

The Production of Speech Errors in Aphasia:

Exploring the dynamic nature of the language system



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DOCTORADO INTERNACIONAL

**THE PRODUCTION OF SPEECH ERRORS IN
APHASIA: EXPLORING THE DYNAMIC NATURE OF
THE LANGUAGE SYSTEM**

**LA PRODUCCIÓN DE ERRORES DEL HABLA EN LA
AFASIA: EXPLORANDO LA NATURALEZA
DINÁMICA DEL SISTEMA LINGÜÍSTICO**

(Tesis Doctoral por compendio de publicaciones)

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La investigación responde a los requisitos de una Tesis Doctoral y la metodología adoptada es apropiada a los fines de investigación. Por tanto, entiende que reúne los requisitos para optar al **Grado de Doctor con Mención Internacional** según la legislación vigente y, en consecuencia, autoriza su depósito y posterior presentación y defensa ante el tribunal designado para tal fin.

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- Gutiérrez-Cordero, I., & García-Orza, J. (2025). *Disassembling an experimental artifact in aphasia: Why phonemic errors with words and semantic errors with numbers?* *Cortex*, 185, 184–210. <https://doi.org/10.1016/j.cortex.2025.02.005>
- Gutiérrez-Cordero, I., Torres-Prioris, M. J., & García-Orza, J. (2025). *Definition: Conduite d’approche*. *Cortex*, 185, 151–152. <https://doi.org/10.1016/j.cortex.2025.02.007>
- Gutiérrez-Cordero, I., & García-Orza, J. (2025). *sunflower: An R package for handling multiple response attempts and conducting error analysis in aphasia and related disorders*. *Frontiers in Psychology*, 16, 1538196. <https://doi.org/10.3389/fpsyg.2025.1538196>

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This dissertation was prepared following the regulations of the Universidad de Málaga to fulfill the requirements for the International Mention in the Psychology Doctoral Program. As stipulated by these regulations, the majority of the thesis is written in English. Two research stays of three months each were undertaken. The first was a national stay at the Universitat de València, from September 20 to December 20, 2021, and the second was an international stay at the Université de Liège in Belgium, from April 1 to July 1, 2024. In addition, a summary chapter in Spanish is included at the end of the thesis (see the Resumen chapter).



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STATUS OF THE WORKS IN THIS DISSERTATION

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Gutiérrez-Cordero, I., & García-Orza, J. (2025). *Is saying “apple” the same as saying “twenty-six”? How the evaluation context influences the production of speech errors in aphasia.* *Ciencia Cognitiva*, 19:2, 75-78. <https://www.cienciacognitiva.org/?p=2568>

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Psycholinguistic variables influencing conduite d'approche in repetition tasks: An experimental exploration and mediation analysis in a person with conduction aphasia.

** Ismael Gutiérrez Cordero is the corresponding author.*

Appendix C presents the journal versions of the papers that constitute the chapters of this thesis.

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GENERAL INTRODUCTION

RESEARCH JUSTIFICATION

“I feel very strongly that good cognitive neuropsychological studies should and do stem from clinical observation and it takes an awful lot of time to build up a base of what is usual and what is exceptional.”

— Elizabeth Warrington (personal communication, 19 November 2014, as cited in Della Sala et al., 2015).

Speech errors reveal the existence of a failure in the mechanisms of language production. These errors are frequent in people with aphasia and cause significant frustration by hindering effective communication. Investigating speech errors in this population provides a fundamental tool to improve our understanding of the cognitive and neural mechanisms that support language production. A variety of behaviors, such as that observed in the *Stimulus Type Effect on Phonological and Semantic Errors* (abbreviated as STEPS) or in *conduite d’approche*, challenge traditional explanations that propose a direct correspondence between the location of the brain lesion, the impaired cognitive mechanism, and the resulting error type. These behaviors highlight the functional complexity and dynamic organization of the language system. Crucially, their study not only allows for the refinement and extension of current theoretical models but also promotes the development of more sensitive assessment tools and the design of more specific and effective clinical interventions.

GENERAL THEORETICAL FRAMEWORK

Following the cognitive revolution in the latter half of the past century, the formal study of language functioning became firmly established within the field of psychology. This development was further complemented by the incorporation of insights from related disciplines such as linguistics and neuroscience, ultimately fostering the emergence of a broader interdisciplinary cognitive science (Miller, 2003).

Since then, cognitive models, conceptualized as theoretical constructs, have become essential tools for investigating mental processes at varying levels of complexity, including working memory (Baddeley & Hitch, 1974), word recognition (McClelland & Rumelhart, 1981), and word production (Levelt, 1989). Built upon behavioral data obtained through tasks such as list recall, word recognition, and word production, these models do more than merely

describe observed behavior. Instead, they identify the underlying cognitive mechanisms and elucidate the relationships among them. Thus, cognitive models not only characterize empirical phenomena but also facilitate the interpretation of the data from which they emerge, enabling the generation of hypotheses and predictions about phenomena yet to be observed. This contributes to a more precise understanding of behavior and the functioning of the human mind. Once formulated, these models are tested either through computational simulations or by conducting experimental studies with human participants. In these contexts, stimulus properties or the conditions in which they are presented are manipulated in accordance with the models' assumptions, thus enabling assessment of their influence on the underlying mechanisms. If the predictions derived from such models do not align with empirical findings, they are revised and refined, which results in a continuous improvement of their explanatory power.

Since the beginning of this cognitive revolution, numerous cognitive models have been proposed to account for language processing, including those specifically focused on language production (e.g., Dell, 1986; Garrett, 1975; Levelt, 1989), which have since undergone successive and substantial refinements based on empirical evidence (e.g., Dell et al., 1997; Levelt et al., 1999; Nozari et al., 2010). However, a good language model should not be limited to explaining behavior under typical conditions; it should also account for alterations observed in pathological contexts. Indeed, a model's capacity to explain both typical functioning and deviations resulting from brain injury represents a critical test of its theoretical validity and its practical applicability (Coltheart, 2001).

At this point, research involving individuals with aphasia becomes particularly relevant, as they exhibit linguistic impairments resulting from brain injury. Analyses conducted within the framework of cognitive neuropsychology, particularly those based on case studies, enable researchers to investigate how damage to specific brain structures or neural networks impacts distinct mechanisms of language processing (Caramazza, 1986). Such analyses provide crucial empirical evidence to validate, refine, or reconsider theoretical models of language. This field has also significantly contributed to establishing systematic associations between specific brain lesions and impaired cognitive mechanisms, thereby allowing researchers to draw inferences about the functional organization of language in the healthy brain.

The analysis of speech errors—the central focus of this dissertation as it will be outlined below—serves as a critical approach to exploring the dynamics of language processing. This holds especially true for individuals with aphasia, in whom speech errors function as

informative indicators of the impaired linguistic mechanisms (e.g., Hillis, 2001; Ramoo et al., 2021), allowing researchers to draw inferences regarding the brain regions involved (e.g., Berthier et al., 2018; Fridriksson et al., 2009; Hickok & Poeppel, 2007; Mirman et al., 2015). On the one hand, these errors provide valuable insights into the cognitive and neural processes underlying word production; on the other, they represent clinical manifestations that help pinpoint specific mechanisms affected by brain injury, thereby supporting diagnostic decision-making and informing the development of rehabilitation approaches that are both theoretically grounded and clinically effective.

At present, there is general consensus among researchers and clinicians that lexical errors, such as semantic paraphasias (for example, saying “story” instead of “tale”), originate from disruptions at the semantic and/or lexical levels, and are commonly linked to damage in the left anterior temporal lobe and other regions within the ventral stream for language processing. In contrast, non-lexical errors, such as phonemic paraphasias (e.g., “lale” instead of “tale”), are attributed to impairments in post-lexical processes, including phonological encoding or the maintenance of phoneme sequences, and are associated with lesions in the left inferior parietal lobe and other dorsal stream areas (Cloutman et al., 2009; Hillis, 2001; McKinnon et al., 2018; Mirman et al., 2015; Ramoo et al., 2021; Schwartz et al., 2009; Walker et al., 2011; Schwartz & Dell, 2016; Stark et al., 2019). Nevertheless, certain data coming from individuals with aphasia challenges this view regarding the relationship between brain lesions, disrupted cognitive mechanisms, and the nature of the resulting errors. This dissertation will focus on two central pieces of evidence that call this consensus view into question.

The first is the *Stimulus Type Effect on Phonological and Semantic Errors* (STEPS) (Cohen et al., 1997; Dotan & Friedmann, 2015), according to which individuals with phonological impairments predominantly produce phonemic errors with content words (e.g., saying “lale” instead of “tale”), as it is expected given the nature of their impairment, but surprisingly exhibit semantic errors when producing numbers (e.g., saying “13” [thirteen] instead of “42” [forty-two]). This phenomenon is difficult to account for within classical models of language production and further challenges the traditional consensus on the nature of speech errors, as the same patients with phonological deficits alternately produce phonemic and semantic errors depending on the type of stimulus (words vs. numbers) on which they are assessed. Not only at the cognitive level, but also from an anatomical-functional perspective, this phenomenon still requires explanation, as semantic errors are observed despite the absence of perceptible impairment at the conceptual level or measurable damage to the ventral language

pathway and phonemic errors are absent despite the existence of damage to the dorsal language pathway.

Second, although it does not initially contradict the established consensus on speech errors, there is a classic behavior observed in individuals with aphasia known as *conduite d’approche* (CdA) (e.g., Goodglass, 1992), whose mechanisms and anatomical correlates are not clearly explained in light of current models of speech production and monitoring (though see Torres-Prioris et al., 2019; Ueno & Lambon Ralph, 2013, for some approaches). CdA is a repetitive verbal behavior characterized by the production of successive self-corrective attempts when attempting to produce a target word (either a real word or a pseudoword). The still limited understanding of the factors that govern this behavior, together with the lack of precision in theoretical frameworks—often reduced to assuming that CdA reflects the operation of monitoring mechanisms or the interaction between language processing streams—highlights a significant gap in our understanding of speech errors and of the cognitive and neural bases underlying word production.

OBJECTIVES AND THEMATIC UNITY

The overarching objective of this dissertation is to investigate two distinct, yet theoretically related phenomena observed in individuals with aphasia: the STEPS effect and CdA. Although they differ in their manifestation, both are error patterns that offer a valuable window into a central, yet often underexplored, question in current models of language production: how the dorsal and ventral processing routes interact when one of them is compromised. By framing the study of speech errors and their self-corrective behaviors within this perspective, the dissertation situates both phenomena in a unified theoretical framework and justifies their inclusion within a single, thematically coherent body of work.

ORGANIZATION AND SPECIFIC OBJECTIVES

This dissertation is organized into two main parts. The first, dedicated to the STEPS effect, examines the hypothesis currently used to explain it and explores alternative accounts, with the aim of determining whether it reflects a specific processing mechanism or an artifact of task demands and the lexical properties of the stimuli. The second part focuses on *conduite d’approche* (that we abbreviated as CdA), with the objective of defining and characterizing this

phenomenon, developing methodological tools for its systematic study, and, as a first step, identifying the psycholinguistic factors that influence its production and resolution.

Each part opens with a critical review of the relevant literature, which frames and contextualizes the corresponding research block as a whole. The state-of-the-art reviews for each study are presented in detail within their respective chapters. Finally, **each part concludes with a statement of its specific research objectives**, which are **further elaborated in each chapter**.

This structure adheres to the most recent amendment to Reglamento 4/2022, de 24 de octubre, de la Universidad de Málaga, concerning doctoral studies (published on 31 October 2023), and is consistent with the University's current doctoral regulations and guidelines. The rationale for this organization is to ensure both narrative coherence and conceptual clarity throughout the document.

GENERAL METHODOLOGY

The experimental studies in this dissertation were conducted using single-case designs, with each participant serving as their own control across tasks and conditions. Data in **Chapters I and II** were analyzed with nonparametric tests appropriate for small samples and non-normal distributions, with the analyses in **Chapter II** conducted in R (R Core Team, 2022). In **Chapter VI** we turned to Bayesian modeling with *brms* (Bürkner, 2017), an R package that interfaces with Stan (Stan Development Team, 2024), a probabilistic programming language for Bayesian inference. This approach allows the use of different probability distributions, the fitting of hierarchical models, and the implementation of mediation analyses entailing considerable “complex” structures.

Chapter V presents an R-based tool for the analysis and classification of speech errors, incorporating machine-learning algorithms and *word2vec* embeddings (Mikolov et al., 2013).

In line with open and reproducible research practices, all materials developed during this doctoral thesis, together with the associated datasets and code scripts, are openly available on the Open Science Framework.

STRUCTURE OF THE DISSERTATION

Before moving on to the specific parts of this work, I summarize the general organization of the dissertation.

Part I, dedicated to the study of the STEPS phenomenon, is divided into three chapters. **Chapter I** presents an initial exploration of STEPS conducted prior to my enrollment in the doctoral program. In this work, we tested a previously proposed model of language/number production, while questioning its main assumptions, such as the idea that the origin of this phenomenon lies in the phonological output buffer, and discussing potential alternative accounts (García-Orza et al., 2020). This early work laid the foundation for **Chapter II** (Gutiérrez-Cordero & García-Orza, 2025), in which we conduct three studies designed to determine whether STEPS is an experimental artifact arising from the interaction between stimulus properties and the specific conditions under which number and word production are assessed. Specifically, we examine whether the semantic errors typically observed with numbers in STEPS also occur with non-numerical words under comparable conditions, and whether such errors can be modulated by word properties such as lexical frequency. Finally, in **Chapter III** we outline the findings from these two studies in a popular science article, available in both English and Spanish, discussing their broader implications for a general audience.

Part II focuses on the study of CdAs and is organized into three chapters. **Chapter IV** is the result of an open discussion with experts in the field, conducted to propose a definition of CdA. This definition helps to establish the conceptual basis for the remaining works in this part. **Chapter V** introduces a methodological contribution for researchers and clinicians that enables detailed analyses of language production quality at different levels (word, phoneme/letter, and, in cases of CdA, attempt level) and supports the automated classification of production errors using algorithms and AI-based models trained in Spanish. **Chapter VI** presents an experimental investigation that identifies the psycholinguistic variables—linked to the dorsal and ventral language streams—that influence the occurrence of CdAs and shape their path toward target-word access, with the ultimate goal of uncovering the processing dynamics underlying this behavior.

The dissertation closes with a general discussion that brings together the main findings of these two parts and considers their implications.



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PART I

*STEPS back to reconsider number and word
production*

INTRODUCTION

In this part, we focus on STEPS, which, as previously noted, refers to a behavioral pattern whereby individuals with aphasia predominantly make phonemic errors when producing ordinary content words (e.g., “lale” instead of “tale”) and pseudowords (e.g., “pamal” instead of “pepal”), but tend to make primarily semantic errors when producing number words (e.g., “thirteen” instead of “forty-two”) (Dotan & Friedmann, 2015). The earliest descriptions of this phenomenon in the literature can be traced to Norman Geschwind’s (1965) classical work, *Disconnexion syndromes in animals and man (Part II)*, published in the journal *Brain*, in which he described this double dissociation between numbers and words in his patients with conduction aphasia. Since then, this phenomenon has been documented through multiple case studies (e.g., Bencini et al., 2011; Cohen et al., 1997; García-Orza et al., 2020; Marangolo et al., 2004, 2005), as well as in studies involving larger samples (e.g., Dotan & Friedmann, 2015; Messina et al., 2009; Ochtrup et al., 2013).

One of the characteristic features of STEPS—the predominance of phonemic over semantic errors during word production—is consistent with the traditional consensus described in the General Theoretical Framework section regarding the relationship between lesions, mechanisms, and symptoms. These patients typically suffer from damage to the inferior parietal regions of the left hemisphere and surrounding areas, which are involved in phonological processing, such as phonological encoding (e.g., Cloutman et al., 2009; McKinnon et al., 2018). However, the other side of this phenomenon—the absence of phonemic errors and the presence of semantic errors specifically during the production of number words—challenges this view, especially considering that these patients have an intact lexical-semantic system (e.g., Dotan & Friedmann, 2015).

It should be acknowledged that some models propose a more flexible relationship between impaired cognitive mechanisms and the types of errors produced. Within the framework of interactive activation models of word production (e.g., Dell, 1986) and repetition (e.g., Martin & Saffran, 1992; Martin et al., 1996; Nozari & Dell, 2013; Nozari et al., 2010), it has been proposed that the coexistence of different error types in patients with phonological deficits may stem from variable difficulties in maintaining the phonological representations of target words over time (Martin & Saffran, 1992; Gold & Kertesz, 2001). According to this view, when the phonological system is compromised, patients tend to rely more heavily on their lexical and semantic knowledge to support their production. This compensatory strategy would

alter the error pattern, leading to a shift from phonological to lexical or semantic errors (Martin et al., 1994; Gold & Kertesz, 2001). However, the specificity of the STEPS effect—particularly the fact that the type of error varies depending on the stimulus category (numbers vs. words)—remains difficult to account for within this framework.

PREVIOUS ACCOUNTS OF THE STEPS

As a reaction to the limitations of current models of speech production to explain the STEPS, Dotan and Friedmann (2015) proposed the *Building Blocks Hypothesis* (BBH), an extension of the account proposed two decades earlier by Cohen et al. (1997). According to the BBH, numbers, letter names and even morphological affixes, in the same way as phonemes, may serve as the basic phonological units of speech, which would be combined to form more complex sequences such as multi-digit numbers or acronyms. This framework offers a way to reconcile the preservation of the lexical-semantic system with the emergence of specific semantic errors in contexts that require the manipulation of these specialized sublexical units.

According to the BBH proposed by Dotan and Friedmann, and the model they outline to explain the production of words, numbers, and other linguistic elements (see Figure 1), the STEPS effect originates from a disruption of the *phonological output buffer* (POB), a condition typically associated with the *reproduction variety* of conduction aphasia (e.g., Shallice & Warrington, 1977; Shallice et al., 2000). The POB is generally conceived as the mechanism responsible for *phonological encoding*, that is, the stage of language production in which phonemes are assembled to form the phonological representation of words and in which these representations are temporarily maintained until the articulatory plans are ready for execution (e.g., Hillis, 2001). When this system is compromised, errors occur in the selection and/or maintenance of phonemes, resulting in omissions, additions, or substitutions in both real words and pseudowords, leading to the characteristic phonemic errors.

The BBH introduces a novel perspective by extending the functional scope of the POB beyond phonemes. Dotan and Friedmann (2015) propose that this system not only stores the representations of single phonemes required for speech production, but is also organized into a series of mini-stores containing preassembled phonological units. Each of these mini-stores holds specific representations of different linguistic units such as phonemes, numbers, letter names, function words, and morphemes, which serve as building blocks within their respective domains. These units allow for the construction of more complex phonological sequences such

as multi-digit numbers, acronyms, or morphologically derived words. According to this hypothesis, when the POB is impaired, the resulting errors are not limited to phonemic omissions or substitutions in word production but may also involve full substitutions of the stored units in these modules. Behaviorally, this manifests as semantic or syntactic errors in number production, errors in letter naming, and morphological errors in affix use. Thus, the BBH offers a compelling account of the STEPS effect, albeit at the cost of challenging the traditional consensus that links brain lesions to specific disrupted mechanisms and their resulting symptoms.

OUR FIRST APPROXIMATION TO THE PROBLEM

Despite the explanatory capability of the BBH in accounting for the STEPS effect, we decided to put it to the test in the study *Saying thirteen instead of forty-two but saying lale instead of tale: Is number production special?* (García-Orza et al., 2020). Although this work was published prior to my enrollment in the doctoral program, it has been included in this dissertation due to its relevance as the foundation of the research conducted during this period, as presented in **Chapter I**. Here, I will examine it in depth, both for its theoretical value and for the conceptual framework it establishes for the present investigation.

In that study, we tested one of the core assumptions of the model proposed by Dotan and Friedmann (2015): that the STEPS effect arises from a disruption in the POB, the mechanism from which phonemes for regular content words and digits for multidigit numbers are retrieved upon their production.

Two individuals with aphasia participated in the study; both also participated in the other investigations on the STEPS effect included in this dissertation. The first of our two patients presented with *reproduction conduction aphasia*, caused by a specific deficit in the POB, a mechanism responsible, as previously explained, for phonological encoding during speech production. Damage to this system results in generalized difficulties in oral production tasks such as repetition, naming, and reading. In contrast, the second patient exhibited a *conduction aphasia of the repetition variety*, associated with a lesion in the *phonological input buffer* (PIB), a mechanism responsible for temporarily storing incoming verbal information via the auditory modality to enable subsequent repetition. Due to the locus of her deficit, this patient showed specific impairments in word and pseudoword repetition tasks, but not in other tasks such as naming or reading, in which the PIB is not involved.

To examine the emergence of the STEPS effect, we assessed both patients using number and non-number word production tasks across three different modalities: naming, reading, and repetition. According to the predictions of the BBH, the effect should appear only in the patient with a lesion in the POB, but not in the one with damage to the PIB. The findings were consistent with the BBH predictions in the case of the patient with the POB lesion, who exhibited the STEPS effect across all three production tasks. However, contrary to what the hypothesis would predict, the STEPS pattern also emerged in the repetition task performed by the patient with the PIB lesion, a mechanism required specifically for this task but minimally involved in naming and reading.

At this point, the BBH, as originally formulated by Dotan and Friedmann, proved insufficient. We therefore considered two possible explanations for the presence of the STEPS pattern in patients with an intact POB. One alternative is that the PIB might be organized in a way that mimics the structure of the POB, incorporating the same type of mini-stores proposed by the BBH (e.g., see Fischer-Baum et al., 2018). However, this explanation introduces additional conceptual complications to a model that already faces challenges in justifying some of its fundamental assumptions.

The proposed model assumes that (1) the POB contains mini-stores that are semantic (e.g., distinguishing between numbers and other words), syntactic (content words vs. function words), and morphologically (word roots vs. affixes) organized; and that (2) this mechanism is sensitive to the linguistic or semantic context in which words are produced. Although this point has not been explicitly addressed earlier in this introduction to the present set of studies, it is important to note that the STEPS effect—specifically, the occurrence of semantic errors—only emerges for number words when they are produced in numerically meaningful contexts; in the absence of such context, errors tend to be phonemic. The same pattern appears for function words: they tend to yield semantic errors when produced within sentences, but phonemic errors when produced in isolation. These two capabilities attributed to the POB led Dotan and Friedmann (2015) to suggest that this mechanism “...is phonological only in a broader sense, because it handles much more than just single phonemes” (p. 345).

However, the main issue with these assumptions is the absence of mechanisms to support them. On the one hand, it remains unclear how the various categories that organize the POB into mini-stores are projected onto a level that is fundamentally phonological in nature and, as such, should be sensitive only to phonological information, not to semantic or grammatical

properties. This issue becomes even more pronounced when considering that the proponents of the model claim that the POB should not be affected by other (lexical) properties like word frequency (Dotan & Friedmann, 2015), despite evidence to the contrary (see, e.g., Shallice et al., 2000). It is therefore difficult to accept that the POB could incorporate semantic and grammatical information while ignoring word frequency, a lexical property that operates between the semantic level and the POB. A similar argument applies to how the POB “knows” when to retrieve a word as a pre-assembled unit or when to construct it using segmented representations, as we pointed out in our work: “If there is a pre-assembled representation for ‘five’, what is the reason to use a segmented one?” (García-Orza et al., 2020, p. 292).

These arguments become even less tenable when considering the possibility that mini-stores are also present in the PIB. Within a serial processing model such as the one proposed by Dotan and Friedmann (2015), the auditory analyzer is the only component that feeds the PIB. It is therefore difficult to accept that this perceptual system could take into account deeper semantic or grammatical information (not only of the words but also the context in which they are assessed) to determine whether a pre-assembled or segmented phonological representation should be selected for language production. This is especially unlikely considering that the PIB is an input mechanism, only minimally involved in production processes.

An alternative explanation to the BBH arises from a detailed analysis of the experimental conditions under which the STEPS effect is typically assessed. In our previous work (García-Orza et al., 2020), we employed the same procedures as those used in other studies investigating this phenomenon. However, several factors suggest that the evaluation of words and numbers may not be equivalent, raising concerns about the comparability of results across these domains. (1) Whereas content words (e.g., “avocado”) are typically presented as single items, number words are often embedded as part of complex numerical expressions (e.g., “three hundred and forty-eight”), which place greater demands on memory and grammatical processing (Ochtrup et al., 2013). (2) Simple number words (e.g., “five”) are extremely high-frequency lexical items, and high frequency has been shown to reduce phonemic errors in patients with POB damage (Kittredge et al., 2008; Shallice et al., 2000). (3) Number production is typically assessed using semantically homogeneous lists, whereas word production studies have employed lists composed of a wide range of semantic categories such as animals, fruits, objects, clothing, toys, and furniture (Bachoud-Lévi & Dupoux, 2003; Bencini et al., 2011; Delazer & Bartha, 2001; Marangolo et al., 2004, 2005; Ochtrup et al., 2013; Rodriguez & Laganaro, 2008). Notably, there is strong evidence that homogeneous lists increase semantic interference in naming tasks

(Damian et al., 2001; Kroll & Stewart, 1994). (4) Finally, multi-digit number lists, composed of a limited and semantically related pool of elements that repeat, closely resemble the blocked-cyclic naming paradigm, which is known to elicit semantic interference effects (Belke et al., 2005; Ochtrup et al., 2013).

At this point, one can think of STEPS as being an experimental artifact rather than the direct manifestation of the specific architecture of a language production system. This possibility is supported by several factors, including the use of semantically homogeneous and repeated number word lists, which may lead to the overactivation of their representations; the increased phonological memory load involved in the production of multi-digit numbers; and the compensatory reliance on lexical-semantic processing observed in patients with phonological impairments (POB or PIB). In fact, evaluating patients in number production tasks may lead them to behave similarly to individuals located along a *deep-phonological continuum*, with a gradual shift from isolated phonological impairments to combined phonological and lexico-semantic deficits. Studies such as the one by Gold and Kertesz (2001) have shown that, depending on the degree of phonological memory load, which induces a condition similar to phonological memory impairment, patients tend to rely more heavily on lexical and semantic information. This shift in processing strategy has been further examined within interactive models of language production (see Martin & Saffran, 1992; Martin et al., 1996), which suggest that the nature of errors may change as a function of phonological impairment, with increased reliance on lexico-semantic processing when phonological processing is compromised. In our 2020 study, we proposed that greater experimental control over the stimuli (referring to those used in previous research) could lead to a more accurate understanding of STEPS, particularly when examined within the theoretical framework of connectionist models of language production (Dell, 1986; Martin & Saffran, 1992; Martin et al., 1996; Nozari & Dell, 2013; Nozari et al., 2010).

THE PRESENT WORK

As discussed above, the aim of this first part was to carry out a detailed exploration of the experimental conditions that give rise to and modulate the STEPS phenomenon. An initial approach to this objective is presented in **Chapter I** and further developed in the second study included in this dissertation—the first empirical investigation conducted during the course of my doctoral studies—published as *Disassembling an experimental artifact in aphasia: Why*

phonemic errors with words and semantic errors with numbers? in Cortex (Gutiérrez-Cordero & García-Orza, 2025). This research, presented in **Chapter II**, comprises three studies through which we identified the specific combination of factors responsible for this effect. Additionally, **Chapter III** presents a final multilingual popular science article, in English and Spanish respectively, summarizing the findings from the studies described in the first two chapters and discussing their broader implications.

OBJECTIVES AND HYPOTHESES

The specific aims of the experimental studies presented in this part are as follows:

- **Chapter I.** The aim of this chapter is to evaluate whether the STEPS effect originates in the phonological output buffer (POB). To this end, we compare two patients with different subtypes of conduction aphasia: one with a lesion affecting the POB and another with a lesion in the phonological input buffer (PIB).

According to the Building Blocks Hypothesis (BBH), the STEPS effect should emerge only in patients with POB damage, but not in patients like the one with PIB damage. This hypothesis posits that the POB stores pre-assembled phonological units (including numbers), and that damage to this buffer results in semantic rather than phonemic errors. In contrast, other word types, which require regular phoneme-by-phoneme assembly, are more likely to yield phonemic errors when the POB is impaired.

- **Chapter II.** This chapter explores whether the STEPS effect results from insufficient experimental control over the materials (words vs. numbers) and evaluation conditions, rather than reflecting a number-specific processing mechanism.
 - **Study 1** investigates whether the production of semantic errors in STEPS stems from increased auditory-verbal short-term memory (AV-STM) load. Specifically, it examines whether multi-digit numbers, which demand greater memory resources than single words, induce a shift in error type from phonemic to semantic.

According to the Continuum Hypothesis, increased memory load should lead to (a) a decline in overall performance and (b) a graded shift in error type, from phonemic to formal and eventually to semantic errors, particularly in the second word of a pair, where phonological resources become saturated while semantic activation persists.

- **Study 2a** tests whether semantic errors in number production result from the combined effects of memory load and semantic interference, rather than from a number-specific processing mechanism. To this end, we replicate the conditions of number production using non-numerical words presented under high memory load. Semantic interference is induced through the repeated production of semantically homogeneous, high-frequency items from a small, closed lexical set (e.g., common color names). Performance in this task is then compared to that observed in number production.

According to the BBH, color production should primarily result in phonemic errors, as is typical for non-number words. However, if semantic errors emerge under these conditions, this suggests that the STEPS effect is driven by the interaction between memory load and semantic similarity during the production of frequent words, rather than by the numerical nature of the stimuli.

- **Study 2b** examines whether the absence of phonemic errors in the production of numbers and other high-frequency words can be explained by lexical frequency, which may exert a protective effect.

To test this, we compare error patterns in the production of the high-frequency color sequences used in **Study 2a** with those elicited by matched low-frequency color sequences. We hypothesize that phonemic errors, the default error type in patients with phonological impairment, will reappear when lexical frequency is low.



CHAPTER I



*Saying thirteen instead of forty-two but
saying lale instead of tale: Is number
production special?¹*

¹ This chapter was published as García-Orza, J., Gutiérrez-Cordero, I., & Guandalini, M. (2020). Saying thirteen instead of forty-two but saying lale instead of tale: Is number production special? *Cortex*, 128, 281–296. <https://doi.org/10.1016/j.cortex.2020.03.020>

ABSTRACT

Stimulus Type Effect on Phonological and Semantic errors (STEPS) occurs when a person, following brain damage, produces phonemic errors with non-number-words (e.g., “lale” for “tale”), but produces semantic errors with number-words (e.g., “thirteen” for “forty-two”). Despite the relative frequency of this phenomenon, it has received little scholarly attention thus far. To explain STEPS, the *Building Blocks Hypothesis* has been proposed (Cohen, Verstichel, & Dehaene, 1997; Dotan & Friedmann, 2015): the phonological output buffer includes single phonemes as the units of speech production for words, whereas entire number-words are the building blocks of multi-digit production. Impairment in the phonological output buffer results in the incorrect selection of these units, leading to phonemic errors when producing non-number-words, but semantic errors when producing numbers. In the present study we consider two patients, one with a deficit in the phonological output buffer, and one with a deficit in the phonological input buffer but with a preserved phonological output buffer. Number-word and non-number-word repetition, naming, and reading abilities were assessed. As expected, STEPS was found in the patient with deficits in the phonological output buffer in the three tasks; more notably, evidence of STEPS was also found for the patient with deficits in the phonological input buffer in the repetition task. Since our results cannot be fully explained by the Building Blocks Hypothesis in its present form, we discuss the suitability of this hypothesis for the current data and consider alternative accounts of STEPS.

Access the article at the journal: <https://doi.org/10.1016/j.cortex.2020.03.020>

CHAPTER II



*Disassembling an experimental artifact in
Aphasia: Why phonemic errors with words
and semantic errors with numbers?²*

² This chapter was published as Gutiérrez-Cordero, I., & García-Orza, J. (2025). Disassembling an experimental artifact in Aphasia: Why phonemic errors with words and semantic errors with numbers? *Cortex*, 185, 184–210. <https://doi.org/10.1016/j.cortex.2025.02.005>



ABSTRACT

There is broad consensus as to the significance of speech errors in aphasia. The analysis of errors is understood to provide clear clues for clinical diagnosis, the identification of those cognitive-linguistic processes affected, and the corresponding impaired cerebral structures. However, Stimulus Type Effect on Phonological and Semantic errors (STEPS), a phenomenon in which a person with aphasia produces more phonological errors with words (e.g., “tamle” for “table”) but more semantic errors with number words (e.g., “thirteen” for “forty-two”), casts doubt on this consensus view. In this paper two studies are described, in which we explore whether STEPS is in fact a result of the lack of rigorous control over the materials compared (words vs. numbers) and the evaluation conditions. Two persons, one with a reproduction conduction aphasia and the other with a repetition conduction aphasia, participated in the studies. Study 1 explored the role of memory load in the emergence of STEPS by eliciting the repetition of pairs of semantically-unrelated words. In Studies 2a and 2b, our participants were asked to produce sequences of high- and low-frequency words from one semantic category (colors), and this was compared to the performance in multi-digit number production tasks. The results showed that sequences of high-frequency colors, like multi-digit numbers, were produced mainly with semantic errors, whereas sequences of low-frequency colors showed a mixed pattern with many phonemic and semantic errors. It seems that the production of semantic errors and the absence of phonemic errors in multi-digit numbers that give rise to STEPS is an experimental artifact caused by the combination of several factors: the use of semantically-related high-frequency words, produced cyclically under high-memory-demand conditions. These findings contribute substantially to the current discussion of language production models and allow for a deeper understanding of the neurocognitive processes that underly speech errors in aphasia.

Access the article at the journal: <https://doi.org/10.1016/j.cortex.2025.02.005>

CHAPTER III



What do speech errors in aphasia reveal about how we process language? The case of numbers and non-number words³

³ This chapter has been published as a popular science article: Gutiérrez-Cordero, I., & García-Orza, J. (2025). Is saying *apple* the same as saying *twenty-six*? How the evaluation context influences the production of speech errors in aphasia. *Ciencia Cognitiva*.

<https://www.cienciacognitiva.org/?p=2568>

ABSTRACT

The study of speech errors provides valuable insights into the functioning of our cognitive system. Several studies with individuals with brain damage have identified a different pattern of errors in the oral production of words and numbers, which has led to the proposal of independent mechanisms for processing these types of stimuli. In a recent study, we evaluated the production of numerical and non-numerical words under strict experimental control and found similar error patterns for both types of stimuli. Therefore, it does not appear necessary to postulate separate systems for the production of words and numbers.

Access the article at the journal: <https://www.cienciacognitiva.org/?p=2568>

CHAPTER III (Spanish version)



*¿Qué cuentan los errores del habla en la
afasia sobre cómo procesamos el lenguaje?
El caso de los números y las palabras no
numéricas⁴*

⁴ This chapter has been published as a popular science article in Spanish: Gutiérrez-Cordero, I., & García-Orza, J. (2025) ¿Es igual decir “manzana” que “veintiséis”? Lo que los errores del habla en la afasia nos revelan sobre los mecanismos del lenguaje. *Ciencia Cognitiva*. <https://www.cienciacognitiva.org/?p=2566>

RESUMEN

El estudio de los errores del habla proporciona información sobre el funcionamiento de nuestro sistema cognitivo. En varios estudios con personas con daño cerebral se ha encontrado un patrón diferente de errores en la producción oral de palabras y números que ha llevado a postular la existencia de dispositivos independientes para el procesamiento de estos estímulos. En un trabajo reciente evaluamos la producción de palabras numéricas y no numéricas bajo estricto control experimental, y encontramos patrones de error similares con ambos tipos de estímulos. Por tanto, no parece necesario postular sistemas independientes para la producción de palabras y números.

Access the article at the journal: <https://www.cienciacognitiva.org/?p=2566>

PART II

The origin of self-corrective verbal behaviors: Conduite d'approche

INTRODUCTION

Conduite d’approche (CdA) is a French term traditionally used to describe a repetitive verbal behavior commonly displayed by people with aphasia, by which they engage in multiple self-corrective attempts, typically improving the quality of their productions while trying to access a given word (e.g., “are, arta, arkel, arti... article!” for “article”). We know, thanks to Eling (2011), that the earliest documented description of this behavior, which has also been referred to as sequences of phonemic approximations (e.g., Joanette et al., 1980; Valdois et al., 1989), can be traced to 1868, in the doctoral dissertation by the Dutch physician Arnoldus van Rhijn, titled *Aphasie*, submitted to the University of Leiden in the Netherlands.

Although this behavior was described before the emergence of cognitive neuropsychology, generally dated to the 1970s and 1980s (see Laine & Martin, 2012, for a review), and has continued to be discussed in several studies since then (e.g., Berthier et al., 2012; García-Orza et al., 2020; Nadeau, 2001; Saffran, 2000; Torres-Prioris et al., 2019), it remains incompletely characterized at the linguistic level and is still not fully understood in either cognitive or neural terms.

AN EXPLANATION FOR THE CONDUITE D’APPROCHE

The current account of CdA proposes that the successive phonemic errors observed in this behavior, particularly in conduction aphasia where it has been described as a hallmark diagnostic feature (e.g., Bartha & Benke, 2003; Bernal & Ardila, 2009; Kohn, 1984, p. 101), stem from difficulties in phonological processing (Ueno & Lambon Ralph, 2013). However, this behavior is not exclusive to conduction aphasia but is also observed in other aphasic profiles, such as Wernicke’s aphasia, where it is considered a less beneficial behavior (Joanette et al., 1980), and in apraxia of speech, where errors originate from more peripheral processes (e.g., Duffy, 2020; Jacks & Haley, 2021). CdA has been proposed by authors such as Nadeau (2001) to function as a self-corrective mechanism supported by the lexico-semantic system. Its production is therefore thought to rely on the integrity of the lexico-semantic pathway, or more broadly, the ventral stream (e.g., Torres-Prioris et al., 2019). These predictions were examined by Ueno and Lambon Ralph (2013), who developed a neurocomputational model grounded in the architecture of the Dual Stream Model (Hickok & Poeppel, 2007) and informed by classic computational frameworks of word production (e.g., Dell et al., 1997).



Using their model, Ueno and Lambon Ralph successfully simulated key features of language impairments associated with different types of aphasia. Conduction aphasia, for instance, emerged when a lesion was introduced to the dorsal pathway. They also observed that successful CdAs occurred more frequently during recovery from such damage and that their production was partly supported by preserved lexical-semantic processing via the ventral stream. These findings align with the notion that the ventral stream provides critical feedback for comparing actual speech output with the intended target (Hickok & Poeppel, 2015; Nadeau, 2001; Ueno & Lambon Ralph, 2013; Torres-Prioris et al., 2019). Accordingly, most models of speech repair propose that the emergence of CdAs relies on the integrity of the ventral pathway in conjunction with damage to the dorsal stream.

By simulating a lesion in the dorsal stream, the model by Ueno and Lambon Ralph (2013) successfully reproduced the linguistic profile of conduction aphasia, including the occurrence of CdAs. Within this framework, they found that successful CdAs—those culminating in the correct production of the target word—were more frequent during the recovery phase, modeled as a period of retraining, and that their likelihood of success increased with the degree of ventral stream preservation. Alternatively, Hickok et al.'s (2011) speech monitoring model, also grounded in the Dual Stream Model (Hickok & Poeppel, 2007), can be extended to account for the production of CdAs. From this perspective, damage to the dorsal stream, typically associated with conduction aphasia, would compromise internal monitoring, hindering the online detection and correction of errors generated during auditory-motor integration and resulting in phonological errors. Consequently, monitoring would rely more heavily on an external mechanism supported by the ventral stream, whose role would become more prominent by enabling comparison of the produced output (here, phonological errors) with the lexical-semantic representation of the target word, thereby guiding self-correction attempts during CdAs. These considerations are consistent with the notion that the ventral stream provides critical feedback for comparing actual speech output with the intended target (Hickok & Poeppel, 2015; Nadeau, 2001; Ueno & Lambon Ralph, 2013; Torres-Prioris et al., 2019). Accordingly, most models of speech repair propose that the emergence of CdAs depends on the integrity of the ventral pathway in conjunction with damage to the dorsal stream.

Nonetheless, this perspective has important limitations. CdAs, although less frequent, have also been documented during the production of pseudowords, a type of stimulus that, by definition, is not supported by lexico-semantic processing and therefore cannot rely on the ventral semantic pathway (Ueno & Lambon Ralph, 2013). In any case, the main issue is not the

proposal of an interaction between streams, but rather the scarcity of direct experimental evidence. Arguments in favor of such interaction are based primarily on indirect observations, such as the lower frequency of CdAs in pseudoword production or their association with better-preserved ventral pathways. These observations nonetheless suggest that additional complementary mechanisms may be involved in triggering CdAs. Consequently, although dorsal and ventral stream accounts provide a valuable theoretical framework, their explanatory power could be enhanced by integration with more dynamic and task-sensitive models of language processing.

THE CURRENT STATE OF RESEARCH ON CDAS AND ITS LIMITATIONS

A review of the literature on CdA shows that analyses of this behavior have primarily focused on specific aspects, such as its relative frequency across different neuropsychological syndromes (e.g., Haley et al., 2023; Joannette et al., 1980; Marshall et al., 1980) and the extent to which its occurrence may indicate the involvement of the ventral stream (Ueno & Lambon Ralph, 2013). However, many fundamental questions have received far less attention or have been entirely overlooked. What causes a CdA? What factors make it more or less frequent? Is it an adaptive behavior? Additionally, we consider that CdAs have been addressed as a monolithic behavior, when in fact they involve producing different numbers of attempts and different types of errors. This raises additional questions, for instance: To what extent is CdA a real approximation to the target? Is the number of attempts related to reaching the target? What leads to abandoning this behavior? Questions like these should be addressed from an experimental point of view, taking into account variables such as task demands or psycholinguistic factors that are well known to affect word production.

Based on the available evidence and in line with interactive models of language processing, upon which Ueno and Lambon Ralph's (2013) computational framework is based, lexico-semantic influences are expected to be more prominent during naming tasks, whereas phonological influences tend to dominate in repetition tasks (Dell et al., 1997). This distinction suggests that the task demands themselves may modulate not only the occurrence of CdAs but also their nature, particularly in individuals with phonological deficits and preserved lexico-semantic processing, as is typically observed in conduction aphasia. In such cases, differences

may emerge not only in the proportion of CdAs produced but also in the degree of improvement achieved through the successive self-corrections they entail.

Despite the existing studies on the production of this behavior, research regarding task-specific differences remains limited and inconsistent. Direct comparisons across modalities are challenged by several methodological limitations, including the absence of data for certain tasks (e.g., Gandour et al., 1994 focused exclusively on spontaneous speech; Odell et al., 1995 examined only repetition; Joannette et al., 1980 assessed repetition and reading but excluded naming; and Ramoo et al., 2021 were unable to analyze naming due to data loss), the use of non-equivalent stimulus sets across tasks, and inconsistencies in how production quality is measured (Joannette et al., 1980; Odell et al., 1995; Sollereeder et al., 2015). Some studies have suggested that naming may elicit a higher proportion of CdAs (Marshall et al., 1980; Marshall & Thompkins, 1982), whereas others have reported more frequent occurrences in repetition than in reading tasks (Joannette et al., 1980; Ramoo et al., 2021). However, such findings should be interpreted with caution due to the considerable heterogeneity in experimental designs, task types, and materials employed across tasks even within the same study.

Moreover, these studies fail to account for psycholinguistic variables known to influence speech production and error patterns in aphasia. For instance, there is clear evidence that individuals with conduction aphasia are particularly sensitive to the phonological memory load induced by word length (see Wilshire, 2017, for a review). However, whether this similarly affects the production of CdAs has not been experimentally addressed. Importantly, from a dynamic perspective, this behavior involves not only engaging in the process but also producing different attempts until either accessing the target word or abandoning the search. Yet little is known about how specific psycholinguistic factors influence or modulate it.

Taken together, this fragmented, and methodologically heterogeneous landscape highlights the need for a systematic investigation of CdAs across different task modalities. Such an approach would allow for a more comprehensive understanding of the mechanisms underlying this phenomenon and its diagnostic and functional relevance in the clinical profile of aphasia. In parallel, it is essential to explore which psycholinguistic variables are involved in the emergence and modulation of CdAs, with the ultimate goal of advancing their linguistic and cognitive characterization.

It is evident that we are still far from a clear and comprehensive understanding of the mechanisms involved in speech error repair, and more specifically, in CdA. From our

perspective, one of the main obstacles to adequately understanding this phenomenon lies in the lack of a precise experimental characterization. To advance our understanding of the mechanisms underlying CdA, a necessary first step is to identify the psycholinguistic variables that may increase or reduce its frequency (such as lexical and syllabic frequency or word length) and modulate its resolution. The next step will be to examine the assessment conditions under which this behavior is triggered (such as the modality of the task used to assess language production). Once these basic factors have been identified, a subsequent approach will involve studying the role of monitoring abilities, both language-specific and domain-general, in the correction of phonemic errors. At this later stage, the analysis of CdA will allow us to explore which systems are involved in error detection and correction, assessing the integrity of the dorsal and ventral streams, as well as brain regions related to auditory and visual perception, and conflict monitoring.

In sum, this part aims to approach CdA from an integrative perspective that considers not only the mechanisms responsible for speech error generation, but also those involved in their repair, starting with psycholinguistic factors. The ultimate goal of this project is to clarify these processes at the cognitive level and to provide a more cohesive theoretical framework for understanding both errors and repair strategies in individuals with aphasia. This knowledge, in turn, should lay the groundwork for the development of more theoretically grounded and effective clinical interventions.

THE PRESENT WORK (WITH OBJECTIVES)

Following the considerations outlined above, the aim of this second part is to explore the nature of CdAs in greater depth, in order to understand the processing dynamics and cognitive mechanisms underlying their emergence and functioning.

The second part of this dissertation opens with **Chapter IV**, which provides a concise and updated definition of CdA intended to serve as a conceptual framework for its future operationalization in research. The formulation of this definition was based on open discussion and received the endorsement of leading experts who have extensively studied CdA, including Marcelo L. Berthier, Yves Joanette, Stephen E. Nadeau, Cristina Romani, and Carlo Semenza. **Chapter V** introduces *sunflower*, a methodological contribution to the study of language production errors in aphasia, which I developed as an R package. This open-source tool enables detailed assessment of production quality at both the word and within-word levels by computing

several indexes, also capturing letter- and phoneme-level performance (positional accuracy) from transcriptions of written and spoken productions. In addition, it automates error classification through algorithms and AI-based models (word2vec) trained in Spanish. Beyond analyzing isolated productions, *sunflower* allows the examination and classification of the successive attempts that occur within CdAs, making it particularly useful for exploring this behavior.

Finally, **Chapter VI** investigates the processing dynamics underlying CdAs in word repetition tasks, focusing on a case of reproduction conduction aphasia with impaired phonological encoding. Specifically, it examines how psycholinguistic factors associated with the dorsal phonological route and the ventral lexico-semantic route influence the production, maintenance, and resolution of CdAs. The analysis began with a series of factorial-design experiments and was subsequently expanded by incorporating word-level data from those experiments together with additional data obtained during ANC assessments in related studies. This comprehensive dataset was then analyzed using Bayesian mediation models.

CHAPTER IV



*A definition of conduite d'approche*⁵

⁵ This chapter was published as Gutiérrez-Cordero, I., Torres-Prioris, M. J., & García-Orza, J. (2025). Definition: Conduite d'approche. *Cortex*. 185, 151–152.

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CHAPTER V



Automating the formal analysis and classification of errors in aphasia with sunflower⁶

⁶ This chapter was published as Gutiérrez-Cordero, I., & García-Orza, J. (2025). sunflower: an R package for handling multiple response attempts and conducting error analysis in aphasia and related disorders. *Frontiers in Psychology, 16*, 1538196. <https://doi.org/10.3389/fpsyg.2025.1538196>

ABSTRACT

Manual classification of production errors and the allocation of speech/spelling scores are time-consuming, laborious and error-prone tasks, even when conducted by clinicians and specialized researchers. Here we present *sunflower*, an R package developed to improve the analysis of language production quality for Spanish data. The package offers various functions, including (1) managing dataframes containing single responses and multiple-attempt responses, (2) conducting formal similarity analyses on words as well as positional accuracy data analyses within words, and (3) the classification of errors by considering lexicality, formal similarity and semantic similarity indexes, which are obtained by means of different algorithms and artificial intelligence techniques such as word2vec. The applications of *sunflower*, which is the first open-source package of its kind, include assessing whether production quality improves over the course of multiple attempts, and identifying which aspects of an individual's productions are most impacted by their impairments. Other potential applications include the analysis of whether improvements arise in a patient's production quality after a given treatment, distinguishing between cases of apraxia of speech and conduction aphasia, as well as simply using the package to improve and speed up the classification of speech/spelling errors with large datasets through automation.

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CHAPTER VI



The psycholinguistic variables influencing conduite d'approche in repetition tasks⁷

⁷ This chapter was published as Gutiérrez-Cordero, I., Berthier, M.L., Torres-Prioris, M.J., & García-Orza, J. (2026). Psycholinguistic variables influencing conduite d'approche in repetition tasks: An experimental exploration and mediation analysis in a person with conduction aphasia.

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ABSTRACT

After brain damage, some individuals exhibit a verbal self-corrective behaviour in which they repeatedly attempt to refine their speech in order to retrieve a target word. This behaviour, traditionally termed *conduite d'approche* (CdA), provides a window into the mechanisms employed by the cognitive and neural systems to correct errors during language production. Here, we investigated which levels of language processing produces and shape the production of CdA in ANC, a person with reproduction conduction aphasia, by examining the impact on this behaviour of various psycholinguistic variables related to either the phonological dorsal areas or the lexico-semantic ventral areas. We explored the factors that influence the production of CdA and its maintenance and resolution during several word and pseudoword repetition tasks first in a set of experiments and then with mediation analyses on a more comprehensive data set. Results indicated a major role for word length, which led to more erroneous responses, more CdAs instances and to a higher number of attempts. Nevertheless, syllable and word frequency effects were not consistent. The mediation analyses further confirmed the relevance of length and identified a role for imageability, both in the number of attempts and in increasing successful access to the word. These findings align with the notion that when dorsal regions involved in phonological processing are lesioned in conduction aphasia, affected individuals compensate for their production difficulties by relying on lexico-semantic processes subserved by spared ventral structures to produce successful CdAs reaching the desired word.

Access the article at the journal: <https://doi.org/10.1080/02687038.2026.2613004>

GENERAL CONCLUSIONS

This dissertation examines two behaviors observed in individuals with aphasia: the *Stimulus Type Effect on Phonological and Semantic Errors* (abbreviated as STEPS throughout this document) and *conduite d'approche* (CdA), which, although distinct in nature, share a common challenge: they do not easily fit within the traditional consensus outlined in the General Theoretical Framework section regarding the associations among specific types of speech errors, the cognitive systems involved, and neuroanatomical damage. As detailed in the Introduction to each part dedicated to these phenomena, there is a clear need for a more precise investigation of the cognitive mechanisms underlying each behavior, as current interpretations remain insufficient.

Although each study includes its own detailed discussion and conclusions, this section provides a synthesis of the most relevant findings from each chapter, outlines the general limitations of the dissertation, and concludes with some final remarks.

CONCLUSIONS PER CHAPTER

PART I. STEPS

Chapter I. The results of this study call into question the Building Blocks Hypothesis (BBH), which has thus far been the predominant explanation for the STEPS effect. We found the STEPS—characterized by the predominant production of semantic errors with numbers and phonemic errors with words—in a patient with a POB impairment, as was predicted by the BBH, but also in a patient with damage to the phonological input buffer (PIB), where such an effect, in principle, would not be expected.

In light of these findings, an alternative version of the BBH was considered, extending the notion of mini-stores to the PIB and proposing that it operates similarly to the POB. However, as we discussed, this account presents more conceptual difficulties than the original BBH. These limitations led us to reject this hypothesis and to propose a more parsimonious explanation. We argued that the evaluation of number and word production differs considerably, not only in terms of their linguistic characteristics but also in how they are presented during tasks. Such differences, which point to an inadequate experimental control when comparing both types of stimuli, may help account for the emergence of the STEPS effect, particularly when interpreted within the framework of connectionist models. In this view, the dissociation observed in the error patterns between number and non-number words seems more plausibly

attributed to variations in processing dynamics shaped by task demands and testing conditions, rather than to the existence of distinct peripheral processes within the POB that are selectively engaged depending on stimulus type.

Chapter II. Building on the conclusions presented in **Chapter I**, this study aimed to determine whether the emergence of the STEPS effect is influenced by the conditions under which the production number is assessed. The findings support the idea that this effect is not intrinsic to stimulus type but instead arises from systematic differences in the typical assessment of number versus word production.

More specifically, the results from Study 1 indicated that increasing memory load during word repetition (by presenting word pairs) was not sufficient to elicit the error pattern characteristic of the STEPS effect. In Study 2a, we observed that when semantically related high-frequency words (in our case, common color names) were tested under high memory load conditions (presented in sequences and repeated within the same task), they elicited an error pattern similar to that observed in number production, thereby replicating the STEPS effect with non-number words. In Study 2b, we found that stimulus frequency plays a crucial role in error production. High-frequency stimuli appeared to have a protective effect against phonemic errors, whereas phonemic errors re-emerged when low-frequency color words were used. These errors, previously minimal with numbers and high-frequency colors (as observed in Study 2a), altered the characteristic pattern associated with the STEPS effect.

Overall, these findings support the view that the STEPS effect is best understood as an experimental artifact resulting from shifts in processing dynamics, particularly within the framework of interactive activation models. Patients with phonological impairment tend to rely on lexical and semantic mechanisms to support word production, especially when tasks impose high cognitive demands. Under these conditions, the repeated presentation and production of semantically related stimuli lead to high levels of interference inducing a blocking effect that affects the accurate selection of target words. This process often results in a shift from phonemic to semantic errors. However, the effectiveness of this compensatory support depends on the robustness of lexical representations: words with stronger representations (e.g., high-frequency items) provide more stable support, facilitating lexical access and increasing the likelihood of semantic errors.

Moreover, our results align with the *Continuum Hypothesis*, developed within the same interactive framework, which posits that phonemic, formal, and semantic errors fall along a

gradient shaped by the degree of phonological degradation and by the level of activation and noise within the system, leading patients with phonological impairments to exhibit error patterns resembling those observed in deep dysphasia. Altogether, these considerations highlight the need for precise control over assessment conditions and stimulus properties in clinical research, as task demands may distort patients' performance by either masking or exaggerating their underlying linguistic impairments. Beyond its mere characterization as an experimental artifact, the STEPS effect also provides neurofunctional evidence of the integrated functioning of both streams. In this view, strong semantic representations combined with a deficient dorsal stream—barely able to maintain the phonological trace of the presented item—in individuals with preserved comprehension favor compensatory support from the ventral stream. However, when this compensation occurs in the context of repeated representations from the same category, it can ultimately disrupt the functioning of an otherwise intact ventral stream.

PART II. Conduite d'approche

Chapter IV. This definitional work focused on CdA, a behavior that has been characterized in the literature using various terms and theoretical approaches. Its development was guided by open discussion with a group of renowned experts in the field (all of whom are acknowledged in this chapter), whose contributions were crucial to its final form. By delineating its core features, this work provides a solid conceptual basis for both future research on CdA and clinical practice, facilitating its systematic and consistent investigation.

Chapter V. This work introduces *sunflower*, a package written in R, one of the most widely used programming languages in our field, which was developed to support the complex analysis of language production samples and the automated classification of errors. This package can be used to assess the formal quality of spoken productions, whether based on orthographic transcriptions (e.g., “jirafa”) or International Phonetic Alphabet (IPA) transcriptions (/xi'rafa/), as well as written productions in Spanish, providing a wide range of metrics for this type of analysis and enabling fine-grained assessments at the phoneme or letter level, including positional and length-based analyses within individual words.

Beyond merely allowing to conduct a formal analysis, this tool also enables the automated classification of speech errors. This process takes direct or orthographic transcriptions (IPA transcriptions are not supported) as input and comprises several steps: (1) it analyzes how

formally similar the response is to the target, (2) checks whether that response exists in the lexicon using dictionaries and language databases, and, if the response is a real word, then (3) it calculates how semantically related it is to the target. The latter is based on artificial intelligence models, specifically word2vec, trained on large language corpora to estimate the degree of semantic relatedness between the two words. Based on the combined results of these analyses, *sunflower* assigns each response to an appropriate error category.

Although the tool requires human supervision, it significantly reduces manual effort and streamlines the analysis of large datasets. Its applications in research are straightforward, but it also has significant translational potential. In clinical settings, *sunflower* might help refine the diagnosis of language disorders by analyzing the nature of patients' productions and identifying specific impairments within them (such as those related to phonological encoding and the phonological output buffer, particularly in the selection and maintenance of phonemes). It may also serve to track patients' performance before and after treatment, thereby informing the design of more effective and individualized rehabilitation strategies.

Chapter VI. In this study, we examined which psycholinguistic variables are associated with the production, maintenance, and resolution of CdAs during repetition tasks, with the goal of elucidating the mechanisms that underlie and regulate this complex behavior.

Our results suggest that, in conduction aphasia, or at least in our case with an impaired POB patient, CdA arises from a disruption in phonological encoding processes subserved by the dorsal stream. The production and maintenance of CdAs, as reflected in the number of repeated attempts, as well as the likelihood of successful resolution, appear to be influenced by stimulus length. Longer words tend to induce CdA production and prompt more attempts, while also reducing the likelihood of retrieving the target word, highlighting the role of phonological load in shaping the dynamics of CdA. In addition, we found that the ventral stream, which is primarily involved in lexico-semantic processing, also contributes to the emergence of CdA during repetition, even though semantic processing is not explicitly required for this task. When CdAs occur, highly imageable words seem to benefit from a more sustained activation, which in turn facilitates access to the intended lexical item. This suggests that, even in repetition tasks where the use of a semantic route is not compulsory, semantic properties may play a compensatory role by helping to stabilize and resolve disruptions caused by phonological deficits.

The findings of this study provide a psycholinguistic perspective that complements current neuroanatomical dual-route models of language that offer an account of CdA and can be integrated into interactive models of language production, which promote the dynamic interplay between different processing levels. When the dorsal stream is impaired or overloaded, as suggested by the influence of word length, the language system appears to recruit additional resources to support production, particularly those associated with the ventral stream. This compensatory mechanism is reflected in the role of imageability, which facilitates word retrieval during CdA episodes. In sum, our results provide further evidence for the dynamic, interactive, and adaptive nature of the language production system.

LIMITATIONS AND FUTURE DIRECTIONS

The experimental studies presented in this dissertation were conducted using single-case designs, a choice driven by limited access to individuals with aphasia and broader challenges in recruiting participants from this clinical population. However, far from being a limitation, this methodological approach enabled the rigorous testing of theoretical hypotheses and allowed for detailed, individualized analyses of our patients' linguistic behavior. In this context, the findings highlight the value of single-case designs as a robust and still-relevant methodological tool in cognitive neuropsychology, particularly well-suited for in-depth investigations of the mechanisms underlying language processing.

This approach is especially relevant in the investigations of the STEPS effect presented in **Chapters I and II**, where the Building Blocks Hypothesis was critically examined and an alternative account was proposed, based on an in-depth analysis of two patients with distinct profiles of conduction aphasia. While this type of study allows for the generation and testing of hypotheses with a high degree of control and detail, its ability to generalize findings is inherently constrained, especially when compared to studies involving larger samples. This limitation becomes even more apparent in the study of CdA in repetition tasks (**Chapter VI**), where, unlike the STEPS investigations, no prior cases or comparable patient data were available to contextualize or contrast the performance of our patient.

While expanding the sample size would generally be desirable in future studies, research on the STEPS effect should focus on two main objectives: (1) to examine how the effect is modulated by the integrity of core cognitive mechanisms, paying particular attention to the nature and severity of phonological impairments, and to determine whether individuals with

lexico-semantic deficits show error patterns analogous to those observed in number production tasks when placed under similar testing conditions; and (2) to investigate the neural underpinnings of the effect through a combination of structural neuroimaging techniques, both non-functional (magnetic resonance imaging [MRI] and diffusion tensor imaging [DTI]) and functional (functional MRI [fMRI], magnetoencephalography [MEG], and electroencephalography [EEG]), together with analysis methods including voxel-based lesion–symptom mapping (VLSM), (DTI-based) tractography, and Connectome–Symptom Mapping (Baboyan et al., 2021), as well as non-invasive brain stimulation approaches such as transcranial direct current stimulation (tDCS) and transcranial magnetic stimulation (TMS). These approaches would help identify the anatomical substrates and functional dynamics associated with the effect, particularly in relation to the dorsal and ventral language pathways.

With regard to the study of CdA, future research should pursue the following directions. A starting point would be (1) to re-evaluate the role of psycholinguistic variables in CdA production in larger samples, examining how these factors influence behaviour as a function of the nature and severity of individuals’ functional impairments. In parallel, (2) to determine which psycholinguistic variables, or combinations thereof, best capture linguistic processing at each level, by evaluating whether simple, transparent indices are sufficient or whether multidimensional composite measures add explanatory value without compromising interpretability. Then, (3) to apply the abovementioned neuroimaging, analytical, and neuromodulation techniques to compare CdA manifestations across different clinical profiles and to investigate the role of individual differences; (4) to investigate the contribution of non-linguistic mechanisms, particularly executive control, in determining whether CdA reflects a language-specific phenomenon or a broader domain-general control process; and (5) to explore the potential influence of personality traits, a factor largely overlooked but possibly relevant to the behavioural expression of this self-corrective strategy.

In both cases, pursuing these research directions would not only advance our theoretical understanding of compensatory mechanisms at both the cognitive and neural levels, but also contribute to clinical research by refining assessment practices. Identifying the conditions under which compensatory strategies emerge, or shift (and how these affect performance) could also inform the design of more targeted and effective therapeutic interventions, tailored to the specific profiles and needs of individuals with aphasia.

Finally, future research should include a formal validation of the R package's classification accuracy by comparing its output with responses manually coded by human raters. This validation should be conducted using standard methods for evaluating the performance of classification systems, such as receiver operating characteristic (ROC) curve analysis, which assesses how effectively the system distinguishes between correct and incorrect responses across different decision thresholds. Based on the results, it may be necessary to train more accurate models or adjust the criteria used to estimate the semantic relationship between stimulus and response (as discussed in **Chapter V**). If the validation is successful, the tool could also be adapted to support other languages, thereby expanding its applicability in both research and clinical contexts.

CONCLUDING REMARKS

The studies presented in this dissertation converge on a central insight: language behavior in aphasia cannot be fully explained by fixed associations between lesion location, impaired cognitive mechanisms, and the resulting verbal behavior (particularly with respect to error types). Instead, language performance emerges from the interaction of multiple factors, including neurocognitive systems, the psycholinguistic properties of the stimuli, and the contextual demands of the task. Our findings on phenomena such as the STEPS effect and CdA illustrate the dynamic, context-sensitive, and adaptive nature of the language production system.

The evidence concerning the STEPS effect challenges prior simplistic interpretations that attribute specific error patterns to discrete lexical categories or modular subsystems (e.g., numbers, letters, function words). Instead, we propose that this pattern arises from the interaction between impaired phonological mechanisms, which are present in our patients but become exacerbated under high memory load, the psycholinguistic properties of the stimuli (e.g., lexical frequency), and the structure of the task itself, particularly the repeated evaluation of semantically related items. These findings support a view of language processing as inherently interactive and flexible. This interpretation is further reinforced by our findings on CdA, where we observed that when the dorsal stream is compromised, as in our case study of a patient with phonological output buffer damage, the system appears to recruit compensatory support from ventral stream resources. This dynamic is reflected in the facilitating effect of

imageability, which enhances word retrieval and supports the resolution of self-corrective behavior.

Together, the STEPS and CdA studies demonstrate that language errors in aphasia are not merely the result of damage to isolated components but often reflect the adaptive reconfiguration of the system under constraint. These findings are consistent with dual-route neuroanatomical models of language (e.g., Hickok et al., 2011; Ueno & Lambon Ralph, 2013), and dovetail with interactive activation frameworks (e.g., Dell et al., 1997) that emphasize the reciprocal influence between semantic and phonological processes in production.

I believe that the work presented in this dissertation advocates for a neuropsychology of language that is mechanistically precise, ecologically valid, and theoretically integrated. It promotes a view of aphasia that treats variability not as noise, but as a valuable window into the resilience and flexibility of the cognitive system; a variability that can inform and refine both theoretical models and clinical interventions.



RESUMEN

INTRODUCCIÓN

Los errores espontáneos del habla que ocasionalmente cometemos los hablantes evidencian fallos en los mecanismos de producción del lenguaje (e.g., Dell et al., 1997; Levelt et al., 1999). Su análisis permite comprender con mayor precisión el funcionamiento del sistema lingüístico y elaborar modelos de procesamiento capaces no solo de explicar la conducta observada, sino también de generar predicciones en contextos aún no explorados. Un modelo sólido de producción del lenguaje, además, debe dar cuenta tanto del desempeño de individuos sanos como del de aquellas personas con alteraciones del sistema (Coltheart, 2001). En este sentido, el estudio de personas con afasia resulta especialmente valioso, ya que en ellas estos errores, conocidos como parafasias, aparecen con mayor frecuencia y consistencia. En esta población, su análisis ofrece información clave sobre los procesos cognitivos y cerebrales que sustentan la producción de palabras (e.g., Caramazza, 1986).

Existe un consenso tradicional que vincula la localización de la lesión cerebral, el mecanismo cognitivo afectado y el tipo de error o parafasia resultante. Así, las parafasias semánticas (e.g., decir “revista” en lugar de “libro”) se atribuyen a alteraciones en los niveles semántico y/o léxico, y suelen asociarse con daño en el lóbulo temporal anterior izquierdo y otras regiones de la vía ventral del procesamiento del lenguaje. En cambio, los errores no léxicos, como las parafasias fonémicas (e.g., “mibro” en lugar de “libro”), se relacionan con alteraciones en procesos post-léxicos, como la codificación fonológica o el mantenimiento de secuencias de fonemas, y se vinculan con lesiones en el lóbulo parietal inferior izquierdo y otras áreas de la vía dorsal (Cloutman et al., 2009; Hillis, 2001; McKinnon et al., 2018; Mirman et al., 2015; Ramoo et al., 2021; Schwartz et al., 2009; Walker et al., 2011; Schwartz & Dell, 2016; Stark et al., 2019).

Sin embargo, ciertos comportamientos observados en personas con afasia, como el efecto del tipo de estímulo sobre los errores fonológicos y semánticos (STEPS) y la *conduite d’approche*, que se describirán en los apartados siguientes, no encajan fácilmente en el consenso tradicional expuesto. Estos fenómenos cuestionan la supuesta correspondencia uno a uno entre errores, por un lado, y niveles y áreas de procesamiento, por otro, planteada por dicho consenso, poniendo de relieve la complejidad funcional y la organización dinámica del sistema lingüístico. De ahí la necesidad de analizarlos en profundidad y situar su discusión en el marco de los modelos actuales de producción del lenguaje.

EL STEPS Y LA PARADÓJICA PRODUCCIÓN DE ERRORES FONÉMICOS CON PALABRAS Y SEMÁNTICOS CON NÚMEROS

El primero de estos comportamientos es el efecto del tipo de estímulo sobre los errores fonológicos y semánticos (en inglés: Stimulus Type Effect on Phonological and Semantic Errors, abreviado como STEPS) (Cohen et al., 1997; Dotan & Friedmann, 2015), según el cual, en personas con afasia, la producción de palabras con contenido léxico se asocia principalmente con errores fonémicos (e.g., “mibro” por “libro”), mientras que la producción de números se caracteriza, en cambio, por la aparición de errores semánticos (e.g., “trece” por “cuarenta y dos”). Las primeras descripciones de este fenómeno fueron realizadas por Geschwind (1965), quien observó una doble disociación entre números y palabras en pacientes con afasia de conducción. Desde entonces, este fenómeno se ha documentado tanto en múltiples estudios de caso (e.g., Bencini et al., 2011; Cohen et al., 1997; Marangolo et al., 2004, 2005), como en investigaciones con muestras más amplias (e.g., Dotan & Friedmann, 2015; Messina et al., 2009; Ochtrup et al., 2013).”

Una de las características del STEPS es, como ya se ha señalado la prevalencia de errores fonémicos en la producción de palabras, lo cual es coherente con el consenso tradicional que vincula las lesiones en las regiones parietales inferiores izquierdas y áreas adyacentes con el procesamiento fonológico, como la codificación fonológica (e.g., Cloutman et al., 2009; McKinnon et al., 2018). Sin embargo, otro aspecto del fenómeno desafía este consenso: la escasez de errores fonémicos y la preponderancia de errores semánticos en la producción de números, incluso cuando el sistema léxico-semántico permanece intacto (e.g., Dotan & Friedmann, 2015). Este patrón, difícil de explicar desde los modelos clásicos de producción del lenguaje, muestra que un mismo déficit fonológico puede manifestarse de manera distinta según el tipo de estímulo (palabras vs. números). Además, desde una perspectiva anatómico-funcional, resulta igualmente problemático: los errores semánticos con los números aparecen sin indicios de deterioro conceptual ni de daño en la vía ventral del lenguaje, mientras que los errores fonémicos están prácticamente ausentes a pesar de la presencia de lesiones en la vía dorsal.

En la primera descripción experimental de este fenómeno, Cohen y sus colaboradores (1997) evaluaron a un paciente francés con afasia de Wernicke que, al producir palabras, cometía principalmente neologismos (errores fonológicos no formales, e.g., “mifra” por “libro”,

considerados más graves que las parafasias fonémicas) y, de manera llamativa, errores semánticos al producir tanto números multi-dígitos como acrónimos, sustituyendo unos números o letras por otros. Para explicar este patrón de comportamiento, los autores propusieron que los números y los nombres de las letras podrían funcionar de manera similar a los fonemas, actuando como unidades básicas (es decir, los *building blocks*) del lenguaje a partir de las cuales se construyen elementos más complejos, como multi-dígitos, acrónimos o palabras. Aunque reconocieron que esta propuesta era especulativa, les permitió dar cuenta del patrón observado: la aparición de errores con base fonológica en palabras no numéricas — atribuibles a una alteración en el trabajo con fonemas— y de errores semánticos en números — explicables por un fallo en la selección de las unidades básicas propias de los números (pp. 1058-1059).

Dos décadas más tarde, Dotan y Friedmann (2015) estudiaron más a fondo el STEPS en una muestra de seis pacientes con afasia de conducción y refinaron la propuesta original de Cohen et al. desarrollando la hipótesis de los building blocks (BBH, por sus siglas en inglés). Esta hipótesis propone que el STEPS se origina en el almacén fonológico de salida (*phonological output buffer*, POB), un mecanismo cuya alteración se ha asociado de forma consistente con la variante de afasia de conducción de repetición (e.g., Shallice & Warrington, 1977; Shallice et al., 2000). En este marco, el POB se concibe como el mecanismo encargado de la codificación fonológica, es decir, la etapa de la producción del lenguaje en la que los fonemas se seleccionan y ensamblan para conformar la representación fonológica de las palabras, la cual se mantiene temporalmente hasta que los planes articulatorios están listos para su ejecución (e.g., Hillis, 2001). No obstante, la BBH amplía esta concepción del POB al proponer que este no se limita a almacenar representaciones de fonemas individuales, sino que también se organiza en una serie de “mini-almacenes” que contienen unidades fonológicas preensambladas. Cada mini-almacén incluiría representaciones específicas de distintos tipos de unidades lingüísticas, como fonemas, números, nombres de letras, palabras funcionales y morfemas, que funcionarían como bloques de construcción dentro de sus respectivos dominios. Estas unidades se utilizarían para formar secuencias fonológicas más complejas, como números multi-dígitos, acrónimos o palabras derivadas morfológicamente.

La alteración del POB no solo provocaría errores de omisión o sustitución de fonemas durante la producción de palabras, sino que también afectaría al trabajo con las unidades almacenadas en los mini-almacenes. En el caso concreto que aquí nos ocupa, esto llevaría a las personas con afasia a cometer principalmente errores semánticos o sintácticos en la producción

de números. De este modo, la BBH ofrece una explicación coherente de la aparición de los errores que caracterizan al STEPS, aunque al hacerlo no solo cuestiona el consenso tradicional que establece una correspondencia directa entre las lesiones cerebrales, los mecanismos específicos alterados y los síntomas observados, sino que también plantea ciertos desafíos conceptuales y experimentales.

En primer lugar, los modelos seriales de producción del lenguaje, como el propuesto por Dotan y Friedmann (2015), tienen problemas para explicar cómo el POB —un sistema que trabaja con información fonológica y que, por tanto, debería organizarse en función de propiedades fonológicas— pudiera distinguir entre palabras en función de sus características léxicas o semánticas. Segundo, la literatura sobre la denominación de palabras y números arábigos en niños (dado que en adultos estos errores son poco frecuentes) muestra que los errores más comunes son de tipo semántico, mientras que los fonémicos son escasos en ambos tipos de estímulo (Barrouillet et al., 2004; McGregor et al., 2002; Moura et al., 2013).

Este patrón sugiere la existencia de mecanismos comunes para el procesamiento de palabras numéricas y no numéricas, lo que pone en duda la necesidad de postular mecanismos diferenciados para ambos dentro del POB. Tercero, el STEPS se ha documentado en estudios de grupo en pacientes con distintos tipos de afasia, como la de Broca y la de Wernicke (Messina et al., 2009), a pesar de que las alteraciones del POB no son habituales en este último perfil (Robson et al., 2012). En su conjunto, estas observaciones cuestionan las asunciones fundamentales del modelo de Dotan y Friedmann, según el cual el STEPS emergería como consecuencia de una alteración del POB, y subrayan la necesidad de someter esta propuesta a un examen más crítico.

Por último, hay que considerar factores metodológicos. La producción de números y palabras no suele evaluarse bajo las mismas condiciones. Las palabras numéricas presentan una alta frecuencia de uso, y cuando se combinan en multi-dígitos, en los que tiende a emerger el STEPS, suelen implicar estructuras morfosintácticas complejas y de considerable longitud que tienden a sobrecargar el sistema de producción más que las palabras (e.g., para 451, “cuatrocientos cincuenta y uno” vs. “cocodrilo”). Además, la evaluación de números suele realizarse presentando listas semánticamente homogéneas, mientras que las de palabras suelen incluir elementos de categorías diversas. Tales diferencias podrían explicar los distintos tipos de errores asociados a la producción de palabras y números sin necesidad de postular mecanismos especializados en el POB.

Por ello, y como se detallará a continuación, la investigación aquí presentada sobre el STEPS se orienta a explorar estas diferencias metodológicas y sus implicaciones en la producción de palabras, tanto numéricas como no numéricas.

OBJETIVOS

Los objetivos específicos establecidos para abordar el estudio del STEPS en la primera parte de esta tesis se han desarrollado en sus respectivos capítulos y fueron los siguientes:

- El **Capítulo I** tiene como objetivo verificar si el efecto STEPS tiene su origen en el POB tal cual se propone desde la BBH (Dotan y Friedmann, 2015). Se compara el rendimiento de dos pacientes con afasia de conducción que difieren en el locus de su déficit fonológico: una con el subtipo de reproducción, asociado a un daño en el almacén de salida fonológica (POB), y otra con el subtipo de repetición, vinculado a una alteración en el almacén de entrada fonológica (phonological input buffer, PIB).
- El objetivo del **Capítulo II** es examinar si el efecto STEPS se debe a una falta de control en las condiciones experimentales empleadas para evaluar la producción de palabras y números, en lugar de reflejar un mecanismo específico del procesamiento numérico (como discutimos en el **Capítulo I**). Más concretamente:
 - Estudio 1. Explorar si la producción de errores semánticos con números se explica por un aumento en la carga de memoria auditivo-verbal a corto plazo durante la producción —aquí repetición— de palabras.
 - Estudio 2a. Analizar si los errores semánticos observados en el STEPS se originan a partir de la combinación de carga de memoria e interferencia semántica en palabras frecuentes, en lugar de reflejar un mecanismo específico del procesamiento de palabras numéricas y no numéricas. Se analiza la producción de secuencias de palabras en tres modalidades —denominación, lectura y repetición—, simulando las condiciones en que habitualmente se evalúa la producción de números.
 - Estudio 2b. Evaluar si la frecuencia léxica cumple con un papel protector frente a la producción de errores fonológicos.

- El **Capítulo III**, en sus versiones en inglés y en español, constituye un artículo de divulgación que presenta los hallazgos sintetizados de los dos capítulos anteriores y sus implicaciones.

RESULTADOS

En lo que respecta a los resultados de las investigaciones experimentales de la primera parte de la tesis, el **Capítulo I** pone a prueba la BBH, hasta ahora la única propuesta formulada para explicar este efecto. Según esta hipótesis, una lesión del POB no solo daría lugar a errores fonémicos por la omisión o selección incorrecta de fonemas durante la producción de palabras, sino también a dificultades en la selección y mantenimiento de números, concebidos como unidades fonológicas preensambladas que actúan como building blocks para la producción de números multi-dígitos. En este caso, la alteración de dicho mecanismo conduciría a que, en lugar de errores fonémicos, aparecieran errores semánticos derivados de una selección inadecuada de los números, lo que explicaría el patrón característico del STEPS. En línea con las predicciones de la BBH, nuestra paciente DNR, con daño en el POB, mostró el STEPS; sin embargo, el mismo patrón se observó también en la paciente ML, con daño en el PIB, donde este efecto no debería aparecer a priori. Estos hallazgos podrían explicarse extendiendo la BBH al PIB, aunque esta reformulación presenta incluso más dificultades conceptuales que la propuesta original. Una alternativa más parsimoniosa es considerar que el STEPS no se debe a la alteración de un mecanismo específico como el POB, sino a las diferencias inherentes en la evaluación de palabras y números. En este marco, el patrón de errores se entiende mejor como resultado de dinámicas de procesamiento moduladas por las demandas de la tarea, en consonancia con modelos conexionistas, y no como la expresión de procesos periféricos diferenciados en el POB.

En el **Capítulo II** desarrollamos la investigación de esta segunda alternativa con el objetivo de determinar si la aparición del STEPS depende de las condiciones de evaluación más que del tipo de estímulo. Los resultados del Estudio 1 mostraron que el aumento de la carga de memoria en la repetición de palabras, por sí solo, no era suficiente para generar el patrón del STEPS. Sin embargo, en el Estudio 2a observamos que, bajo condiciones de alta carga y con repetición de palabras frecuentes y semánticamente relacionadas —las mismas en las que se evalúa la producción de números—, emergía un patrón similar al observado con los números. Finalmente, en el Estudio 2b confirmamos el papel de la frecuencia léxica en la aparición de

este efecto: las palabras de alta frecuencia protegían frente a los errores fonémicos, mientras que con palabras de baja frecuencia estos reaparecían, modificando el patrón característico del STEPS.

En conjunto, nuestros hallazgos sugieren que el efecto STEPS se comprende mejor como un artefacto experimental, fruto de cambios en las dinámicas de procesamiento inducidos por las condiciones de evaluación no siendo su única causa la existencia de una lesión específica del POB, ni siendo necesaria la necesidad de postular building blocks más allá de los fonemas. Hemos mostrado que los pacientes con déficit fonológico tienden a apoyarse en los niveles léxicos y semánticos preservados para sostener la producción verbal, particularmente cuando las tareas imponen altas demandas cognitivas. En estas condiciones, la repetida exposición y producción de estímulos semánticamente relacionados puede desencadenar una fuerte interferencia, produciendo un efecto de bloqueo que dificulta la selección precisa de las palabras objetivo. Esto se traduce en una transición de los errores fonémicos, propios de estos perfiles afásicos, hacia errores semánticos, a priori inesperados. La eficacia de este apoyo compensatorio depende, no obstante, de la solidez de las representaciones léxicas: las palabras con representaciones más robustas (como los ítems de alta frecuencia) brindan un soporte más estable, facilitan el acceso léxico e incrementan la probabilidad de errores semánticos. Así, el STEPS ilustra cómo los recursos léxico-semánticos vinculados con la ruta ventral pueden sostener y reorganizar la producción cuando el sistema fonológico dorsal se ve comprometido.

LA CONDUITE D'APPROCHE COMO COMPORTAMIENTO AUTO-CORRECTIVO

La conduite d'approche (abreviada a lo largo de este trabajo como CdA) es el término francés utilizado para designar una conducta verbal repetitiva observada en personas con afasia, mediante la cual se realizan sucesivas auto-correcciones fonémicas con el fin de aproximarse y, en última instancia, alcanzar una palabra objetivo durante la producción del habla (por ejemplo: “ar, arta, arquel, arti... artículo” para “artículo”) (e.g., Goodglass, 1992; Kohn, 1984). En la literatura se ha propuesto que la CdA surge como resultado de la compensación de la ruta ventral cuando la ruta dorsal del procesamiento lingüístico se encuentra dañada (Nadeau, 2001; Ueno & Lambon Ralph, 2013). No obstante, como veremos más adelante, esta propuesta resulta vaga en la actualidad, ya que no considera qué factores determinan o modulan la aparición de la CdA, ni contempla la posible participación de otros mecanismos relevantes en su producción.

Más en profundidad, las explicaciones actuales de este comportamiento, considerado incluso una característica diagnóstica distintiva de la afasia de conducción (e.g., Bartha & Benke, 2003; Bernal & Ardila, 2009; Kohn, 1984, p. 101), lo vinculan con dificultades en el procesamiento fonológico (Ueno & Lambon Ralph, 2013). No obstante, la CdA no es exclusiva de este síndrome, ya que también se observa en otros perfiles afásicos, como el de Wernicke, así como en la apraxia del habla —donde el locus del déficit se sitúa en procesos más periféricos—, en los que la aproximación o acceso a la palabra objetivo resulta, sin embargo, menos evidente o eficaz (Duffy, 2020; Jacks & Haley, 2021; Joanette et al., 1980).

Inicialmente, Nadeau (2001) argumentó que el proceso de autocorrección subyacente a la CdA podría estar respaldado por el sistema léxico-semántico durante la producción de palabras, lo que podría explicar que resulte más beneficiosa en la afasia de conducción que en la afasia de Wernicke. En consecuencia, su aparición dependería de la integridad de la vía léxico-semántica o, en un sentido más amplio, de la ruta ventral (e.g., Torres-Prioris et al., 2019). Luego, Ueno y Lambon Ralph (2013) retomaron estas ideas y las incorporaron en un modelo (neuro)computacional, basado en la arquitectura del Modelo de Doble Ruta (Hickok & Poeppel, 2007) e inspirado en marcos computacionales clásicos de la producción de palabras (e.g., Dell et al., 1997), con el que simulaban las características principales de distintos tipos de afasia (véase también Ueno et al., 2011).

Ueno y Lambon Ralph (2013) simulaban una lesión en la ruta dorsal y lograron reproducir el perfil lingüístico característico de la afasia de conducción, incluida la producción de CdAs. En este marco, observaron que las CdAs exitosas —es decir, aquellas que culminaban en la producción correcta de la palabra objetivo— eran más frecuentes durante la fase de recuperación, representada en el modelo como un período de reentrenamiento, y su probabilidad de éxito aumentaba con el grado de preservación de la ruta ventral. Alternativamente, el modelo de monitorización del habla de Hickok et al. (2011) puede ampliarse para intentar explicar la producción de las CdAs. Desde este marco, la afectación de la ruta dorsal, que típicamente asociamos con la afasia de conducción, comprometería la monitorización interna, dificultando la detección y corrección en línea de los fallos generados durante la integración auditivo-motora y dando lugar a errores fonológicos. En consecuencia, la monitorización pasaría a depender de un mecanismo externo sostenido por la ruta ventral, cuyo papel ganaría importancia al permitir contrastar las producciones realizadas, en estos casos los errores fonológicos, con la representación léxico-semántica de la palabra objetivo, guiando los intentos de autocorrección durante la CdA. De este modo, los modelos actuales de reparación del habla plantean que la

aparición de CdAs depende de la integridad de la ruta ventral en combinación con un daño en la ruta dorsal.

Sin embargo, esta visión presenta algunas limitaciones en cuanto al origen y la resolución de la CdA. Las CdAs, aunque menos frecuentes, también se han documentado durante la producción de pseudopalabras, un tipo de estímulo que, por definición, no está sustentado por el procesamiento léxico-semántico y, por tanto, no puede apoyarse en la vía semántica ventral. Además, las propuestas teóricas, como la existencia de una interacción entre rutas, deben explicar además de la producción de las CdAs, las variables y mecanismos implicados en la producción de diferentes intentos tanto exitosos como no exitosos hasta la producción de la última respuesta. Es decir, deben entender las CdAs como una conducta reparadora compleja y salvo honrosas excepciones (see Joannette et al., 1980; Ueno & Lambon Ralph, 2013), el acercamiento a las CdAs ha sido bastante superficial.

A estas limitaciones teóricas se suman otras de carácter empírico. El estado de la cuestión evidencia cómo el estudio de esta conducta se ha centrado en aspectos generales, como estimar su frecuencia relativa en distintos síndromes neuropsicológicos y cuantificar la mejora en la calidad de las producciones que posibilita en cada uno de ellos (e.g., Haley et al., 2023; Joannette et al., 1980; Marshall et al., 1980), o valorar hasta qué punto su aparición podría reflejar la implicación de la ruta ventral (Ueno & Lambon Ralph, 2013). Sin embargo, permanecen abiertas cuestiones fundamentales, como qué la desencadena, qué factores modulan su frecuencia y si constituye una conducta funcional. Abordar estas preguntas exige un enfoque experimental que considere explícitamente las demandas de la tarea y variables psicolingüísticas con efectos conocidos en la producción de palabras.

En esta misma línea, la investigación comparativa entre modalidades de producción resulta todavía limitada y metodológicamente desigual. Existen pocas comparaciones directas entre las tareas habitualmente empleadas para evaluar la producción del lenguaje en contextos clínicos o experimentales (e.g., Gandour et al., 1994, se centraron en el habla espontánea; Odell et al., 1995, examinaron solo repetición; Joannette et al., 1980, evaluaron repetición y lectura pero no denominación; Ramoo et al., 2021, no pudieron analizar la denominación por pérdida de datos). A ello se suman el uso de conjuntos de estímulos no equivalentes entre tareas y la aplicación de criterios heterogéneos para medir la calidad de las producciones (esto es, los intentos) que conforman las CdAs (Joannette et al., 1980; Odell et al., 1995; Sollereeder et al., 2015). Así, mientras algunos estudios sugieren que la denominación podría elicitarlas en mayor

proporción (Marshall et al., 1980; Marshall & Thompkins, 1982), otros informan de más ocurrencias en repetición que en lectura (Joanette et al., 1980; Ramoo et al., 2021). En conjunto, estos resultados deben ser considerados con cautela debido a la considerable heterogeneidad de diseños, tareas y materiales, tanto entre estudios como dentro de un mismo estudio. De acuerdo con la evidencia disponible y en línea con los modelos interactivos de procesamiento del lenguaje en los que se basa la propuesta (neuro)computacional de Ueno y Lambon Ralph (2013), se espera que las influencias léxico-semánticas sean más prominentes en las tareas de denominación, mientras que las fonológicas tiendan a dominar en la repetición (Dell et al., 1997; Nozari & Dell, 2013). Esta distinción sugiere que las demandas de la tarea pueden modular no solo la ocurrencia de la CdA, sino también su naturaleza, especialmente en personas con déficit fonológico y procesamiento léxico-semántico preservado.

A las carencias identificadas en la investigación de las CdAs, se suma, además, la escasa atención que han recibido las variables psicolingüísticas en la comisión de CdAs, a pesar su valor como indicadores clave del funcionamiento en distintos niveles de procesamiento. El conocimiento actual sobre los factores que determinan este fenómeno sigue siendo limitado, y los marcos teóricos disponibles adolecen de precisión, a menudo reducidos a suponer que la CdA respalda la existencia de mecanismos de monitorización (Hickok et al., 2011). En la afasia de conducción, donde la CdA es especialmente característica, se ha documentado sensibilidad a factores como la frecuencia léxica y, sobre todo, la longitud de la palabra, que incrementa la carga de memoria fonológica y afecta al rendimiento en tareas de producción del lenguaje (véase Wilshire, 2017, para una revisión). Con todo, sigue sin establecerse de forma experimental en qué medida estos factores inciden específicamente en la CdA como conducta compleja.

Este panorama fragmentado y heterogéneo justifica una agenda de investigación sistemática que compare modalidades con materiales controlados e incorpore predictores psicolingüísticos relevantes.

Una caracterización experimental más precisa permitirá delimitar los mecanismos que generan y reparan la CdA, para luego poder pasar a estudiar el papel de la monitorización, tanto lingüística como general, pues como se ha discutido más arriba, la evidencia experimental que apoya la explicación de las CdAs como fruto de un daño dorsal en el contexto de la preservación de estructuras ventrales es además de escasa ciertamente genérica, al no ofrecer detalles de cómo y en qué circunstancias concretas se produce esta interacción. Sólo a partir de la

elaboración de un marco teórico más sólido que explique tanto la producción de errores como las estrategias de corrección en la afasia, podremos desarrollar procedimientos que tengan repercusiones directas sobre la evaluación y la intervención clínica de las personas con afasia.

OBJETIVOS

Los objetivos específicos que nos establecimos para abordar el estudio de la CdA en la segunda parte de la tesis fueron los siguientes por capítulo.

- Nuestra finalidad con el **Capítulo IV** es proporcionar una definición clara y actualizada de la conduite d'approche, mediante un foro de discusión con expertos en afasiología y neurociencia cognitiva.
- En el **Capítulo V** el objetivo es desarrollar una herramienta open source (paquete de R) para analizar la calidad formal de producciones lingüísticas y clasificar errores de acuerdo con la tipología tradicional en el área (véase Dell et al., 1997).
- Finalmente, en el **Capítulo VI** se investiga qué factores lingüísticos y, en consecuencia, qué niveles de procesamiento dan origen y modulan la producción de la CdA en la afasia de conducción asociada al daño del POB. En particular, se analiza cómo diferentes variables psicolingüísticas, vinculadas a la ruta fonológica dorsal o a la ruta léxico-semántica ventral, inciden en la aparición y el curso de este comportamiento durante una tarea de repetición de palabras.

RESULTADOS

En esta segunda parte dedicada al estudio de la CdA, el **Capítulo IV** ofrece una definición actualizada de este comportamiento, elaborada a partir del consenso de reconocidos expertos en el área: Marcelo L. Berthier, Yves Joanette, Stephen E. Nadeau, Cristina Romani y Carlo Semenza. El **Capítulo V** presenta *sunflower*, un paquete de R diseñado para analizar la calidad formal de las producciones lingüísticas tanto a nivel de palabra como de sus elementos constitutivos (fonemas/letras) y de los intentos que conforman las CdAs. Asimismo, este paquete de funciones incorpora la posibilidad clasificación automática de errores (parafasias) a partir de medidas de similitud formal, lexicalidad y proximidad semántica, siguiendo la tipología tradicional del área (Dell et al., 1997). Esta herramienta reduce de manera significativa

el esfuerzo manual de investigadores y clínicos, y posibilita un análisis más exhaustivo y sistemático de fenómenos como la CdA, incluso cuando se trabaja con grandes volúmenes de datos.

En esta parte también llevamos a cabo una exploración experimental de la CdA, presentada en el **Capítulo VI**. En este estudio examinamos qué variables psicolingüísticas modulan la producción, el mantenimiento y la resolución de la CdA durante tareas de repetición, con el objetivo de esclarecer los mecanismos que subyacen y regulan este comportamiento. Nuestros resultados sugieren que, en el caso de nuestro paciente, ANC, con daño en el POB, y muy probablemente en aquellos con afasia de conducción, la CdA surge de una alteración en los procesos de codificación fonológica soportados por la ruta dorsal. La producción y el mantenimiento de la CdA, reflejados en el número de intentos producidos, así como la probabilidad de acceso a la palabra objetivo, parecen estar influenciados por la longitud del estímulo: las palabras más largas tienden a inducir la CdA, generar más intentos y reducir la probabilidad de recuperar la palabra objetivo, lo que resalta el papel de la carga fonológica en la dinámica de este comportamiento.

Además, encontramos que la ruta ventral, relacionada con el procesamiento léxico-semántico, también contribuye a la producción de la CdA durante la repetición de palabras, aun cuando este tipo de procesamiento no es estrictamente necesario. Concretamente, en el caso de ANC, las palabras con alta imaginabilidad parecen beneficiarse de una activación más sostenida durante las CdAs, lo que facilita el acceso al ítem léxico, compensando los déficits fonológicos

Los hallazgos de este estudio ofrecen una perspectiva psicolingüística que complementa los modelos neuroanatómicos de doble ruta del lenguaje aplicados a la CdA, y que puede integrarse en modelos interactivos de producción lingüística, los cuales destacan la interacción dinámica entre distintos niveles de procesamiento. Cuando la ruta dorsal está alterada o sobrecargada, como sugiere la influencia de la longitud de la palabra, el sistema lingüístico parece reclutar recursos adicionales para apoyar la producción, específicamente aquellos relacionados con la ruta ventral. Este mecanismo compensatorio se evidencia con el efecto de la imaginabilidad, que facilita la recuperación léxica cuando se entra a producir CdAs. En conjunto, nuestros resultados refuerzan la concepción del sistema de producción del lenguaje como un mecanismo esencialmente dinámico, interactivo y adaptativo.

CONCLUSIONES

Los estudios presentados en esta tesis doctoral convergen en una idea central: el comportamiento lingüístico en la afasia no puede entenderse únicamente a partir de asociaciones fijas entre la localización de la lesión, los mecanismos cognitivos alterados y el tipo de errores resultantes. Más bien, el desempeño lingüístico emerge de la interacción de múltiples factores, que incluyen los sistemas neurocognitivos, las propiedades psicolingüísticas de los estímulos y las demandas contextuales de las tareas.

La evidencia recogida sobre el efecto STEPS cuestiona interpretaciones previas que atribuían patrones de error específicos —fonémicos con palabras y semánticos con números— a categorías léxicas discretas o a subsistemas modulares (e.g., números, letras o palabras funcionales) en el nivel fonológico del POB. En su lugar, proponemos que dicho patrón emerge de la interacción entre mecanismos fonológicos alterados, presentes en nuestras pacientes y exacerbados en condiciones de alta carga de memoria, las propiedades psicolingüísticas de los estímulos (como la frecuencia léxica) y la propia estructura de la tarea, en particular la repetida evaluación de ítems semánticamente relacionados. Estos hallazgos respaldan la concepción de que el procesamiento lingüístico es inherentemente interactivo y flexible. Esta interpretación se ve además reforzada por los hallazgos sobre la CdA, que muestran que cuando la ruta dorsal está comprometida, como en el caso de nuestro paciente con daño en el *phonological output buffer* (PIB), el sistema recluta apoyo compensatorio de los recursos de la ruta ventral. Esta dinámica se refleja en el efecto facilitador de la imaginabilidad, que favorece la recuperación de palabras y contribuye a la resolución de los intentos autocorrectivos.

En conjunto, los estudios sobre el STEPS y la CdA muestran que los errores lingüísticos en la afasia no son simplemente la consecuencia de un daño en componentes aislados, sino que con frecuencia reflejan la reconfiguración adaptativa del sistema bajo condiciones de restricción. Estos hallazgos son coherentes con los modelos neuroanatómicos de doble ruta del lenguaje (e.g., Hickok et al., 2011; Ueno & Lambon Ralph, 2013) y se integran en los marcos de activación interactiva (e.g., Dell et al., 1997), que enfatizan la influencia recíproca entre los procesos semánticos y fonológicos en la producción.

El trabajo desarrollado en esta tesis doctoral aboga por una neurociencia y neuropsicología del lenguaje que combine precisión metodológica, validez ecológica y robustez teórica. Bajo este foco, la variabilidad y los “comportamientos dinámicos” observados en la afasia no deben concebirse como mero ruido o anomalía, sino como una ventana privilegiada

hacia la comprensión de la flexibilidad y la capacidad adaptativa del sistema cognitivo. Así pues, lejos de constituir un obstáculo, esta variabilidad se revela como una oportunidad para afinar los modelos teóricos y orientar no solo la evaluación, sino también el diseño de intervenciones clínicas más ajustadas e individualizadas.



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APPENDICES



Appendix A. Supplementary Materials for Chapter II

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Appendix B. Supplementary Materials for Chapter VI

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Appendix C. Journal versions of papers

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