



## Dyscravia: Voicing substitution dysgraphia

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### ARTICLE INFO

#### Article history:

Received 12 October 2009

Received in revised form 6 March 2010

Accepted 9 March 2010

Available online 16 March 2010

#### Keywords:

Dysgraphia

Dyslexia

Hebrew

Dyscravia

Spelling

Voicing

### ABSTRACT

We report a new type of dysgraphia, which we term *dyscravia*. The main error type in dyscravia is substitution of the target letter with a letter that differs only with respect to the voicing feature, such as writing “coat” for “goat”, and “vagd” for “fact”. Two Hebrew-speaking individuals with acquired dyscravia are reported, TG, a man aged 31, and BG, a woman aged 66. Both had surface dysgraphia in addition to their dyscravia. To describe dyscravia in detail, and to explore the rate and types of errors made in spelling, we administered tests of writing to dictation, written naming, and oral spelling. In writing to dictation, TG made voicing errors on 38% of the words, and BG made 17% voicing errors. Voicing errors also occurred in nonword writing (43% for TG, 56% for BG). The writing performance and the variables that influenced the participants' spelling, as well as the results of the auditory discrimination and repetition tasks indicated that their dyscravia did not result from a deficit in auditory processing, the graphemic buffer, the phonological output lexicon, the phonological output buffer, or the allographic stage. The locus of the deficit is the phoneme-to-grapheme conversion, in a function specialized in the conversion of phonemes' voicing feature into graphemes. Because these participants had surface dysgraphia and were forced to write via the sublexical route, the deficit in voicing was evident in their writing of both words and nonwords. We further examined whether the participants also evinced parallel errors in reading. TG had a selective voicing deficit in writing, and did not show any voicing errors in reading, whereas BG had voicing errors also in the reading of nonwords (i.e., she had dyslexia in addition to dyscravia). The dissociation TG demonstrated indicated that the voicing feature conversion is separate for reading and writing, and can be impaired selectively in writing. BG's dyslexia indicates that the grapheme-to-phoneme conversion also includes a function that is sensitive to phonological features such as voicing. Thus the main conclusion of this study is that a separate function of voicing feature conversion exists in the phoneme-to-grapheme conversion route, which may be selectively impaired without deficits in other functions of the conversion route, and without a parallel deficit in reading.

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### 1. Introduction

This paper presents a new type of dyscravia. This is the way the participants in this study might write “this paper presents a new type of dysgraphia”. The predominant error in this dysgraphia is voicing error: the substitution of a voiced letter with a voiceless one (writing *p* instead of *b*), and of a voiceless letter with a voiced one (writing *b* instead of *p*). The main challenge of this study is to find the location of the deficit in the spelling process that leads to this type of error, and to describe the nature of this newly identified spelling impairment.

Before describing the possible impairment loci which cause various dysgraphias, we start with a short introduction of the model we

assume for writing, presented in Fig. 1. To write a word, in free writing or to dictation, two routes are available—a lexical route and a sublexical route. The most efficient route is the lexical route, which uses the orthographic output lexicon (marked (2) in Fig. 1), in which orthographic representations of words are stored and activated. This lexicon can be accessed either from the semantic system (1), in free writing, or from the phonological input lexicon (6) (possibly via the phonological output lexicon (7)), in writing to dictation. The graphemes selected from the lexicon are held for a short time in the graphemic buffer (3), a graphemic short-term memory store, and are then transmitted to the allographic stage (4), where the abstract letter forms are stored. The final stage is the motor execution of writing, namely, the graphemic motor pattern stage (5), in which the specific motor patterns for the specific letters are activated in order to perform the hand movements required for writing. Only items that exist in the orthographic output lexicon can be written via this lexical route, and hence nonwords and new words cannot be written through this route.

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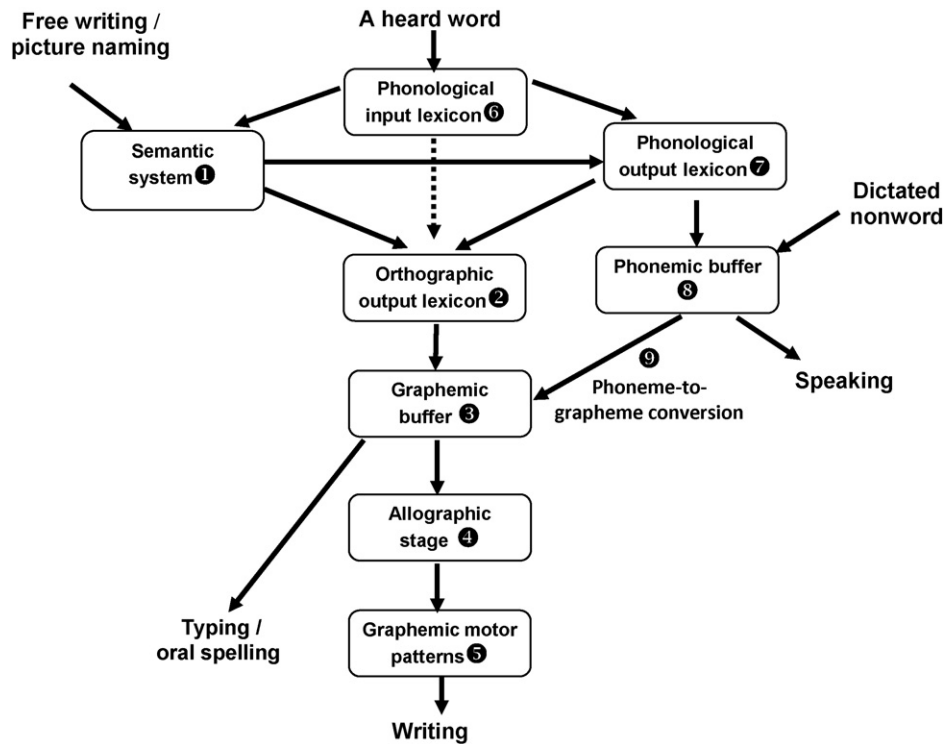


Fig. 1. Single word writing model.

The other route, the sublexical route, passes through the phonemic buffer (8) directly to the graphemic output buffer (3) using phoneme-to-grapheme conversion (9). The products of the phoneme-to-grapheme conversion, like those of the lexical route, are maintained in the graphemic output buffer. This sublexical route is used mainly for writing new words and nonwords—letter sequences that do not exist in the orthographic lexicon. It is also used when the lexical route is impaired, as is the case in surface dysgraphia. Words that have more than a single possible conversion from phonemes to graphemes, and words that do not obey standard phoneme-to-grapheme conversion rules, namely, words with homophonic letters and irregular words, may be written incorrectly via this sublexical route.

In recent years, several distinct types of acquired dysgraphia have been identified, each type resulting from a selective impairment to a different part of the spelling process (Ellis, 1993; Miceli & Capasso, 2006; Tainturier & Rapp, 2001). A deficit to the lexical route results in *surface dysgraphia* (Romani, Ward, & Olson, 1999; Tainturier & Rapp, 2001; Temple, 1985; Weekes & Coltheart, 1996), in which the writer is forced to write via the phoneme-to-grapheme conversion route, causing regularization errors (writing *det* instead of *debt*), and homophonic letter substitution errors (writing *sity* instead of *city*). *Phonological dysgraphia* (Barry, 1994; Ogden, 1996; Rapcsak & Beeson, 2002) results from an impairment to phoneme-to-grapheme conversion, with intact lexical route, causing an inability to write new words and nonwords, whereas the writing of words that are already stored in the orthographic output lexicon remains intact. *Deep dysgraphia* (Bub & Kertesz, 1982; Cipolotti, Bird, Glasspool, & Shallice, 2004; Hillis, Rapp, & Caramazza, 1999; Raman & Weekes, 2005; Weekes, 2006) entails impairment in both nonword writing and semantic errors in word spelling. *Graphemic buffer dysgraphia* (Caramazza & Miceli, 1990; Posteraro, Zinelli, & Mazzucchi, 1988; see Miceli & Capasso, 2006 for a review) is a selective impairment at the graphemic output buffer, which causes letter identity errors (substitutions), letter additions and deletions, and errors of letter position within the word (letter

transpositions), both in real words and in nonwords. The writing of individuals with graphemic buffer dysgraphia is affected by word length, because the buffer is a temporary store with limited capacity (Caramazza, Miceli, Villa, & Romani, 1987; but see Sage & Ellis, 2004 for a different view). Selective impairments within the graphemic buffer stage have also been identified, leading to selective letter identity (Cotelli, Abutalebi, Zorzi, & Cappa, 2003; Kay & Hanley, 1994; Kokubo, Suzuki, Yamadori, & Satou, 2001; Posteraro et al., 1988; Shallice, Rumiati, & Zadini, 2000; see Miceli & Capasso, 2006 for a review) or selective letter position errors (Gvion & Friedmann, in press).

Neglect dysgraphia is also assumed to result from a deficit at the graphemic buffer level (Baxter & Warrington, 1983; Caramazza & Hillis, 1990; Hillis & Caramazza, 1995). Until today no specific dysgraphia has been reported that selectively causes voicing substitutions (But see the report of patient DR in the dysgraphia rehabilitation study by Luzzatti, Colombo, Frustaci, and Vitolo (2000), who made many devoicing errors in writing, as well as some other substitutions, and Graham, Patterson, and Hodges (2000), who reported individuals with semantic impairments who made voicing errors in spelling in addition to other types of errors; see also an abstract by Tainturier (1996) briefly reporting a patient with voicing errors in writing<sup>1</sup>).

<sup>1</sup> Many other studies of graphemic buffer dysgraphia, surface dysgraphia, allographic dysgraphia, and phonological dysgraphia reported individuals who made letter substitutions in spelling, usually in addition to other types of errors, however, none of them referred to the relation in voicing between the target and the substituting letter (Behrmann & Bub, 1992; Blanken, Schafer, Tucha, & Lange, 1999; Chialant, Domoto-Reilly, Proios, & Caramazza, 2002; Cholewa, Mabtey, Heber, & Hollweg, 2010; Cipolotti, Bird, Glasspool, & Shallice, 2004; Delazer, Lochy, Jenner, Domahs, & Benke, 2002; Glasspool, Shallice, & Cipolotti, 2006; Graham, Patterson, & Hodges, 1997; Hanley & Peters, 2001; Kirk, Blonder, Wertman, & Heilman, 1991; Miceli & Capasso, 2006; Miceli, Capasso, Benvegnù, & Caramazza, 2004; Neils, Roeltgen, & Greer, 1995; Ogden, 1996; Panton & Marshall, 2007; Rapcsak & Beeson, 2002; Rapp, 2005; Rapp & Kong, 2002; Rapp, Epstein, & Tainturier, 2002; Schiller, Greenhall, Shelton, & Caramazza, 2001; Ward & Romani, 2000; Zesiger, Martory, &

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