Cognition 115 (2010) 466–490

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Representation of letter position in spelling: Evidence from acquired dysgraphia

Simon Fischer-Baum *, Michael McCloskey, Brenda Rapp

Department of Cognitive Science, Johns Hopkins University, MD, United States

ARTICLE INFO

Article history:
Received 13 July 2009
Revised 2 March 2010
Accepted 10 March 2010

Keywords:
Letter-position coding
Dysgraphia
Spelling
Letter perseveration errors
Orthographic processing

ABSTRACT

The graphemic representations that underlie spelling performance must encode not only the identities of the letters in a word, but also the positions of the letters. This study investigates how letter position information is represented. We present evidence from two dysgraphic individuals, CM and LSS, who perseverate letters when spelling: that is, letters from previous spelling responses intrude into subsequent responses. The perseverated letters appear more often than expected by chance in the same position in the previous and subsequent responses. We used these errors to address the question of how letter position is represented in spelling. In a series of analyses we determined how often the perseveration errors produced maintain position as defined by a number of alternative theories of letter position encoding proposed in the literature. The analyses provide strong evidence that the grapheme representations used in spelling encode letter position such that position is represented in a graded manner based on distance from both-edges of the word.

1. Introduction

Many cognitive functions require the ability to represent and process sequences of items or events. Sequence information is essential, for example, in recalling a telephone number, reasoning about causes and effects, navigating a route through an environment, or producing a sentence. As Karl Lashley pointed out more than 50 years ago in *The problem of serial order in behavior* (Lashley, 1951), the question of how the brain represents and processes ordered sequences is far from trivial; and this question remains a central concern for research in a variety of cognitive domains (e.g., working memory: Henson, 1998; motor control: Bullock, 2004; reading: Grainger & Whitney, 2004; music performance: Palmer, 2005; spoken language production: Dell, Svec, & Burger, 1997).

This article addresses the serial order issue in the context of spelling. Spelling a word requires not only information about the identities of the letters in the word, but also information about the ordering of those letters. This ordering information could be encoded in a variety of ways. In the word PENCIL, for example, the letter E could be represented as the second letter in the word, the letter five positions from the end of the word, the letter in the nucleus of the first (orthographic) syllable, or the letter that follows P and precedes N. In each case the E's position is specified according to a different representational scheme. If we say that the E is the second letter in the word, we implicitly adopt a left-edge based scheme, in which a letter's position is defined in terms of distance in letters from the left edge of the word. By this positional scheme, P is the first letter, E is the second, and so forth. Alternatively, if we say that E is the letter following P and preceding N, we are using a letter-context scheme, in which a letter's position is specified with respect to the surrounding letters.

The goal of present study was to identify the scheme for representing letter position in the graphemic representations that underlie spelling performance. Several research-

* Corresponding author at: Department of Cognitive Science, Johns Hopkins University, 3400 North Charles Street, Baltimore, MD 21218, United States. Tel.: +1 410 516 7625; fax: +1 410 516 8020.
E-mail address: fischerbaum@cogsci.jhu.edu (S. Fischer-Baum).

0010-0277/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.cognition.2010.03.013

ers have offered hypotheses about the representation of letter position in spelling (e.g., Brown & Loosemore, 1994; Caramazza & Hillis, 1990; Glasspool, 1998; Glasspool & Houghton, 2005; Houghton, Glasspool, & Shallice, 1994; Houghton & Zorzi, 2003). However, the relevant empirical evidence is sparse, and no studies have directly compared the alternative proposals. In the present study we examine a broad range of positional schemes in light of data from two individuals with acquired dysgraphia, LSS and CM. In spelling tasks LSS and CM made frequent letter perseveration errors, in which letters from prior responses intruded into subsequent responses. We argue that these letter perseveration spelling errors motivate strong conclusions about the representational scheme used for specifying letter position in spelling.

Perseveration errors – both from impaired and unimpaired individuals – have been used in a variety of domains to infer how the positions of elements in a sequence are represented (e.g., Boomer & Laver, 1968; Cohen & Dehaene, 1990; Henson, 1999). In the present study extensive testing of LSS and CM provided large sets of letter perseveration errors that allowed us to contrast alternative hypotheses of letter position representation in spelling. Additional aspects of the participants' spelling performance localized their perseveration errors to the level of abstract letter representation – what we call the level of graphemic spelling representation. This localization places some constraints on the levels of processing at which the implicated letter position representations may be active.

Patterns of performance in individuals with dysgraphia acquired as a result of neural insult (e.g., stroke) have been used extensively as a basis for conclusions about the cognitive representations and processes that support spelling in the intact brain (e.g., Caramazza & Hillis, 1990; Caramazza & Miceli, 1990; McCloskey, Badecker, Goodman-Schulman, & Aliminosa, 1994; McCloskey, Macaruso, & Rapp, 2006; Rapp, Benzing, & Caramazza, 1997; Tainturier & Caramazza, 1996, see McCloskey (2003) for discussion). The logic by which impaired performance can be used to draw inferences about normal cognition has been discussed at length elsewhere, and we refer the interested reader to those sources (e.g., Caramazza, 1984, 1986, 1992; Caramazza & Coltheart, 2006; McCloskey, 1993, 2001, 2003; McCloskey & Caramazza, 1988). In accord with this logic we assume that the brain damage suffered by LSS and CM has caused their previously-normal spelling processes to malfunction (leading to perseverations and other errors), but has not resulted in creation of novel representational schemes for specifying letter position. Given this assumption we can use the perseveration errors to draw conclusions about representation of letter position in the normal spelling system. An important advantage of studying impaired performance is that, as in the present study, one can often accumulate large corpora of errors that arise from a single level of representation, and are highly informative about the nature of the representations at that level.

The question of how the position of an element in a sequence is represented is critical for all domains that rely on sequence processing. In the past few years, this question has received a great deal of attention in the domain of reading (e.g., Davis, 1999; Davis & Bowers, 2004, 2006; Grainger et al., 2006; Grainger & van Heuven, 2003; Gomez, Ratcliff, & Perea, 2008; Kinoshita & Norris, 2009; Perea & Lupker, 2003, 2004; Schoonbaert & Grainger, 2004; Van Assche & Grainger, 2006; Whitney, 2001). The research on reading provides a source of hypotheses regarding position representation in orthographic processing generally. However, it is important to emphasize that our results and conclusions are specific to spelling. Because we do not know whether reading and spelling use the same scheme for representing letter position (and because we did not study LSS's or CM's reading in detail), we make no claims about position representation in reading.

As a framework for subsequent discussion, we begin by sketching a theory of the cognitive mechanisms involved in spelling, and then lay out a variety of hypotheses concerning the encoding of letter position in graphemic spelling representations. Next we offer case histories for CM and LSS, and characterize their spelling deficits. Following this introductory material we present results demonstrating that both participants often perseverate letters from spelling responses into subsequent responses. We then report an extensive series of analyses that use the letter perseveration phenomenon as a tool for probing the representation of letter position in graphemic spelling representations. Finally, we conclude with a brief discussion of issues arising from our results and conclusions.

2. A cognitive spelling theory

Most of the data we report come from a writing to dictation task, in which a word or nonword is dictated, and the participant produces a written spelling response. Consequently, we describe the cognitive spelling theory in the context of this task (see Miceli & Capasso, 2006; Tainturier & Rapp, 2001).

The theory assumes that when a familiar word (e.g., "table") is dictated, the corresponding phonological lexeme is activated in a phonological lexicon (see Fig. 1). This lexeme then activates a lexical–semantic representation, which in turn activates an orthographic lexeme in an orthographic lexicon. Some authors have also proposed a direct connection between the phonological and orthographic lexemes (e.g., Patterson, 1986). Next, the orthographic lexeme activates a graphemic representation that specifies the identities and ordering of the letters in the word (e.g., T-A-B-L-E). These graphemic representations are assumed to abstract away from information about how the letter is to be produced; Table is represented with the same T grapheme whether the word is to be typed, handwritten or spelled aloud. Note that we use the terms *grapheme* and *graphemic* simply to refer to abstract letter representations, and not specifically to letter representations corresponding to single phonemes (e.g., Rapp & Caramazza, 1997). In the present study our focus is on the representation of letter order, and we leave open the question of whether digraphs (letter pairs associated with a single phoneme, such as the SH in FISH) are represented by one unit or two at the graphemic level (Houghton & Zorzi, 2003; Tainturier & Rapp, 2004).