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# Origin of phoneme substitution and phoneme movement errors in aphasia

Marina Laganaro[1, 2] and Carmel Zimmermann[1]

*1. Division of Neurorehabilitation, Geneva University Hospital and University of Geneva*

*2. Inst. Sciences du Langage, Logopédie, FLSH, University of Neuchâtel, Switzerland*

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Corresponding Author:

Marina Laganaro

FLSH, Inst. Sciences du Langage, Logopédie

Université de Neuchâtel

1, Espace Louis-Agassiz

CH-2000 Neuchâtel

E-mail: marina.laganaro@unine.ch

**Abstract**

Despite a general consensus about the lexical-phonological origin of phonological errors, a debate persists concerning a single or multiple origins of such errors. In particular, a similar post-lexical origin has been attributed to milder phonological paraphasias, such as phoneme substitution errors, and to normal slips of the tongue. However, most slips of the tongue have a contextual origin, while most phonological paraphasias are not contextual errors. Here we explore the possibility that even at post-lexical encoding levels different errors are generated by distinct processes. We take advantage of the production of an unusual proportion of within-word phoneme movement errors in a patient with conduction aphasia (SJ) and tackle the question of their origin in comparison to phoneme substitution errors. Error properties relative to phoneme substitution and phoneme movement errors produced by SJ were analysed and compared to those of a second patient (GF) who produced a similar proportion of substitution errors but no movement errors. Very similar profiles between the two patients emerged on substitution errors, while phoneme movement errors displayed different properties.

The observation that substitution and movement errors are not affected by the same factors favours a different origin of these errors. The sub-lexical frequency and similarity effects and the lexical bias in substitution errors indicate an interaction between multiple encoding levels during the production of these errors; by contrast, movement errors seem related to a different and independent process bearing no interaction with other levels of representation.

Keywords: phonological encoding, aphasia, phoneme substitution, phoneme movement

## Introduction

Phonological errors (phonological paraphasias) produced by aphasic speakers include a variety of types of errors with different degrees of severity (distance from the target word). The severity of phonological errors varies from the transformation of a single segment to the production of non-words displaying limited phonological overlap with the target word (neologisms). In all cases, phonological paraphasias include several kinds of transformations, such as phoneme substitution, omission, addition and movement errors (metatheses and shifts).

Phonological errors are traditionally defined in contrast to phonetic errors, associated with the speech of dysfluent aphasia (Lecours and Lhermitte, 1969; Blumstein, Cooper, Goodglass, Statlender and Gottlieb, 1980; Nespoulous, Joanette, Ska, Caplan & Lecours, 1987). The latter have been ascribed to the level of phonetic encoding or articulatory programming (Code, 1998; Darley, Aronson and Brown, 1975; Varley and Whiteside, 2001; Blumstein, 1990), while phonological errors are thought to originate during earlier encoding processes.

Despite the consensus that phonological errors arise during the encoding of word form, different proposals have been made concerning the origin of phonological paraphasias. A first point of disagreement is whether multiple processes or a single process are involved in the generation of phonological errors. Phonological errors may arise either at “lexical-phonological” or at “post-lexical” encoding levels in models where multiple origins are proposed. For instance, different origins have been suggested for more severe (distant) transformations, such as neologisms, and for milder (closer) transformations such as single phoneme transformation (Kohn and Smith 1994, see also Butterworth, 1992) or for errors arising only in tasks involving lexical selection (picture naming) and those arising also in repetition and reading (Goldrick and Rapp, 2007). Although the representation and processes attributed to the proposed encoding levels vary according to the different theoretical positions, in most accounts the lexical-phonological level includes the retrieval of suprasegmental information and segmental representation. The segmental representation is either totally underspecified (Béland, Caplan and Nespoulos, 1990; Kohn and Smith, 1994) or phonological features are partially specified along with segmental representation in other theoretical proposals (Levelt, Roelofs and Meyer, 1999). During post-lexical encoding the retrieved phonological information is ordered and feature specification is completed in order to build an articulation plan.

In the framework of the multiple origins of phonological errors, only the “milder” type of phonological errors in aphasia are thought to have the same post-lexical origin as phonological slips of the tongue (Shattuck-Hufnagel, 1979; Levelt, 1989; Levelt et al., 1999), while a different origin is attributed to more severe phonological transformations (neologisms), which are specific to aphasic transformations only. The latter errors are attributed to impaired access to stored suprasegmental and/or segmental information. The missing information is either omitted or “reconstructed” through a mechanisms attributing phonological information by default (Butterworth, 1992; Kohn and Smith, 1994). At the post-lexical level, phonological errors arise when the retrieved information is mis-ordered or lost, or because feature specification fails.

Against multiple origins of phonological errors, a single account for all kinds of errors has been proposed in the framework of connectionist models (Dell, Schwartz, Martin, Saffran and Gagnon, 1997; Foygel and Dell, 2000; Schwartz, Wilshire, Gagnon and Polansky, 2004). In these models, all phonological errors are generated by mis-selection of phonemes. Mis-selection is due either to impaired connection weights between lexical and phonological nodes (Foygel and Dell, 2000) or to impaired connection weights or decay rates throughout the whole production system (Dell et al., 1997). In this kind of proposal, the distance of the phonological error from the target word is tied to the severity of the impairment rather then to different underlying processes generating the errors and aphasic errors have the same origin as normal slips of the tongue.

The debate between single or multiple origins of phonological paraphasias is articulated around the variables affecting one type of error or the other (milder or more severe phonological transformations). Indeed, errors arising at the post-lexical level should not be sensitive to lexical variables, such as lexical frequency; conversely, errors generated at lexical-phonological level should not be affected by phonological variables like feature similarity between target and error or phonological complexity. On the one hand, studies in the framework of the double or multiple origin have attempted to demonstrate that distinct factors affect different kinds of errors, for instance neologisms and milder phonological errors, or errors produced by fluent and dysfluent aphasic patients (Valdois, 1990; Kohn and Smith, 1994, 1995; Kohn, Melvold and Shipper, 1998; Wilshire and McCarthy, 1996; Romani and Calabrese, 1998; Romani and Galluzzi, 2005). On the other hand, studies in the framework of interactive activation models have sought to show that all kinds of errors are affected by the same lexical and phonological variables (Wilshire, 2002; Schwartz, Wilshire, Gagnon, and Polansky, 2004; Olson, Romani and Halloran, 2007).

An alternative way of testing a single versus multiple origin of phonological errors could be the analysis of different kinds of errors within the mild phonological paraphasias. For instance, single phoneme substitution and phoneme movement errors, i.e. errors in which all target phonemes are preserved, represent mild phonological errors. In particular, the kind of errors in which all phonemes have been correctly selected but mis-ordered, such as in phoneme movement errors, is most likely to occur at a post-lexical level, after correct segmental retrieval, while phoneme substitution, even of a single phoneme, might originate at either level (either because of missing or of mis-selected segmental information at lexical-phonological level or because information is lost or features are mis-selected at post-lexical level). A third category of "mild" phonological paraphasias, consisting of phoneme anticipations and perseverations, is situated between phoneme movement and phoneme substitution errors. Indeed, phoneme substitution errors in which the source of the errors can be identified within the intended word or sentence (another phoneme from the target word or from the preceding or following words replaces the target phoneme) are thought to have a contextual (syntagmatic) origin, like phoneme movement errors. However, each phoneme anticipation and perseveration error is not bound to have a contextual origin, since it could be generated by the random substitution of a phoneme which incidentally also appears in the target word (therefore resembling a syntagmatic error). Contextual errors, i.e. errors in which the source can be identified within the intended sentence represent the main proportion of phoneme substitution errors in non-aphasic speech errors (mainly phoneme anticipation and perseveration). For instance, 94% of phonological slips of the tongue produced by French speakers have a contextual origin (Rossi and Peter-Defare, 1998). This contextual origin of phoneme substitution errors in slips of the tongue constitutes the main argument in favour of a post-lexical locus of these errors. The interpretation of anticipations and perseverations is that segments are correctly selected but they are mis-ordered when they are assembled with a word frame (Shattuck-Hufnagel, 1979; 1992) or when phonetic syllables are addressed from an abstract phonological representation (Levelt et al., 1999).

If contextual errors dominate phonological slips of the tongue, the contextual origin of errors in aphasic speakers is less clear, particularly when errors are observed during single word production. The rate of contextual errors in aphasic speakers has been analysed in depth by Wilshire (2002) with a large corpus of errors. The proportion of contextual errors was very low, not significantly different from chance. Only 3 out of 25 subjects in the analysis carried out by Wilshire (two in study 1 and one in study 2) produced a rate of contextual errors beyond chance. On the other hand their errors did not differ from those produced by other

patients on all other analysed properties (length effect, word position effect). The similarity between contextual and non-contextual errors in that study constituted an argument against a multiple origins of phonological paraphasias.

If the contextual origin of phoneme anticipation and perseverations errors is not straightforward, metatheses (exchange between two phonemes) and other phoneme movement errors (shift of a phoneme in other positions in the word) have a clearer contextual origin, since the error preserves all the target phonemes. Metatheses are quite rare in slips of the tongue: they represent about 7% of sub-lexical errors in the French corpus (Rossi and Peter-Defare, 1998). Metatheses are rare in aphasic errors as well: for example, Wilshire (2002, study 1) found only 6 exchange errors (1.3% of all phonological errors) in the errors elicited with a picture naming task in 18 aphasic subjects and no phoneme movement errors were found by Kohn and Smith (1990) in connected speech. However, a single case reporting the occurrence of an exceptional rate of methatheses has also been described: Prunet, Béland and Idrissi (2000) reported the case of a bilingual Arabic patient producing a high rate of metatheses in Arabic (21% in picture naming and 32% in reading and repetition), but only a limited number of such errors in French.

In sum, the debate about a multiple or single origin of phonological paraphasias is based on the analyses of errors which do not have a clear contextual origin. Conversely, phonological slips of the tongue, which are supposed to have a post-lexical origin in models proposing multiple origins do have a contextual origin. The analysis of aphasic errors preserving all the target phonemes, such as within-word phoneme movement errors, would allow a more equitable comparison with normal slips of the tongue. If all mild phonological transformations have the same origin, phoneme movement errors and phoneme substitutions should be affected by the same factors.

In this study we exploit a high proportion of metatheses and shifts produced by an aphasic speaker in single word production in order to carry out a systematic comparison between phoneme substitution and phoneme movement errors. If substitution errors may potentially occur at different levels of the encoding process as illustrated above, within-word phoneme movement errors are more likely to be originated by mis-ordering of correctly selected phonemes. Therefore, observing that phoneme substitution and phoneme movement errors display the same patterns and are affected by the same factors would favour a single origin for these errors. Conversely, the observation that these two kinds of errors have different properties would constitute an argument in favour of multiple origins of phonological errors.

Among the wide range of properties of error which may be investigated, we carried out two sets of analysis. We first computed a preliminary analysis of the effect of lexical and post-lexical variables on production accuracy. A second set of analyses was performed on phoneme movements and phoneme substitution errors and was aimed to assess whether lexicality (lexical bias), feature similarity and sub-lexical frequencies affected each kind of error. Besides the comparison between movement errors and substitution errors produced by the patient SJ and in order to assess the reliability of the analyses carried out, we included an analysis of the substitution errors produced by a second subject with conduction aphasia (GF), who produced a similar proportion of substitution errors as SJ but very few movement errors.

**Case reports**

The two subjects in the study presented with a diagnosis of conduction aphasia following left hemispheric stroke and were in the post-acute stage.

SJ is a 55-year-old native French-speaking but multilingual financial administrator who suffered a CVA four months before the beginning of this study. MRI image obtained 10 days after stroke revealed a left superficial ischemic lesion in the temporal-parietal region. The first language assessment carried out a few days after stroke reported severely reduced oral expression with a verbal stereotypy, onomatopoeia and very impaired repetition. Comprehension was relatively preserved and severe agraphia was described.

In depth neuropsychological assessment was carried out at the moment of the study. Spontaneous production as well as description was fluent, not very informative because of word-finding difficulties, phonological transformations and the production of *conduites d'approche* (phonologically oriented sequences). Picture naming was very impaired (19% correct on an easy naming task, 37% correct on monosyllabic words, 13% on disyllabic and 0% on trisyllabic words) and was characterized by *conduites d'approche*, sometimes reaching the target word, and neologisms. Repetition and oral reading were correct on 50% of monosyllabic words (30+/60) and performance decreased with length. Verbal fluency was moderately impaired in the semantic condition and severely impaired in the phonological condition. Auditory and written comprehension were preserved for single words and for simple sentences (Montreal-Toulouse 86 Aphasia Battery, Nespoulous, et al., 1992), but some

errors were observed on complex sentences and texts (French version of the Boston Diagnostic Aphasia Examination, Mazaux and Orgogozo, 1981). Discrimination of minimal pairs was within the normal range (37+/40, Montréal-Toulouse auditory agnosia test, Agniel, Joanette, Doyon and Duchein, 1992), despite an important premorbid auditory loss (~30-40 dB) and performance was in normal range in a lexical decision task. Writing was superior to oral production (80% of correct responses in a written naming task). Some syntactic errors appeared in the production of written sentences. Semantic assessment (Pyramid and Palm Trees Test, Howard and Patterson, 1992) revealed normal performances with pictures and with words.

Calculation was severely impaired except for simple additions. There was no oral apraxia but a residual limb apraxia. In other cognitive domains, there were no signs of visual, spatial agnosia or neglect. Short-term visual memory was in the normal range and long-term memory was in the inferior range on the Rey Complex Figure test (Osterrieth, 1944). Verbal memory was very impaired and difficult to asses in depth. Performances were in the normal range on attention assessment tasks (TEA, Zimmermann and Fimm, 1994) and on auto-activation and mental flexibility tasks (Frises de Luria, Regard, Strauss and Knapp, 1982).

GF is an 80-year-old woman, retired book-binder and a French native speaker. She suffered a left ischemic stroke affecting the left parietal region three months before the study period. Shortly after onset, her spontaneous speech was fluent, grammatically well-formed but not informative and characterised by phonological paraphasias and phonological jargon produced alternately with short, correct and informative sentences. At the time of the study, her spontaneous speech was mostly informative despite many phonological paraphasias. Naming was very impaired (10% correct on an easy naming task, 22% on monosyllabic, 8% on disyllabic and 3% on trisyllabic words) with frequent *conduites d'approche* and phonological paraphasias. The same transformations were observed in reading and repetition (35/60 correct on monosyllabic words). Verbal fluency was in the normal range on semantic condition. Auditory comprehension was unimpaired (Montreal-Toulouse 86 Aphasia Battery, Nespoulous et al., 1992) and discrimination of minimal pairs was preserved (40+/40, Montréal-Toulouse auditory agnosia test, Agniel et al., 1992). Written comprehension was unimpaired for words and simple sentences (Montreal-Toulouse 86 Aphasia Battery, Nespoulous et al., 1992) but text comprehension was moderately impaired (French version of the Boston Diagnostic Aphasia Examination, Mazaux and Orgogozo, 1981). Writing was correct for isolated words and simple sentences. Performances were at ceiling in semantic

tasks (Pyramid and Palm Trees Test, Howard and Patterson, 1992). Calculation was unimpaired only in the written modality. A discrete oral apraxia and mild limb apraxia were observed. GF was oriented in space and time. Neither visual or spatial agnosia nor neglegt were reported. Short-term visual memory and visual recognition were in the normal range (Doors and people test, Baddeley, Emslie, Nimmo-Smith, 1994). Verbal memory was impossible to assess because of the importance of phonological impairment. Performances were within normal range on attention tests (D2, Brickenkamp and Zillmer, 1998, TMTA, Reitan and Wolfson, 1985). Very discrete impairment was reported on figural fluency (Regard et al., 1982) and Trail Making tests (Reitan and Wolfson, 1985).

In sum, SJ and GF presented typical profiles of conduction aphasia with impaired phonological encoding at the forefront. Their performances were similar in naming and repetition with a length effect and mostly phonological paraphasias in all verbal output tasks with virtually no other kinds of errors. Both of them received out-patient language therapy during the study period.

## Method

As the aim of the study was to analyse a corpus of phonological paraphasias produced on single words, errors were elicited in a naming task for both aphasic patients. Additional errors were elicited with specific material for SJ only.

*Eliciting phonological errors: naming*

Each subject underwent a picture naming task composed of 120 pictures corresponding to 60 monosyllabic and 60 bisyllabic words, selected from a French database (Alario and Ferrand, 1999). Several pre-linguistic and linguistic variables were available from the same database (image complexity, familiarity and age of acquisition of words). Lexical frequency, syllable frequency, phoneme frequency were taken from the database Lexique (New, Pallier, Ferrand, and Matos, 2001) and phonological neighbourhood from VoCoLex (Dufour, Peereman, Pallier, and Radeau, 2002).

Picture naming was performed five times over a period of two months on the entire naming material, except two sessions in which only half of the items were presented to SJ.

*Eliciting additional movement errors in SJ*

The following reading and naming tasks were used in order to seek additional movement errors in SJ. The syllabic structure of the eliciting material was manipulated in order to allow consonant exchanges in monosyllabic (CVC) and disyllabic words (CV.CVC), since this kind of error was observed in the naming task, but there were not enough CVC syllables to enable intra-syllabic consonant exchange errors.

a. Reading 240 monosyllabic CVC words and 150 disyllabic CV.CVC words.

b. Naming and reading 50 monosyllabic CVC words and 50 disyllabic CV.CVC words.

These tasks were carried out in different sessions over a period of three weeks overlapping with the end of previous testing period.

*Scoring*

All productions were recorded and transcribed by an experienced therapist and checked by a second one.

**Results**

*Accuracy and error distribution in the naming task*

Correct production (productions entirely correct at first attempt) on the five picture naming sessions was respectively 42% in SJ and 34% in GF. Phonological paraphasias represented the most frequent error type in both patients (95% of errors in SJ and 94% in GF). The remaining errors were semantic paraphasias and no-responses (respectively 2% and 3% in SJ and 2% and 4% in GF).

The phonological errors were further classified as phoneme substitution, omission or addition, phoneme movement, neologism and other kinds of errors. Movement errors included intra-word phoneme shifts (e.g., /kat/ (card) produced [kat], /tabu/ (drum) produced [tabu])

and metatheses or exchanges, (e.g., /bal/ (ball) produced [lab], /valiz/ (suitcase) produced [vilaz]), that is, only errors preserving the segmental content of the target word[1]. Substitution errors comprise a maximum of one segment substitution per syllable (e.g. /gita{/ (guitar) produced [gital] or /medyz/ (jellyfish) produced [mydiz]). Addition and omission errors are single phoneme addition or omission (e.g. /{ob/ (skirt) produced [g{ob] or /ski/ produced [si]). Neologisms were defined as phonological transformations of more than one phoneme per syllable. Other errors included word fragments, or combination of two kinds of errors (e.g. /sit{o)/ (lemon) produced [si:] or /Sapo/ (hat) produced [poSo]).

When a response included several phonological errors like in *conduites d'approche*, each word or non-word error was coded separately. The total number of phonological errors was 276 in SJ and 427 in GF (see Table 1).

*[Table 1 about here]*

The main phonological error subtypes were phoneme substitutions and neologisms in both subjects. SJ and GF produced a similar proportion of phoneme substitution errors (Chi-square calculated on the rate of phonological errors in the two patients: $\chi^2 < 1$), additions and omissions ($\chi^2 = 2.4$, $p = .12$). SJ produced more movement errors than GF ($\chi^2 = 20.2$, $p < .0001$) and the proportion of neologism was higher in GF than in SJ ($\chi^2 = 16.0$, $p < .0001$).

*Variables affecting naming accuracy and errors*

In order to analyse the effect of linguistic variables on naming, correlations were computed between each psycholinguistic factor (image complexity, familiarity, age of acquisition of words, lexical frequency, phonological neighbourhood, syllable and phoneme frequency) and successful naming per item on the 5 naming sessions for each patient, as well as between the psycholinguistic predictors and the number of phonological errors, separately for the main error subtypes (substitutions and neologisms). Results are shown in Table 2. Naming accuracy correlated with word length and phonological neighbourhood in both patients. Neologisms

[1] Differently from previous classifications (for instance Nespoulous et al., 1987), phoneme anticipations or perseverations were not classified as phoneme movement errors. Indeed, if a salient feature distinguishing phoneme movement errors from substitution errors is preservation or change of the segmental content of the target word, anticipations and perseverations do not preserve the entire segmental content. Therefore anticipations and perseverations were classified as phoneme substitution errors with a possible contextual origin (which was further investigated).

also correlated with these two variables (less neologisms on short words with dense phonological neighbourhood), while none of these factors predicted the production of substitution errors. Due to the high correlation between length and phonological neighbourhood: ($r = -.850$ with token neighbourhood and $r=-.792$ with type) we examined whether phonological neighbourhood effects appear also on words of a fixed length. Correlations were calculated again on the subset of 41 four-phoneme words. The number of phonological neighbours correlated with accuracy in both patients ($r = .548$ in SJ and $r = .331$ in GA, significant respectively at $p<.001$ and $p<.05$), but there was no significant correlation with neologisms ($r= -.233$ and $r= -.134$).

*[Table 2 about here]*

*Target-error phonological overlap in neologisms*

Neologisms were the most frequent error type in both patients but, since our criteria for this category was very liberal (all phonological transformations of more than one phoneme per syllable), the distance from the target word might vary between patients. The phonological overlap between neologism and the target words was analysed as follows: the number of common phonemes in each target word and each neologism (regardless of position in the word) were added and divided by the sum of the number of phonemes of the target and the error. Target-error overlap was respectively 66% in SJ and 59% in GF, with no significant difference between the two patients ($\chi^2 = 1.2$, $p = .28$).

*Error distribution in the additional tasks (SJ)*

In the additional tasks conceived in order to elicit movement errors, SJ produced 45% of errors in the naming task and 38% in the reading tasks. Error distribution is shown in Table 3 with the same coding as in Table 1.

*[Table 3 about here]*

The proportion of movement and substitution errors did not differ significantly between the reading and naming tasks ($\chi^2 <1$ for movement errors and $\chi^2 = 1.5$, $p = .2$ for substitution errors). These errors will be added to those elicited with the repeated naming task for the following comparison between phoneme substitution and phoneme movement errors .

*Analyses of movement and substitution errors*

A total of 197 phoneme substitution and 66 phoneme movement errors were analysed in the corpus of errors produced by SJ and 136 substitution errors from GF (GF also produced 4 movement errors which were discarded).

The following analyses were carried out separately on movement and substitution errors: contextual origin of the error, lexical bias, featural similarity, syllable and phoneme frequencies. Each analysis will be described in detail below.

*Contextual errors*

Whereas intra-word phoneme movements are bound to be contextual errors, phoneme substitution errors on single words may also have a (at least apparently) contextual origin. For the following counts only within-word phoneme anticipations or perseverations (e.g. /banan/ (banana) produced [baban], /pubɛ̃/ (trash) produced [pulɛ̃]) were considered to be potentially contextual errors. Table 4 shows the distribution of perseverations and anticipations in SJ and GF for disyllabic words (monosyllabic words were excluded from this count because of the low probability of generating anticipations or perseverations). The probability of contextual error by chance was computed. The procedure closely followed that described in Wilshire (2002). This count consisted of all potential contextual errors when each substituting segment from each patient's errors was matched to each target word from the same corpus. This random matching was applied separately for all consonants and all vowel errors in the corpus (each different vowel from the error corpus was matched with each target word that generated a vowel substitution error and the same for consonants). The rate of contextual errors due to chance corresponded to the mean number of contextual errors resulting from this exhaustive error-target matching. This "relative" probability was near to the absolute probability of contextual substitution errors, since most French phonemes were represented in the error corpora (respectively 28 and 24 phonemes in SJ and GF).

*[Table 4 about here]*

Only SJ produced a considerable proportion of contextual errors (about 20%), including a similar number of anticipations and perseverations, while there are virtually no contextual errors in GF's substitution errors.

The rate of contextual errors in SJ was not greater than would be expected by chance either in the naming or in the reading task (both $\chi^2 < 1$), but the proportion of contextual errors in the naming task was significantly higher in SJ than in GF ($\chi^2 = 9.2$, $p < .01$).

It is worth pointing out here that all the contextual errors in SJ were non-words (none was a formal paraphasia).

*Lexical outcome*

This analysis was aimed at investigating whether the proportion of lexical outcome (of formal paraphasias) in the substitution and movement errors was above chance. The rate of formal paraphasias was tested against the probability of generating real-word errors, which was calculated in different ways for substitution errors and for movement errors. For substitutions, the probability of word outcome was evaluated according to the number of phonological neighbours per plausible substitution of each phoneme in the word. For the probability of word outcome due to a movement error, the number of phonological neighbours was calculated for all phonologically plausible phoneme movements (shifts and exchanges) in the target word. For example, for the target word /bokal/ (jar) there are three plausible single phoneme shift errors (/bloka/, /bolka/, /bokla/) and four exchanges (/kobal/, /lokab/, /bolak/, /balok/), and only one of them is a French word (/bloka/).

*[Table 5 about here]*

The distribution of lexical and non-lexical outcome in phoneme substitution errors is very similar in the two patients. Both produced more words among (non-contextual) substitution errors than would be expected by chance (see table 5). By contrast, the production of formal errors does not exceed chance in phoneme movement errors and in phoneme anticipation or perseveration errors.

*Feature similarity between target and error*

To test whether phoneme substitution and phoneme exchange errors are influenced by feature similarity between target and error phoneme and between the two interacting phonemes in

exchange errors we calculated the number of errors differing on one, two, three or more features (based on 9 features for French consonants and 5 features for vowels). The expected distribution of target-error distance by chance was obtained by computing the distance in features between the target phoneme and each of the other plausible substituting phonemes (separately for consonants and vowels and considering phonotactic constraints for consonants). The rate of substituting segments differing on only one or two features from the target phoneme is higher than chance estimate in SJ and GF (see Table 6). The observed distribution differs from the expected distribution for substitution errors in both patients (one group chi square $\chi^2$ (3) = 66.7, p<.0001 for SJ and $\chi^2$ (3) = 117.7, p<.0001 for GF). By contrast, the distribution of featural distance in anticipation and perseveration substitution errors does not differ from chance ($\chi^2$ (3) = 4.1, p=.25) and a very small proportion of exchange errors involve less than three features.

[Table 6 about here]

*Sub-lexical frequencies effect*

In order to analyse whether the frequency of sub-lexical units affects phoneme substitution and/or phoneme movement errors, the frequency of the produced unit (phoneme or syllable) containing an error was compared to the frequency of the target syllable and phoneme. Phoneme and syllable frequency ranks were taken from the database LEXIQUE (New et al. 2001). The rate of produced syllable or phoneme of higher frequency than the target unit was compared to the probability of producing a higher frequency syllable or phoneme by chance. Chance of producing a syllable of higher frequency than the target syllable was calculated as follows. For each target-error substitution, all possible legal syllables resulting from a phoneme substitution in the same syllabic position where the error occurred were counted and the proportion of syllables of higher frequency than the target syllable was computed. For example, systematic substitution of the coda in /lyn/ generates 11 legal syllables, 5 of them are of higher frequency than /lyn/; systematic substitution of the vowel in the syllable /bys/ generates 7 legal syllables and only one of them is of higher frequency than /bys/.

The same chance estimation was computed for target phonemes: the number of phonemes which were of higher frequency than the target relative to the total number of legal phoneme substitutions.

For each phoneme movement error all possible legal syllables resulting from an intra-word phoneme movement error (separately for consonants and vowels) were counted and the proportion of syllables of higher frequency than the target syllable was computed. For example, for /klu/ (nail) produced [kul] (higher frequency than the target) a second possible legal movement error was /luk/, which is of lower frequency than the target (chance = 0.5).

Results are shown in Table 7. Contextual substitution errors (phoneme anticipation and perseverations) were analysed separately and errors which were illegal French syllables were removed from the analysis.

*[Table 7 about here]*

The rate of produced syllables of higher frequency than the target was greater than would be expected by chance in the substitution errors (one sample chi square respectively $\chi^2 = 19.1$, $p < .001$ and $\chi^2 = 8.9$, $p < .01$ for SF and GF). The proportion of produced syllables of higher frequency than the target was greater for real-word errors than for non-word substitution errors (respectively 65% and 49% in SJ, Fisher's $p < .05$, and 70% vs 49% in GF, $p < .03$).

Anticipation and perseveration errors in SJ also displayed a significant effect of syllable and phoneme frequency (54% of the produced syllables are of higher syllable frequency - chance = .31 - and 71% are of higher phoneme frequency – chance = 0.34, min $\chi^2 = 7.3$, $p < .01$).

By contrast, the rate of production of higher frequency syllables did not exceed chance in phoneme movement errors (mean syllable frequency is lower for produced syllables than for target syllables).

The rate of produced phonemes of higher frequency was superior to chance in SJ ($\chi^2 = 11.8$, $p = .001$), with non-significant difference between real-word and non-word errors (respectively 62% and 58%, Fisher's $p = .5$). It was not different from chance in GF when all errors were pooled ($\chi^2 = 1.5$, $p = .2$), but the proportion of substituting phoneme of higher frequency than the target was significantly higher than chance in formal errors (67% of produced phonemes were of higher frequency, chance = .48, $\chi^2 = 6.7$, $p<.01$).

**Discussion**

We analysed phoneme substitution and phoneme movement errors in an aphasic patient, SJ, who produced a high proportion of movement errors (shifts and metatheses). In order to assess the reliability of the data, the same analyses were carried out on a second patient, GF, producing a similar proportion of substitution errors. Overall the two patients exhibited very similar profiles on accuracy, error distribution and on the properties of phoneme substitution errors.

By contrast with these similarities between the two patients, opposite patterns arose from the comparison between phoneme substitution and phoneme movement errors produced by SJ.

Only word length and phonological neighbourhood affected naming accuracy in both subjects. The effect of phonological neighbourhood appeared independently of word length. The observation that words with dense phonological neighbourhood are less error prone to phonological errors is in line with previous observations on healthy subjects (Vitevitch, 1997, 2002) and on a group of aphasic speakers (Gordon, 2002).

Lexical variables such as lexical frequency did not affect production accuracy; this adds additional negative evidence to the previous contradictory literature on lexical frequency effect on the production of phonological errors. Indeed, positive as well as negative results have been reported with regard to lexical frequency effects on phonological errors (see Pate, Saffran and Martin, 1987, Gordon, 2002, compared to Best, 1996, Schwartz et al., 2004, for opposite results). As argued in the introduction, following the predictions of multiple origins of phonological errors, absence of an effect of lexical factors such as frequency rather favours a post-lexical locus of impairment in both patients. An impairment in later processes of word-form encoding is also in line with the similar pattern of performance displayed by both patients in the different output tasks, as suggested in the neuropsychological literature (see also Goldrick and Rapp, 2007) and with the production of almost exclusively phonological errors.

[Table 8 about here]

The results of the analyses on phoneme substitution errors are summarised in table 8. Since the analysis of naming accuracy and of substitution errors showed very similar patterns between the two patients and differences were observed between substitution and movement errors, we will base the discussion on these differences. The similarity between subtypes of error (for example between contextual and non-contextual errors in Wilshire, 2002, or

between distant and close phonological errors in Schwartz et al., 2004) has been evoked as an argument against the double origin of errors. Here, we will follow the same reasoning and argue that the observed differences indicate that movement and substitution errors are generated by different encoding processes.

*Origin of substitution errors*

Phoneme substitution errors are largely affected by lexical and sub-lexical factors. The lexical bias together with the sub-lexical effects suggests an interaction between the encoding processes responsible for these errors and other encoding processes.

Two different accounts of the lexical bias in phonological errors have been proposed in the literature. First, an editing (or internal monitoring) mechanism has been suggested in serial models, which is programmed to suppress non-word errors (Levelt et al., 1999). This editing mechanism, based on internal monitoring processes, detects all errors giving rise to a non-word and suppresses them, while it is unable to detect word errors. A tendency for a lexical outcome in aphasic patients may indicate that this mechanism is at least partially doing its job. But how can we explain that this mechanism seems to operate differently for substitution errors than for movement errors? It might suggest that monitoring takes place prior to the generation of movement errors, but after or during the production of substitution errors.

An alternative account for the lexical bias has been proposed in the framework of interactive activation models (Dell, 1988; Dell et al., 1997) where lexical bias is due to feed-back activation spreading from the later phonological level to the word nodes level. Activated phonemes feed back to connected lexical nodes (or morphemes), which then feed forward to other phonemes. In this proposal, real-word errors (formal paraphasias) are more likely to occur than non-word errors.

The syllable frequency effect observed in substitution errors indicates that the produced syllables are of higher frequency than target syllables. Although syllabic representations are thought to be retrieved during phonetic encoding (Levelt et al., 1999, see Laganaro & Alario, 2006 for empirical evidence), syllable frequency effects have not only been reported on phonetic errors produced by patients with apraxia of speech (Aichert and Ziegler, 2004; Staiger and Ziegler, 2008; Laganaro, 2008), but also on phonological errors produced by aphasic patients (Stenneken, Hofmann and Jacobs, 2005; Laganaro, 2005, 2008). The syllable frequency effect on substitution errors observed in conduction aphasia has been interpreted as the outcome of default activation of frequent syllables from an incomplete phonological input

(Laganaro, 2005). This suggests that phonemes are not mis-selected, but rather they can not be selected and the missing information is compensated by default activation. However, feature similarity between the target and the substituting phoneme and phoneme frequency also affects mis-selection.

Produced phonemes have been found to be of higher frequency in a study by Levitt and Healy (1985) with healthy subjects and in an aphasic subject by Goldrick and Rapp (2007). Since default processes may be guided by the activation of more frequent (more activated) units, syllables or phonemes may be the candidate.

Feature similarity between target and error represents a robust effect in normal slips of the tongue and it has been reported in other studies of aphasic patients with a post-lexical impairment (Goldrick and Rapp, 2007). The observation of feature similarity between target and error phonemes favors proposals claiming that (at least) partial feature specification is represented and activated along with segmental information before phonetic encoding. If featural nodes are shared between phonemes, mis-selection of closely linked phonemes becomes more plausible than mis-selection of distant phonemes. In accounts postulating feed-back between all representation levels (Dell, 1986, 1988), feed-back activation from shared features can be at the origin of mis-selection.

Differently from the cases presented here, the patient BON reported by Goldrick and Rapp (2007), who showed phoneme frequency and feature similarity effects, did not display phonological neighbourhood effects. How can we reconcile then the sub-lexical frequency and similarity effects with the lexical bias observed in our patients? We can attempt an interpretation of the origin of substitution errors in line with both effects. First, phonemes can be mis-selected due to the feed-back activation to connected lexical nodes (to phonological neighbours), which then feed forward activating other phoneme nodes and generate mis-cuing. The outcome of this is the production of formal errors. Moreover, phoneme substitutions giving rise to a word outcome may have a higher probability of generating syllables of higher frequency than a non-word outcome. A similar proposal has been made for the observation that phonological slips of the tongue tend to create “strings of frequently occurring phonemes” in co-occurrence with the tendency to create real-words (Dell, 1985). Alternatively, substitution errors may occur not because of mis-selection, but because of lack of selection of the target phonemes. This may result in the default activation of syllables from an incomplete phonological representation. Selecting frequent syllables instead of less frequent ones may also increase the probability of generating real words. Indeed, the production rate of higher frequency syllables than the target was greater for formal errors than

for non-word errors in SJ and in GF. So, the syllable frequency effect and lexical bias may be linked in one way or the other.

We have identified at least two different processes which could generate substitution errors with the observed properties. Despite the possible link between these lexical and sub-lexical factors, multiple processes might be implied in the generation of phoneme substitution errors. Indeed, none of the observed factors affect the majority of phonological errors: a real-word outcome (lexical bias) is observed in approximately 40% of the errors, feature similarity in approximately 50-60% and a syllable frequency effect in about 60% of the errors. If the weight of the different processes implied in error generation during phonological encoding varies across errors, the influence of one or the other variable has a more or less strong impact.

*Origin of phoneme movement errors*

Contrary to phoneme substitution errors, phoneme movement errors (shifts and metatheses) do not display a lexical bias effect, nor a feature similarity effect and they do not give rise to the production of high frequency syllables or phonemes. The observation that neither the lexical store, nor a syllabic stock or phonological features affect the outcome of this kind of errors seems to indicate that movement errors occur during a specific “encapsulated” or “autonomous” encoding process, with no influence from other encoding processes. Since all target phonemes are preserved in movement errors, their misplacement may occur during a process of ordering or keeping at their correct position in the word the already (correctly) retrieved segments. According to current models of phonological encoding the activated phonemes are attributed to a frame specifying their serial (Levelt et al., 1999) or categorical (for example in terms of syllabic position) order (Dell, 1986; 1988; Dell et al., 1997). These models predict that misordering can occur when phonemes are ordered into frame slots. Exchange errors are explained by an interaction of anticipation and perseveration errors. A phoneme anticipation error occurs due to erroneous timing-sequencing in the ordering mechanisms, which triggers a following perseveration involving the item that was replaced in the anticipation (Dell, 1986).

The explanation of the generation of mis-ordering or exchange errors is closely linked to the idea that the activated phonological information is held in a buffer before undergoing following encoding processes. Neuropsychological accounts explicitly proposed a separate output phonological buffer holding ordered abstract segmental information before phonetic

encoding (Caramazza, Miceli, and Villa , 1986; Shallice, Ruminati and Zadini, 2000). Although not always explicitly stated, models of speech production also include buffers which temporarily store the output of a processing level to be used as an input for the following processing level. For instance, the abstract phonological representation issued from phonological encoding must be temporarily held in order to undergo syllabification and address phonetic syllables in Levelt et al. (1999). An explicit integration of phonological buffering and speech production processes has been proposed by Martin and Saffran (1997) and by Hartley and Houghton (1996) in the framework of connectionist models. In these accounts, mis-selection happens when another item (another phoneme for instance) has reached/kept a higher activation level than the target item, whose activation has undergone decay over time. Although the decay of activated information specially accounts for phoneme substitution errors, it can account also for movement errors. An activated non-target phoneme from the word can be mis-selected, generating an anticipation error, which then triggers the selection of the remaining unselected phoneme (as in perseveration errors). One could argue here that both phoneme substitution and phoneme movement are due to the same disrupted process: in one case a phoneme from the word replaces the lost (decayed) representation; in the other case another phoneme receives more activation because of interaction with other lexical and sublexical representations. Also, in the neuropsychological literature defending the multiple origin of phonological errors (see the Introduction), the phonological buffer has been identified as the locus of errors in patients producing “mild” phonological errors and displaying length and word position effects. In the reported cases, errors attributed to a disruption of the phonological buffer were mostly phoneme substitution errors (Shallice et al., 2000). However, in single word production once the segmental composition has correctly been encoded and buffered, one might expect that other phonemes linked to the encoded word are the best candidates to replace a “lost” phoneme (whose activation has decayed). Therefore, this error generation mechanism seems to account better for phoneme anticipation, perseveration and exchange errors than for (non-contextual) phoneme substitution errors. It rather suggests that in (non-contextual) substitution errors missing phonemes are already missing or mis-selected before the phonological representation of the entire word has been encoded and buffered, allowing other levels of representation to influence mis-selection or default activation of missing representation, as exposed in the previous section.

However this error mechanism holds for phoneme exchange errors, not for phoneme shift. The explanation of phoneme shift must be tied to some disruption of the representation of

serial position of phonemes. In interactive activation models of phonological encoding, serial position is encoded in relation with syllable position information and linked to an abstract syllabic structure (Dell, 1986) or an abstract word structure (Dell, 1988). Phoneme misordering, such as in phoneme shift errors, then corresponds to the decay of the information about syllable or word position. This second interpretation also holds for phoneme exchange errors.

In serial models (Levelt et al., 1999), phonemes are activated with a linear word position information (from the beginning to the end of the word), then associated to a word frame. This abstract phonological representation is then kept in a buffer, just as long as is necessary to undergo phonological processes (syllabification) and to address the corresponding entries in the syllabary. Movement errors can occur either during the assembling procedure (Shattuck-Hufnagel, 1979) or the positional trace associated with each phoneme can be degraded in the buffer and fail to index the correct syllable (Levelt et al., 1999). It is unlikely that misordering occurs during later processes in this kind of model. The absence of a syllable frequency effect excludes an implication of the syllabary in the generation of movement errors and, once syllables have been addressed, phonemes should not be able to shift, since the activation of syllables implies sort of chunks (Levelt and Wheeldon, 1994).

In sum, phoneme movement errors are generated during an encoding process without interaction with other encoding levels. This “autonomous” encoding level can be identified in assembling (correctly) retrieved phonemes and suprasegmental structure or buffering ordered phonemes. This stage of encoding is not affected by other encoding levels and only generates phoneme movement. It is worth to mention that SJ also produced more perseveration and anticipation errors than the second patient (about 20% of his substitution errors). The co-occurrence of phoneme movement errors with a higher proportion of other kinds of within-word contextual errors might indicate that (within-word) phoneme anticipation or perseveration also may have the same origin as movement errors. Indeed, phoneme anticipation and perseveration did not exhibit a lexical bias effect nor the feature similarity effect, which makes them closer to the properties of phoneme movement errors than to those of phoneme substitution errors.

*Phonological paraphasias and slips of the tongue*

As already mentioned in the Introduction, contextual (syntagmatic) errors represent the main proportion of phonological errors in spontaneous slips of the tongue. Although most of these

errors are between-word errors, especially when errors are elicited in experimental tasks, an important rate of within-word errors has also been reported in spontaneous speech of the tongue (36% of all contextual vowel errors and 31% of consonant errors are within-word errors in Rossi and Defare, 1995[2]). Overall, spontaneous and elicited slips of the tongue have been found to be affected by feature similarity and by lexicality (Dell and Reich, 1981; Baars, Motley and McKay, 1975; Oppenheim and Dell, 2008). However, these effects do not appear in all speech production situations. The lexical bias effect is modulated by speech rate (Dell, 1985) and by the lexical or non-lexical nature of the material used in the error elicitation experiments (Baars et al., 1975). More importantly, the tendency for phonological errors to result in real words has not always been observed in natural slips of the tongue, especially in within-word errors (only 2% of within-word French errors give rise to real words in Rossi and Defare, 1995, see also Garrett, 1976). Also, feature similarity has been reported to be higher in non-contextual substitution errors than in contextual errors (Stemberger, 1985). It seems therefore that the phoneme movement errors observed in SJ share some properties with within-word errors produced in (spontaneous) slips of the tongue: limited lexical bias and limited similarity effects. As noted above, although the rate of perseveration and anticipation errors produced by SJ (20% of his substitution errors) did not exceed the chance of producing a within-word contextual substitution error, the properties of these errors (no lexical bias nor the feature similarity effect) were closer to those of phoneme movement errors than to those of phoneme substitution errors  We might speculate here that within-word errors, including metatheses and phoneme anticipation or perseveration are generated by similar processes in aphasic errors and normal slips of the tongue, while  different processes give rise to (non-contextual) substitution errors and between-word contextual errors.

In conclusion, phoneme substitution and phoneme movement errors exhibit different properties, which favour the interpretation that they are generated by different mechanisms. By analysing quite pure sub-types of errors even in the category of “mild” phonological errors we observed different error properties suggesting that multiple processes inside the phonological encoding system are responsible for the production of phonological errors.

[2] It should be noticed that the rate of within-word errors was lower in the English and German slips corpora (respectively 14% and 10%) analysed by Berg (2005). However, only consonantal slips were included in this count. See also Berg and Abd-El-Jawad (1996) for evidence of intra-word errors in Arabic slips of the tongue.

The present results also point to an interaction between different encoding levels in the generation of phoneme substitution errors. We discuss how the error generation processes might be affected simultaneously by lexicality (lexical bias) and by sub-lexical frequencies and similarities, but the precise manner in which these levels of representation interact during the generation of phoneme substitution errors needs further investigation.

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TABLES

TABLE 1

Table 1. Distribution of phonological errors in the naming task (percentage based on total number of words with phonological errors).

| | SJ (N = 276) | GF (N = 427) |
|---|---|---|
| movement | 9% | 1% |
| substitutions | 31% | 32% |
| additions/omissions | 14% | 10% |
| neologisms | 39% | 52% |
| other | 8% | 4% |

TABLE 2

Table 2. Correlations (r) between each psycholinguistic variable and naming accuracy, neologisms and substitution errors (z values are indicated for significant correlations at p<.01).

| | | FAM | COM | AoA | F-Lex | Ph-Neigh | Length (pho) | Syll-F | Pho-F |
|---|---|---|---|---|---|---|---|---|---|
| SJ | accuracy | .091 | .032 | -.203 | .125 | **.419** *z=4.8* | **-.462** *z=-5.4* | -.158 | .127 |
| | neologisms | .052 | -.130 | -.002 | .016 | **-.352** *z=-3.9* | **.484** *z=5.7* | .191 | -.049 |
| | substitution | -.047 | .047 | .032 | -.008 | -.137 | .042 | -.020 | .103 |
| GF | accuracy | .024 | -.083 | -.181 | .130 | **.372** *z=4.2* | **-.374** *z=-4.2* | -.048 | .204 |
| | neologisms | .064 | .015 | -.011 | .068 | **-.257** z=-2.8 | **.263** *z=2.9* | .043 | -.099 |
| | substitution | .056 | .008 | -.066 | .059 | -.159 | **.084** | .144 | .022 |

FAM: Concept familiarity; COM: Image visual complexity; AoA: Age of acquisition; F-Lex: lexical frequency; Ph-Neigh: phonological neighbourhood; Length: length in phonemes; Syll-F: Syllable frequency; Pho-F: phoneme frequency.

TABLE 3

Table 3. Distribution of phonological errors in the reading and naming tasks (percentages on total number of words with phonological errors).

| | Naming (N=44) | Reading (N=182) |
|---|---|---|
| movement | 15% | 19% |
| substitutions | 58% | 47% |
| additions/omissions | 4% | 6% |
| neologisms | 8% | 14% |
| other | 15% | 14% |

TABLE 4

Table 4. Proportion of contextual substitution errors (phoneme anticipation or perseveration)

| | Contextual errors | Chance estimate |
|---|---|---|
| SJ : naming (58) | 16% | 15% |
| SJ : reading (49) | 24% | 17% |
| GF : naming (73) | 1% | 14% |

TABLE 5

Table 5. Proportion of formal errors and probability of lexical outcome

| | SJ | | | GF |
|---|---|---|---|---|
| | movement | substitution | | substitution |
| | | contextual | non contextual | |
| *N* | *66* | *21* | *173* | *136* |
| real-word (formal error) | 0.14 | 0.00 | 0.40 | 0.36 |
| *chance* | *0.11* | *0.06* | *0.23* | *0.26* |
| *Chi square and p values* | *<1* | *<1* | *27.3* | *7.7* |
| | | | *<.001* | *<.01* |

TABLE 6

Table 6. Proportion of errors as a function of feature similarity between target and error or between interacting segments (chance in brackets)

| | SJ | | | GF |
|---|---|---|---|---|
| | substitutions | | exchanges | substitutions |
| | non-contextual | anticipation / perseveration | | |
| 1 feature | 0.35 (*.16*) | 0.08 (*.16*) | 0.06 | 0.37 (*.11*) |
| 2 features | 0.27 (*.19*) | 0.21 (*.20*) | 0.10 | 0.19 (*.12*) |
| 3 features | 0.18 (*.22*) | 0.42 (*.26*) | 0.21 | 0.14 (*.19*) |
| ≥ 4 features | 0.21 (*.43*) | 0.29 (*.38*) | 0.63 | 0.29 (*.58*) |

TABLE 7

Table 7. Mean syllable and phoneme frequency (per million syllable or phoneme, log transformed) and proportion of produced syllables and phonemes of higher frequency than target (in brackets) and chance estimate.

| | | Syllables | | Phonemes | |
|---|---|---|---|---|---|
| | | target / error log frequency and proportion of produced syllables of higher frequency than target | *Chance* | target/error log frequency and proportion of produced syllables of higher frequency than target | *Chance* |
| SJ | substitution errors, naming (N=110) | 2.52 / 2.68 (*.58*) | *.46* | 4.84 / 4.93 (*.61*) | *.47* |
| | substitution errors, reading (N=71) | 2.42 / 2.43 (*.51*) | *.30* | 5.0 / 5.0 (*.55*) | *.31* |
| | movement errors (N=74) | 2.54 / 2.36 (*.45*) | *.46* | - | - |
| GF | substitution errors (N=131) | 2.73 / 2.72 (*.58*) | *.45* | 4.81 / 4.82 (*.50*) | *.45* |

TABLE 8

Table 8. Summary of results.

| | Phoneme substitution | | Phoneme movement |
|---|---|---|---|
| | SJ | GF | SJ |
| Lexical bias | yes | yes | no |
| Sub-lexical frequency effects | yes | yes | no |
| Feature similarity effect | yes | yes | no |