100%	100%	468.08	89% (L :7.8% ; P :0% ; O :3.3%)	X	X
P22	62	F	Ischemic	16	**85**%	**87**%	**50%**	100%	100%	100%	100%	619.33	83% (L :6.7% ; P :1.1% ; O :8.9%)	X	X

MPO: month post-onset; L: lexical errors; P: phonological errors; O: omission errors

Appendix 2. Results of the generalized mixed-effects models on type of error dependent variable, and task condition (naming alone, +150 ms, +300 ms and +450 ms) as fixed factors in picture naming task in Experiment 1

Model on	Contrast	z	β	SE	P-value
Phonological errors (N=333) (1)	Naming alone vs SOA +150	0.64	0.11	0.18	.525
	Naming alone vs SOA +300	2.37	0.40	0.17	**.018**
	Naming alone vs SOA +450	2.25	0.38	0.17	**.024**
Omission errors (N=96) (2)	Naming alone vs SOA +150	2.32	0.68	0.29	**.020**
	Naming alone vs SOA +300	1.68	0.51	0.30	.094
	Naming alone vs SOA +450	0.32	0.11	0.34	.748
Lexical errors (N=62) (3)	Naming alone vs SOA +150	1.20	0.41-	0.34	.229
	Naming alone vs SOA +300	-0.49	-0.20	0.41	.627
	Naming alone vs SOA +450	0.35	0.13	0.35	.727
Phonetic errors (N=52) (4)	Naming alone vs SOA +150	-1.31	-0.64	0.49	.189
	Naming alone vs SOA +300	-0.27	-0.11	0.42	.788
	Naming alone vs SOA +450	-0.84	-0.38	0.46	.399

(1) glmer(PhonologicalErrors~taskcondition+(1|Subjects)+(1|Items).
(2) glmer(OmissionErrors~taskcondition+(1|Subjects)+(1|Items).
(3) glmer(LexicalErrors~taskcondition+(1|Subjects)+(1|Items).
(4) glmer(PhoneticErrors~taskcondition+(1|Subjects)+(1|Items).

Appendix 3. Results of the generalized mixed-effects model on type of error as dependent variable, and task condition (naming alone, +150 ms, +300 ms and +450 ms) as fixed factors in picture naming task in Experiment 2

Model on	Contrast	z	β	SE	P-value
Phonological errors (N=309) (1)	Naming alone vs SOA +150	1.11	0.20	0.18	.269
	Naming alone vs SOA +300	4.46	0.74	0.17	**<.001**
	Naming alone vs SOA +450	2.81	0.48	0.17	**.005**
Omission errors (N=73) (2)	Naming alone vs SOA +150	2.22	0.80	0.36	.027
	Naming alone vs SOA +300	3.00	1.04	0.35	**.003**
	Naming alone vs SOA +450	3.01	1.04	0.35	**.003**
Lexical errors (N=48) (3)	Naming alone vs SOA +150	0.95	0.36	0.38	.345
	Naming alone vs SOA +300	-1.36	-0.75	0.55	.175
	Naming alone vs SOA +450	0.31	0.13	0.41	.754
Phonetic errors (N=42) (4)	Naming alone vs SOA +150	-0.29	-0.13	0.45	.770
	Naming alone vs SOA +300	-0.36	-0.16	0.45	.717
	Naming alone vs SOA +450	-1.34	-0.74	0.56	.181

(1) glmer(PhonologicalErrors~taskcondition+(1|Subjects)+(1|Items).
(2) glmer(OmissionErrors~taskcondition+(1|Subjects)+(1|Items).
(3) glmer(LexicalErrors~taskcondition+(1|Subjects)+(1|Items).
(4) glmer(PhoneticErrors~taskcondition+(1|Subjects)+(1|Items).