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Typing pictures: Linguistic processing cascades into finger movements

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ABSTRACT

The present study investigated the effect of psycholinguistic variables on measures of response latency and mean interkeystroke interval in a typewritten picture naming task, with the aim to outline the functional organization of the stages of cognitive processing and response execution associated with typewritten word production. Onset latencies were modulated by lexical and semantic variables traditionally linked to lexical retrieval, such as word frequency, age of acquisition, and naming agreement. Orthographic variables, both at the lexical and sublexical level, appear to influence just within-word interkeystroke intervals, suggesting that orthographic information may play a relevant role in controlling actual response execution. Lexical-semantic variables also influenced speed of execution. This points towards cascaded flow of activation between stages of lexical access and response execution.

1. Introduction

Language production involves transforming a communicative intention into a physical output, be it a spoken word, a written word, or a sign. Both cognitive and motor processes are necessary to accomplish this task. Curiously, the investigation of the cognitive and the motor sides of language production has proceeded along relatively independent paths, as pointed out in the fields of both spoken (Hickok, 2014) and written (e.g., Kandel & Perret, 2015; Weingarten, Nottbusch, & Will, 2004) word production. As a result, the issue of how information flows from central cognitive processes to motor execution in word production has, to date, received relatively little attention.

During the initial cognitive levels of word-form retrieval is processing encapsulated or does it percolate into actual response execution? This question calls into play the traditional distinction between serial and cascaded models of language processing (e.g., Damian, 2003; Kello, Plaut, & MacWhinney, 2000). In serial models, information needs to be fully processed at a given stage before it can provide an input for the next process. In this scenario, variables affecting information processing within central linguistic stages of word retrieval (semantic, lexical) should play no role during subsequent output (response execution) stages. By contrast, with cascaded activation as soon as information becomes available at given level, it is immediately forwarded for processing to the next (downstream) level. Under this scenario variables affecting central linguistic processing – processing prior to output initiation – can also affect processing at the output stage.

With this in mind, our paper explores which of these two models better describes the functional relationship between language processing and response execution in typewriting. With this aim, we assessed to what extent do semantic, lexical and sublexical variables affect both response retrieval and response execution. Specifically, we studied participants providing typewritten names to pictures of everyday objects, measuring both response latency and rate of production once the response had been initiated (i.e., mean inter-keystroke interval). These data permit isolation of effects prior to and concurrent with language output. Response latency is the time elapsing from the onset of the to-be-named stimulus until the first keystroke of the response. It is considered a measure of the processing occurring before the response stage, and thus it is mostly linked with linguistic central stages of word retrieval. Mean interkeystroke interval is the average of the time intervals between the keystrokes of the response. This is typically considered more related to peripheral stages of response execution (e.g., Logan & Crump, 2011). The need to go beyond just measuring response onset time has been frequently noted (e.g., Abrams & Balota, 1991; Balota & Abrams, 1995; see also Bangert, Abrams, & Balota, 2012; Spivey & Dale, 2006; Spivey, Grosjean, & Knoblich, 2005). Typewriting makes possible precise measures of execution

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after response onset in the context of a genuine language production task.

The effects of semantic and lexical variables such as familiarity, age of acquisition and word frequency, which are typically considered to affect lexical retrieval at a central level, have been repeatedly reported in response times in both picture naming and writing tasks (e.g., Almeida, Knobel, Finkbeiner, & Caramazza, 2007; Barry, Hirsch, Johnston, & Williams, 2001; Belke, Brysbaert, Meyer, & Ghyselinck, 2005; Bonin, Roux, Barry, & Canell, 2012; Caramazza, 1997; Catling & Johnston, 2009; Cycowicz, Friedman, Rothstein, & Snodgrass, 1997; Levelt, Roelofs, & Meyer, 1999; Navarrete, Scaltritti, Mulatti, & Peressotti, 2013; Peressotti, Job, Rumiati, & Nicoletti, 1995; Roux & Bonin, 2012). Once word forms have been retrieved, sublexical representations then also become available and can affect the speaker or writer's performance (e.g., Gentner, Larochelle, & Grudin, 1988). However, the extent to which lexical and sublexical effects are present in post-onset measures of response execution is still unclear. In spoken production different approaches have been used in order to investigate this issue. Speech errors contain the articulatory features of the unproduced but intended target sound (e.g., Goldrick & Blumstein, 2006) and studies consistently report that the output duration of words within a sentence depends on the extent to which words can be predicted (e.g., Gahl & Garnsey, 2004; Griffin & Bock, 1998; Tily et al., 2009). These findings support the cascaded information flow hypothesis.

However studies exploring the effect of lexical variables in the production of sounds report mixed results. In line with cascaded flow of information, studies of spontaneous speech corpora have found frequency effects on articulation durations (Gahl, 2008; Pluymaekers, Ernestus, & Baayen, 2006). In single word production, a longer duration of the initial phoneme has been reported for words entailing irregular vowel pronunciation, compared to words with a regular vowel pronunciation (Kawamoto, Kello, Jones, & Bame, 1998). Also, lexical frequency seems to affect initial phoneme durations, but not rhyme durations (Kawamoto, Kello, Higareda, & Vu, 1999; see also Mousikou & Rastle, 2015). Lexical frequency effects have actually been detected in a reading aloud task with delayed responses (Balota & Chumbley, 1985), but this result has been debated (Balota & Chumbley, 1990; Monsell, Doyle, & Haggard, 1989). Additionally, the effect of neighborhood size seems to be different in single word production and in spontaneous speech. Studies with single words report more expanded vowel spaces for words from denser neighborhoods (Munson & Solomon, 2004; Yiu & Watson, 2015). Studies with spontaneous speech show that words from dense neighborhoods are phonetically reduced (Gahl, Yao, & Johnson, 2012). Finally, paradigms based on semantic congruency effects produced very mixed evidence. In the seminal work by Balota, Boland, and Shields (1989), semantic priming effects were shown to influence both onset and duration times. Damian (2003), however, using both a picture-word interference and a blocked naming paradigm, found semantic interference and phonological facilitation effects in response onset times, but not in response durations. Further, he showed that spoken response durations were unaffected by Stroop interference (but see Kello et al., 2000), suggesting that interference effects do not cascade into articulatory processes.

For handwriting, there is evidence that spelling processes affect motor execution. For example, motor production is slower for words with irregular spelling-to-sound mapping compared to regular words (Afonso, Álvarez, & Kandel, 2015; Delattre, Bonin, & Barry, 2006; Kandel & Perret, 2015; Roux, McKeeff, Grosjacques, Afonso, & Kandel, 2013; but see Damian & Stadthagen-Gonzalez, 2009). Studies on handwriting have also shown that movement duration could be influenced by the phonological structure of the word. Kandel, Peereman, Grosjacques, and Fayol (2011) investigated the role of syllabic structure in a copy task and showed that both syllable structure and bigram frequency affected mean stroke duration.

Finally, and particularly important for the present study, Logan and Zbrodoff (1998; see also Damian & Freeman, 2008) found a Stroop effect on onset latencies of typed response but not on interkeystroke intervals, suggesting that response execution starts only once the target response, or the word form, has been selected (see also Logan & Crump, 2011). Other findings, however, seem more consistent with cascaded flow of information, showing that lexical variables exert an influence on both onset latency and interkeystroke intervals. For example, lexicality (typing a word versus typing a nonword) and word frequency have been found to affect the duration of interkeystroke intervals (e.g., Gentner, Larochelle, & Grudin, 1988; but see Baus, Strijkers, & Costa, 2013; Pinet, Ziegler, & Alario, 2016). Sublexical factors in particular, such as bigram frequency or syllabic structure, have also been found to affect interkeystroke intervals. Gentner et al. (1988) found that bigram frequency (i.e., the frequency with which specific letter pairs occur within written language, in this case Dutch and English) predicted interkeystroke intervals so that for higher frequency bigrams shorter intervals were found. Further, it has been demonstrated that the interval between two keystrokes is affected by syllabic boundaries (e.g., Gentner et al., 1988; Pinet et al., 2016; Weingarten et al., 2004): Interkeystroke intervals are longer when the same two letters belong to different syllables, compared to when they are part of the same syllable. These data suggest that sublexical representations are important during response execution.

1.1. The present study

Studies investigating the influence of linguistic factors on typewriting have typically adopted a factorial approach: The effect of a critical variable (or several critical variables) on behavior is assessed by comparing two groups of items which are polarized at the extremes of this variable, while controlling for other word characteristics. For typing studies, the case for a factorial and controlled approach appears particularly cogent. When dealing with interkeystroke intervals, for example, purely peripheral factors such as biomechanical and physical constraints (e.g., specific movements, hands and finger constraints, keyboard layout), are likely to be a major determinant of the results, up to the point that a computational model based mainly on these factors (Rumelhart & Norman, 1982) correlated well with the performance of human typists (0.66 in Rumelhart & Norman, 1982; 0.57 in Gentner et al., 1988). If any peripheral factors happen to co-vary with the linguistic variables of interest, this may lead to spurious interpretations of the results. In order to convincingly demonstrate an effect of bigram frequency, for example, Gentner et al. (1988) had to compare Dutch and English typists. The rationale is that some digraphs have different frequency across languages, yet they obviously entail the same movements irrespective of the typist's language. The reliable bigram frequency effect found across the two languages led the authors to conclude that the effect was genuinely linguistic. For the frequency effect, Gentner and colleagues compared sequences of 4 letters occurring within high and low frequency words (e.g., *yste* in *system* and in *oyster*). In fact, a given interkeystroke interval is influenced by the two keystrokes executed before, as well as by the two keystrokes occurring afterwards (e.g., Rumelhart & Norman, 1982). By comparing the interkeystroke interval between the second and the third letter (*s* and *t*) of the same four letter sequence (*yste*) occurring within high (*system*) vs. low frequency words (*oyster*), the authors demonstrated that the frequency effect they detected was not explained just by previous and subsequent movements.