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How do we code the letters of a word when we have to write it? Investigating double letter representation in French

Sonia Kandel [a,b,c,*], Ronald Peereman [a], Anna Ghimenton [d]

[a] Univ. Grenoble Alpes, LPNC CNRS UMR, 5105 Grenoble, France
[b] GIPSA-Lab CNRS UMR 5216, Dept. Parole & Cognition, Grenoble, France
[c] Institut Universitaire de France, Paris, France
[d] Univ. Paris 3 — Sorbonne Nouvelle, France

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ABSTRACT

How do we code the letters of a word when we have to write it? We examined whether the orthographic representations that the writing system activates have a specific coding for letters when these are doubled in a word. French participants wrote words on a digitizer. The word pairs shared the initial letters and differed on the presence of a double letter (e.g., LISSER/LISTER). The results on latencies, letter and inter-letter interval durations revealed that L and I are slower to write when followed by a doublet (SS) than when not (ST). Doublet processing constitutes a supplementary cognitive load that delays word production. This suggests that word representations code letter identity and quantity separately. The data also revealed that the central processes that are involved in spelling representation cascade into the peripheral processes that regulate movement execution.

1. Introduction

Knowing how to write is an essential skill in everyday life. To write a word, we recall its spelling and then write the letter string by producing hand movements with a pen/pencil. Most experimental studies on written word production have focused either on the spelling processes or on the motor production process. There has hardly been any interaction between the two approaches. This is quite surprising because to write a word needs both kinds of processes. First we have to recover its spelling from long term memory and then execute the movements to produce the writing. Research on spelling processes essentially used reaction time data to examine the spelling processes involved before we start to write (Afonso & Álvarez, 2011; Bonin, Peereman & Fayol, 2001; Qu, Damian, Zhang &, Zhu, 2011; Zhang & Damian, 2010). The studies on the motor aspects of written production investigated movement kinematics and considered writing as a manual movement, just like grasping or pointing movements. In this perspective, to write a word, we recall the shapes of the letters, activate the corresponding motor programmes and produce them following biomechanical and motor constraints (Teulings, Thomassen, Van Galen, 1983; Van Galen, Smyth, Meulenbroek, & Hylkema, 1989). According to Van Galen's (1991) model writing words involves the activation of its letter components in a linear fashion and, once the allograph is selected (Van Galen, 1991), we should always write a letter in the same way. Previous studies indicate, however, that spelling processes modulate motor process to optimize word production (cf. Roux, McKeeff, Grosjacques, Afonso, & Kandel, 2013; Delattre, Bonin, & Barry, 2006). The timing of motor production not only depends on the shape of the letter but also depends on the way the orthographic representations encode the letters for spelling recovery. Neuropsychological studies provide data suggesting that word representations code letter identity and order, of course, but are complex structures that also include syllable and letter doubling information (Caramazza & Miceli, 1990). The present study addresses the question of letter doubling. Most of us have written at least once a double letter in a word that is not the letter that has to be doubled (e.g., MISSING written MISINNG). What happens is that we know a letter in the word has to be doubled but we do not remember which one. Is there a special coding for double letters in orthographic representations? Case studies analysing the spelling errors of dysgraphic patients suggest that orthographic representations code letter identity and quantity independently (McCloskey, Badecker, Goodman-Schulman, & Aliminosa, 1994; Tainturier & Caramazza, 1996). However, we do not know what kind of information is actually being processed while we write. In the present research French participants wrote words on a digitiser that recorded the movements they produced while writing.

* Corresponding author at: Université Grenoble 2, Laboratoire de Psychologie et NeuroCognition (CNRS UMR 5105), BSHM — B.P. 47, 38040 Grenoble Cedex 09, France. Tel.: +33 476 82 56 30; fax: +33 476 82 78 34.
E-mail address: Sonia.Kandel@upmf-grenoble.fr (S. Kandel).

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The words had an embedded doublet (e.g., LISSER, to smooth) or not (LISTER, to list). We examined the effect of letter doubling before the participants started to write the word and while they wrote it.

1.1. Doublet coding in orthographic representations

The first studies on written language production assumed that the orthographic representations that we activate to write a word only code information on letter identity and order (Van Galen, 1991; Wing & Baddeley, 1980). The word MISSING for example would be represented as $M_1I_2S_3S_4I_5N_6G_7$. Neuropsychological studies soon argued against this linear conception of orthographic representations on the basis of the spelling performance of patients with a graphemic buffer disorder. Caramazza and Miceli (1990) presented the case study of an Italian dysgraphic patient LB, indicating that orthographic representations code letter identity and order but also other kinds of information like syllable structure and the letters' consonant/vowel status. They suggested that orthographic representations are multi-dimensional structures that code information on various levels of linguistic processing. LB's spelling errors also pointed to the idea that there could be a specific coding for double letters. The transposition errors of double consonants, unlike other consonant clusters, always involved a double consonant (e.g., TROPPO → PROTTO, but not PROTPO or PROPTO).

McCloskey et al. (1994) investigated double letter representation more deeply through a case study of an English-speaking dysgraphic patient. Their patient HE exhibited twice as many spelling errors for words with embedded double letters than for equivalent words without double letters. Furthermore, 83% of the errors in the words containing double letters concerned the doubled portion (e.g., CROSS → CROOS). The data globally indicated that letter identity and quantity are coded at different processing levels. This idea was also examined by Tainturier and Caramazza (1996) who suggested that double letters may behave as independent processing units. Their analysis of the spelling errors of another dysgraphic English-speaking patient indicated that double letters do not follow the same error patterns as letters that appear twice within a word but not in adjacent positions (e.g. CACTUS) or as letter chunks that represent a phoneme (e.g., ROCKET where CK = /k/). It is also noteworthy that the patient's spelling performance revealed that he preserved knowledge on the graphotactic rules that apply to letter doubling in English, since he never produced double consonants in word initial and only doubled the letters that can be doubled in English (e.g. never YY). This suggests that brain damage may selectively affect grapheme identity and grapheme quantity. It is worth mentioning that other neuropsychological studies also present case studies that support the idea that a letter is not coded in the same manner when it is doubled than when it is not (in Italian Miceli, Benvegnú, Capasso & Caramazza, 1995; Venneri, Cubelli & Caffara, 1994; and in English Ellis, Young & Flude, 1987).

Data on doublet representation from non-brain impaired individuals is scarce. Developmental studies on spelling acquisition provided evidence for a specific processing of double letters. In an experiment by Cassar and Treiman (1997), English-speaking first graders considered pseudo-words that had an embedded "legal" and frequent doublet (e.g., LL) as more word-like than pseudo-words that had an "illegal" doublet (e.g., HH). Further research conducted in French indicated that very early in the acquisition process the children are sensitive to the position of the doublet within the word. Pacton and colleagues (Danjon & Pacton, 2009; Pacton, Borchardt, Treiman, Lété, & Fayol, 2014; Pacton, Perruchet, Fayol, & Cleeremans, 2001; Pacton, Sobaco, Fayol, & Treiman, 2013) presented data in which first to fourth graders preferred pseudo-words that had the doublet in medial position like FOMMIR than pseudo-words with a doublet in initial position (e.g., FFOMIR, which is illegal in French). These studies suggest that the processing of double letters is different from the processing of the same letters in non-adjacent positions within the word. This kind of letter processing seems to be present very early, as soon as the children become familiar with written language. However, the authors do not refer to doublets as a level of coding in orthographic representations but rather to knowledge the children have on the statistical co-occurrence of letters in specific positions within words. As in the neuropsychological studies, the analysis in these experiments also relies on off-line measures and there is no information on how the knowledge on doublets modulates the writing process.

Several typing experiments investigating serial motor behaviour paid particular attention to letter doubling and provide on-line data on movement production. They measured the duration of inter-key intervals in consonant sequences that either contained double letters or not (Sternberg, Knoll, Monsell & Wright, 1983; Sternberg, Knoll, & Turock, 1990). The duration was a linear function of the number of elements in the sequence (e.g., SFCRZ > SFCR). For the sequences of equal length but containing double letters the durations were shorter than for the ones not containing double letters (e.g., SFCRZ > SCCRZ) and were equivalent to the durations of the sequences that contained four letters (e.g., SCCRZ = SFCR). The authors accounted for the data in terms of motor production. They were not concerned by orthographic representations and did not argue in favour of a specific level for double letter coding. They argued that duration decreased because the two elements of the doublet were processed as a single motor unit. However, Gentner (1987) reported data indicating that this speed gain is not systematic and depends on the location of the letter of the matched controls on the keyboard. Typing two letters with different hands was faster than producing a doublet with the same finger. The neuropsychological data together with these observations have been integrated in a computational spelling model that proposes a specific "geminate" node in its architecture (Glasspool & Houghton, 2005). It is also worth mentioning that letter chunking strategies in typewriting can be determined by the linguistic structure of word representations (Weingarten, 2005; Weingarten, Nottbusch & Will, 2004). Weingarten and colleagues reported evidence indicating that syllable and morpheme structure, among others, modulate the timing of typing movements. Many errors on letter doublets in everyday life are typewriting errors. Rumelhart and Norman (1982) discuss this kind of error and model it computationally. In their model they include a specific coding for doublets. When an error arises and the wrong letter is doubled it is because the doubling schemata were applied to the wrong letter. Doublets are processed differently because an activated letter needs to be inhibited to prevent perseveration. In the present study we examined whether the orthographic representations we activate for producing handwritten words code double letters and how they influence the motor production process.

1.2. Word representation in handwriting production

According to Van Galen's (1991) model word writing is the result of a series of processing modules that are organized in a hierarchical architecture. The higher order processing levels are common to the production of speech, typing and handwriting and were taken from Levelt's (1989) model of speech production. They concern concepts, semantic recovery and syntactic construction. Handwriting differs from speech at the level of spelling recovery, which is then followed by lower-order "motor" modules like allograph selection, size control and muscular adjustment. The higher-order levels – like the spelling module that processes orthographic representations – anticipate and process information related to forthcoming parts of the word in parallel to lower-order processing (e.g., local parameters such as letter size or movement velocity). When various representational levels are activated simultaneously, and because the writing system has limited capacities, movement production becomes more time consuming and duration increases. We focused on the interaction between the spelling and motor modules.

The model represents words as serial sequences that code information on letter identity and order (e.g., $L_1I_2S_3S_4E_5R_6$). Letters are