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Research report

Steps towards understanding the phonological output buffer and its role in the production of numbers, morphemes, and function words

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ABSTRACT

The Stimulus Type Effect on Phonological and Semantic errors (STEPS) describes the phenomenon in which a person, following brain damage, produces words with phonological errors (fine → fige), but number words with semantic errors (five → eight). To track the origins of this phenomenon and find out whether it is limited to numbers, we assessed the speech production of six individuals with conduction aphasia following a damage in the left hemisphere, who made phonological errors in words. STEPS was found in all six participants, and was not limited to number words – several other word categories were also produced with semantic rather than phonological errors: function words, English letter names, and morphological affixes were substituted with other words within their category. This supports the building blocks hypothesis: when phonological sequences serve as building blocks in a productive process, they end up having pre-assembled phonological representations, ready for articulation. STEPS reflects a deficit that causes substitutions of one phonological unit with another. In the case of plain content words, this causes substitutions of one phoneme with another, but in the case of pre-assembled phonological units, this causes substitutions of number words with other number words, function words with function words, and morphological affixes with other affixes. An analysis of the participants' functional locus of deficit revealed that they all had a deficit in the phonological output buffer, and this was their only common deficit. We therefore concluded that the pre-assembled phonological units are stored in dedicated mini-stores in the phonological output buffer, which processes not only phonemes but also whole number words, function words, and morphemes. We also found that STEPS depends on the word's role: number words were produced with semantic errors only when they appeared in numeric context, and function words triggered semantic errors only in grammatical context. This suggests that the phonological representation of a word can be obtained either from the phonological output lexicon or from a store of pre-assembled representations in the phonological output buffer, depending on the word's role.

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1. Introduction

SZ was admitted to hospital following a left fronto-parietal infarct that damaged his speech. A series of examinations revealed that he had conduction aphasia (a phonological buffer deficit, Gvion & Friedmann, 2012a). More than half of the words he said were produced with phonological errors (such as *kangaroo* → *kanbaroo*, or *bell* → *cell*, but SZ was tested in Hebrew, his native language). He showed a similar pattern in nonwords, which he produced with phonological errors (e.g., *kizuma* → *dizuma*). Quite surprisingly, when SZ said numbers, he managed to say them without phonological errors. However, he often did not produce the numbers he intended to say, but different numbers. His errors in numbers were semantic – substitutions of a number word with another number word (e.g., *forty-two* → *forty-five*), and syntactic errors – changing the syntactic structure of the number (e.g., *thirteen* → *one hundred and three*; note that the terms syntactic and semantic errors have slightly different meanings when talking about numbers than when talking about speech in general). In the current study we explore how systematic the difference in error pattern is in SZ's production, and how systematic it is for other individuals with aphasia who are impaired in the same functional locus as SZ. A systematic difference in error patterns between words and numbers would indicate that number words and non-number words are processed in different ways. We then explore what gives rise to this pattern, by identifying the participants' locus of functional deficit.

The pattern of SZ's performance is characterized by two phenomena: one phenomenon is the occurrence of phonological errors in non-number words and nonwords, but not in number words. We called this phenomenon *the stimulus type effect on phonological errors*. The other phenomenon is the occurrence of semantic errors in number words but not in non-number words (*the stimulus type effect on semantic errors*). When the two phenomena co-exist in the same patient, like in SZ's case, we call them *STEPS – the Stimulus Type Effect on Phonological and Semantic errors*.

The present study investigated STEPS in detail. We aimed to identify the locus of the cognitive deficit in the lexical retrieval process that underlies STEPS, to discover whether the phenomenon is limited to number words or is a more general phenomenon that applies to other kinds of words, and eventually – to offer a theoretical framework that can account for STEPS and its properties as reflected in the results of the current study and of findings from previous studies of STEPS.

1.1. Previous cases of STEPS

SZ is not the first reported case of STEPS. The phenomenon was first investigated by Cohen, Verstichel, and Dehaene (1997). They reported a French teacher who had neologistic jargon following a left temporal infarct, with phonologically related errors in non-number words. This patient produced 98% of the target number words without phonological errors and with semantic errors. This is the only case we are aware of in which both phenomena – phonological errors that appear selectively in non-number words, and semantic errors that appear selectively in numbers – co-exist in a single person in a clear manner. Messina, Denes, and Basso (2009) analyzed an impressively large group of 57 aphasic patients and found the STEPS phenomenon on the group level, namely, the group had mostly semantic errors in number reading (20% semantic *vs* 2% phonological errors) but mostly phonological errors in reading words (10% phonological *vs* less than 1% verbal paraphasias) and nonwords (25% phonological errors). Essentially similar results were found in repetition tasks.

There are several single-case studies in which one of the two phenomena (phonological errors only in non-number words or semantic errors in number words) was found whereas the complementary phenomenon was not reported, or was less clear-cut. Table 1 lists these cases.

Girelli and Delazer (1999) described BP and GS, two patients who exhibited a STEPS phenomenon, although only in some tasks. In word production, GS made phonological and semantic errors, and BP made both neologisms and paraphasias the type of which was not specified. Both patients had semantic errors in numbers, and neither had phonological errors in most of the number production tasks, with the exception of neologisms when reading visually-presented number words.

Several studies reported phonological errors that appeared in non-number words but not in numbers. Bencini et al. (2011) and Semenza et al. (2007) investigated GBC, a man with Wernicke's aphasia who produced numbers flawlessly but made many phonological errors in word production (only in vowels). Patient LT (Shallice, Rumiati, & Zadini, 2000) had an impaired phonological output buffer and made many phonological errors in word production. His phonological error rate in single word repetition was 30%–50%, yet in a digit span task his error rate in single digits was smaller than 20% (the error type was not reported).[1] Regarding the semantic errors in number production, LT's error rate when producing digit names in the digit span task was low, yet it is possible that the semantic error rate would have been higher had he been asked to produce multi-digit numbers. Such a difference between single digits and multi-digit numbers was found in other studies reported here, and, as we will see later, also in the present study (see Section 4.1.1.3). Another patient who showed the stimulus type effect on phonological errors is DPI (Bachoud-Lévi & Dupoux, 2003), who had phonological errors in word production, yet his number production was spared, with neither phonological nor semantic errors. We do not know, however, whether he was requested to produce multi-digit numbers or only single digits, so again it is possible that semantic errors would have appeared in multi-digit numbers. Another patient who exhibited this error pattern was FS (Delazer & Bartha, 2001), who produced content words with

[1] In the digit span task, LT correctly repeated 80% of the 20 four-digit sequences presented to him. The authors said that only digits that were "accurately produced" were counted as correct. Thus, LT produced at least 64/80 digits with no phonological errors. It would be reasonable to assume that in several cases LT erred only in some of the digits in the four-digit sequence, and that some of his errors were not phonological but semantic or digit omissions, so his phonological error rate in single digits was probably lower than 20%.