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Morphemes also serve as processing units in handwriting production

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Abstract

This investigation aimed to show that the morphological structure of a word constrains motor programming in adult handwriting production. Participants wrote French suffixed and pseudo-suffixed words in upper-case letters, lifting their pen between each letter. The duration of the inter-letter intervals provides information on the timing of motor programming. The results revealed that the inter-letter intervals separating the root from the suffix in

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suffixed words were significantly longer than the corresponding serial position in pseudo-suffixed words. The latencies for suffixed words were higher than for pseudo-suffixed words. Thus handwriting production may be regulated by morpheme-sized processing units, at least for suffixed words.

I. Introduction

Handwriting is different from other hand movements like grasping or pointing. In addition to the processing of parameters such as direction, force and size that are associated with production of handwriting movements, handwriting has a linguistic component that necessitates specific processing at various levels. In handwriting as in speech production, the intention to produce a linguistic sequence is followed by semantic activation and syntax construction of the sentence (Dell 1986; Dell 1988; Levelt 1989, 1992; Levelt, Roelofs et al 1999). Handwriting also involves other modules that activate spelling information, enable allograph selection, and control letter size and muscular adjustment (Van Galen 1991). The present study investigated the spelling dimension of handwriting production in French with a view to gaining insight into how linguistic units mediate motor outputs.

Handwriting motor programming involves more than just letter string activation (Teulings, Thomassen et al 1983; Caramazza, Miceli et al 1987; Van Galen, Smyth et al 1989). The writing process is modulated by other higher-order linguistic components of orthographic representations (Wing and Baddeley 1980; Caramazza, Miceli et al 1987; Caramazza and Miceli 1990; McCloskey, Badecker et al 1994; Tainturier and Rapp 2001). The higher order linguistic units that have been investigated thus far are chiefly related to the phonological aspects of the spelling processes. This research examined the role of a kind of unit that is more related to semantics, namely morphemes, which are defined as the smallest units of meaning in the language (Sandra 1994). For example, the French word *maison* ("house") is monomorphemic. However, the adjunction of the suffix *–ette* at the end of the word changes meaning to "small house." It is likely that morpheme-sized units play an important role in handwriting production in French, since 75% of French words contain more than one morpheme, thus making them morphologically complex (Rey-Debove 1984). In fact, there is considerable evidence supporting the concept that morphological representation and processing occur during both written and spoken word recognition (see Sandra, 1994, and McQueen & Cutler, 1998, for reviews). This concept is also supported by a number of studies indicating that morphological structure constrains speech production processes and points to the existence of an independent morphological level of processing (Janssen, Roelofs and Levelt, 2004; Levelt, Roelofs & Meyer, 1999; Roelofs, 1996; Roelofs & Baayen, 2002; Zwitserlood, Bölte and Dohmes, 2000). For example, longer preparation times have been observd for morphologically complex words than for morphologically simple words (Roelofs and Baayen 2002), which suggests that morphological processing is an autonomous mechanism that is not governed by semantics. There is also evidence that the planning of successive morphemes is subject to a clear serial sequence (Roelofs 1996). This is particularly relevant for the present research owing to the similarity of this mechanism in speech production and ours in handwriting. In addition, morpheme-sized units appear to affect the timing of typing and other linguistic movements (Weingarten, Nottbuch and Will, 2004). Experiments conducted with German morphemes suggest that morphemes are processing units that are measurable over time during writing, insofar as the morpheme boundaries coincide with a syllable boundary (Weingarten et al 2004).

Some recent research has investigated the linguistic units that structure orthographic representations and influence handwriting timing. For example, an analysis of the temporal and spatial features of handwriting movements produced on a digitiser revealed that higher order units other than letters (i.e. syllables) modulate handwriting production in French and Spanish (Kandel, Alvarez and Vallée 2006). The French participants in the latter study wrote words such as *tra.ceur* and *trac.tus* that start with the same letter but have different syllable boundaries. These words were presented visually and the participants were instructed to write in upper case letters, lifting the pen between the letters. The duration of inter-letter intervals was measured on the assumption that this would provide information on the timing of motor programming. It was found that when the initial syllable of the word was composed of a consonant cluster such as CCV or CCVC, the inter-syllable and inter-letter intervals (between *a* and *c* in *tra.ceur*) were longer than within syllables (*trac.tus*). The intervals were longer at the syllable boundary by virtue of the fact that the motor system anticipated the production of the succeeding syllable. For intra-syllablic intervals, the movement needed to produce the syllable was preprogrammed, thus obviating the need for further processing at this level. In cases where the first syllable of the word was simple (e.g. CV in *pa.rent* and CVC in *par.don*) the inter-letter interval at the syllable boundary (between *a* and *r*) was longer than the corresponding inter-letter interval in a intra-syllabic position, but the results were not statistically significant. Other cross-linguistic experiments have examined the role of syllables in the production of French and Spanish words. Here, the participants wrote cognates (i.e. words sharing the same spelling and meaning in both languages) and pseudowords. All the items had an embedded gn sequence. The gn sequence is intra-syllabic in French and inter-syllabic in Spanish (e.g. *ma.gnolia* and *mag.nolia*, respectively). Here too it was shown that the inter-letter interval between *g* and *n* was always shorter in French than in Spanish for both words and pseudowords. This pattern was also observed even when French-Spanish bilinguals wrote the same items in French and Spanish. Hence it can be said that there is a syllable-sized processing unit between letters (Teulings, Thomassen et al 1983; Van Galen, Smyth et al 1989) and words (Van Galen, 1991) that constrains motor programming during handwriting production, at least in syllable-timed languages. This pattern has been observed in the earliest stages of French writing acquisition (Kandel and Valdois, 2006a; Kandel and Valdois, 2006b; Kandel, Soler, Valdois and Gros, 2006).

However, between syllables and words, intermediate grained units such as morphemes may also be involved in the writing process as has been observed in typing and speech production. Unlike syllables and letters, whose processing mainly involves the phonological components of orthographic representations, morphemes relate to meaning. Morphology in the handwriting production domain has received little attention. According to one study (Orliaguet and Boë 1993), latency and movement time increase when a grammar rule (conjugation and pluralization) has to be applied in order to resolve a spelling uncertainty. For example, the French word *bois* has two meanings but is always pronounced */bwa/*. When *bois* is monomophemic, it means *forest*. When it has two morphemes, it is the first person singular of the verb *boire*, means *I drink*, and combines the root of the verb *boire* and the flexional suffix (*boi* + *s*). In the aforementioned study, these types of words were embedded in carrier sentences such as *ce bois brûle vite* (*this wood burns quickly*) or *je bois de l'eau* (*I drink water*) indicating the intended meaning. The participants were asked to write the target word after being read the carrier sentence followed by the target word. The pluralization rule was tested using the word *vers* which means *towards* when it is monomorphemic and *worms* when it is plurimorphemic (*ver* + *s*, plural). In both cases, the word is pronounced /vɛR/. It was shown that latency and movement time increased when participants had to write *bois* and *vers* in a plurimorphemic context because they had to apply conjugation and pluralization rules.

To some extent, these findings support – but do not prove – the hypothesis that morphemes are a handwriting processing unit, for the following reasons: (a) The aforementioned effect was observed during the first trials, but then disappeared with practice; (b) There were few stimuli due to the use of homograph homophone words; (c) The study disregards morphology owing to the fact that it mainly focuses on the application of grammar rules rather than plurimorphemic words; and (d) The study investigated inflectional morphology, which has only a syntactic function in French.

In the interest of determining whether morphological structure mediates handwriting production, the present study focused on derivational morphology since its main function is semantic.

The increases in duration observed in the studies by Kandel and colleagues, as well as by Orliaguet and Boë, can be explained by Van Galen's (1991) linear and parallel model of handwriting production, according to which handwriting is the product of a constellation of processing modules that are organized in a hierarchical structure. The model comprises seven modules: intentions, semantic/syntactic factors, spelling, allograph selection, size modulation and muscular adjustment. The first three modules occur during speech and handwriting production, so they were taken from Levelt's (1989) speech production model. The differences arise at the spelling level, where the processing units comprise words that are stored as linear sequences of letters containing information relating to their identity and order. Then, there is the allograph selection level, the size control module, and the muscular adjustment level. The parallel character of the model suggests that all of the modules can be active simultaneously. However, the higher order processing levels (i.e. the linguistic modules) are supposed to be further ahead during the execution of a movement than the lower ones. Thus, the higher order modules anticipate and process information related to forthcoming parts of the word during the writing of the current sequence. When various levels are active concurrently movement duration and trajectory length increase due to the fact that processing capacities are limited. Within this theoretical framework, the increases in duration that have been observed in the aforementioned studies are attributable to supplementary cognitive loads occasioned by parallel processing of local parameters (e.g. size, rotational direction, force) and linguistic information such as syllablic and morphemic structure, but only insofar as these linguistic levels of processing are included in the model.

The concept that morpheme-like units may modulate handwriting production is also supported by neuropsychology research. The writing performance of patients with acquired dysgraphia provides intriguing data on the structure of the orthographic representations stored in the spelling module. Several case studies have shown that words are not coded as mere sequences of letter strings (Wing and Baddeley 1980; Caramazza, Miceli et al 1987), but are instead symbolic entities that are stored in memory together with information concerning the various linguistic levels of which they are composed. There is also evidence that orthographic representations are multidimensional (Caramazza and Miceli 1990, McCloskey et al 1994). The first of the aforementioned levels involves the identity of the letters that constitute the spelling of the word, whereas the second level stores information on word consonant or vowel status. The third level refers to syllabic structure and contains information on syllable boundary position. A fourth level differentiates double letters from other consonant clusters (Tainturier and Caramazza 1996). A morphological level is not defined in the aforementioned study, but one case study found that orthographic representations also encode information on morphemic structure (Baddecker, Hillis et al 1990; for a review, see Allen and Badecker 2001).

In this case study, Patient DH had suffered brain damage that engendered a deficit at the graphemic output buffer. This temporary storage device regulates the lexical and non-lexical processing of abstract letter representations for spelling tasks and the more peripheral components of the writing sequence. DH mostly produced spelling errors towards the end of words, especially when they were long. However, his performance with morphologically complex words was conditioned by more than just word length, in that morphological word composition affected error position: "The affix region of prefixed and suffixed words tended to induce fewer spelling errors than did monomorphemic, length-matched words" (Badecker et al 1990, p. 233). For example, in the word *darkness*, errors were more frequent towards the end of the stem *dark*. They decreased at the first letter of the suffix, only to taper off again toward the end of the suffix. In addition, plurimorphemic words engendered fewer errors than matched monomorphemic words. The authors hypothesize that morphologically complex words are processed as sequences of morpheme-sized units and are therefore represented in the lexicon in a morphologically decomposed form. This suggsts that the spelling process activates not only letters, syllables and whole words, but also morpheme-sized units. Hence handwriting motor programming may also be mediated by the morphological components of words.

Thus handwriting experiments, neuropsychological data and reseach on speech production and reading processes all suggest that morphemes may serve as processing units in handwriting production as well. The present study attempted to shed some light on this issue. Moreover, the morphological structure of words may play a major role in "chunking" letter strings by virtue of the fact that a semantic component comes into play. The fact that morphemes vehicle meaning may indicate that they constitute a different processing level. If this is the case, morpheme-like units will modulate movement programming during the writing of morphologically complex words. In other words, although a letter (or its abstract representation, the grapheme) constitutes a programming unit in handwriting production (Teulings, Thomassen et al 1983; Van Galen, Smyth et al 1989), larger units than the syllable (Kandel, Alvarez et al 2006) may also be involved in motor programming at higher hierarchy representation levels (Caramazza and Miceli 1990; Tainturier and Rapp 2001).

We tested this hypothesis by having participants write suffixed words such as *boulette* on a digitiser. We then compared the production of the suffixed words with the production of matched pseudo-suffixed words such as *goélette*.

Although pseudo-suffixed words end with the same letters as their counterpart suffixed words, these letters are not a suffix. If morphemes are in fact processing units in handwriting production, then the intervals between letters in suffixed words should be longer between morphemes than at the same serial position in pseudo-suffixed words. For example, the interval between *l* and *e* should be longer in *boulette* than in *goélette* since the interval in the former is a morpheme boundary and in the latter is an intra-morpheme interval. If morphology is processed, motor programming should occur at morpheme boundaries and thus engender additional processing loads with respect to the same interval position in a pseudo-affixed word. In such a case, a processing load should occur at the morpheme boundary for the following reason: the handwriting system anticipates the movement needed to produce the succeeding morpheme, which must be processed while local parameters such as size and direction and direction are calcualted, thus lengthening process time (cf. Van Galen's 1991 model). Duration should not increase in an intra-morphemic interval since the morphological dimensions of the movements needed to produce the succeeding letter sequences have already been processed.

II. Methods

Participants

Thirty-eight right-handed students (mean age 23) at Université Pierre Mendès France participated in this experiment. All of them were native French speakers, were unaware of the purpose of the experiment, had normal or corrected-to-normal vision, and had no motor or hearing disorders.

Material

We selected 54 French words (see Appendix), half of which were suffixed (e.g. *boulette*) with the derivational suffixes *-ette*, *-age*, *-ier*, *-eux*, *-able* or *-iste*. In this case *-ette* is a diminutive (e.g. *boulette* means "little ball") whereas *-eux* generally creates an adjective such as *crémeux* (creamy). All of the suffixed words had an intra-syllabic boundary between the root and the suffix. We matched these suffixed words to non-suffixed (i.e. pseudo-suffixed) words such as *goélette* whose suffixes contain the same letters at the same serial position and that have the same number of letters as the suffixed words. In both types of words there was a critical inter-letter interval, which was at the same serial position within a word. The interval between *l* and *e* in *boulette* marks the boundary between the root and the suffix in suffixed words, but not in pseudo-suffixed words (*goélette*). All critical intervals in the pseudo-suffixed words were intra-syllabic. Suffixed and pseudo-suffixed words were matched for lexical and bigram frequency insofar as possible. According to the Lexique 2 French Data Base (New, Pallier et al 2001), mean word frequency for suffixed words is 1097 per million (SD = 1975) and 1155 per million for pseudo-suffixed words (SD = 1914), Z(27) = .07, p = .94. Mean bigram frequency for suffixed words is 3376 (SD = 1950) and 3084 for pseudo-suffixed words (SD = 1273), Z(27) = 0.04, p = .95. The mean bigram frequency at the morpheme boundary for suffixed words is 588 (SD = 393) and the mean bigram frequency at the same serial position in the pseudo-suffixed words is 812 (SD = 450), Z(27) = 1.82, p = .06 (Content and Radeau, 1988).

Procedure

Each word was presented to the participant in upper case Times New Roman 18, at the centre of a Sony Vaio PCG-FX203K laptop screen. This was preceeded by a 200 ms auditory signal and fixation point. The participants were intructed to copy each word into a digitiser (Wacom Intuos 1218, sampling frequency 200 Hz, accuracy 0.02 mm) that was connected to a computer that monitored the participant’s movements. The participants were told to copy the words in upper-case letters and lift the pen “naturally” between each letter (no instructions were given regarding the pen lifting process). The height of the pen lift consisted of a very slight upward and downward movement of the wrist. Prior to performing the task, the participants practiced lifting the pen between letters while writing their names a number of times, until they felt they could perform the task almost “spontaneously” for purposes of the experiment. The participants were told to start writing as soon as possible after being shown the stimulus, but to write at their natural writing speed. There were no time limits or speed constraints. The participants did their writing, using an Intuos Inking Pen, on lined paper that was attached to the digitiser (the vertical limit was 8 mm and the horizontal limit was 17 cm). The subsequent item was presented once the participant completed the previous task. The experiment was preceeded by two practice items so as to enable to participants to get the feel of the digitiser and pen. The items were randomised and presented in 2 blocks of 20 stimuli and one block of 14 stimuli. The experiment was conducted on one subject at a time in a quiet room and lasted approximately fifty minutes.

Data processing and analysis

The data were smoothed using a Finite Impulse Response filter (Rabiner and Gold 1975) with a 12 Hz cut-off frequency. The duration of the intervals between the critical letters for each item were measured, whereby the interval was defined as the period during which two letters were separated by a pen lift. The end of a letter corresponded to pressure = 0 and initiation of the succeeding letter corresponded to pressure > 0. Latency comprised the time that elapsed between stimulus presentation and handwriting movement initiation (pressure > 0). Although the main measure was the inter-letter interval, we also measured latencies since this indicates the time needed for visual word analysis and for handwriting movement preparation.

III. Results

This section describes the inter-morpheme interval duration and latency results for suffixed and pseudo-suffixed words. Separate ANOVAs were realized for both measures, with suffixed versus pseudo-suffixed words as a factor. We excluded from the analysis latencies that were more than 2.0 standard deviations above or below the mean for each participant and condition (1% of the data). Mean latencies and inter-letter interval durations are shown in the following Table 1.

The analysis revealed that inter-morpheme intervals in suffixed words (the interval between *l* and *e* in *bou**lette***) were longer than the same interval in pseudo-suffixed words (*l* and *e* in *goé**lette***), $F_1(1, 37) = 306.73$, $p < .001$; $F_2(1, 52) = 351.52$, $p < .001$. The latency ANOVA showed higher latencies for suffixed than pseudo-suffixed words, $F_1(1, 37) = 62.43$, $p < .001$; $F_2(1, 52) = 90.18$, $p < .001$.

Table 1. Mean inter-morpheme intervals (in ms) and latencies (in ms) for suffixed and pseudo-suffixed words.

	Suffixed words	**Pseudo-suffixed words**
Inter-morpheme interval	144 (SD = 26)	87 (SD = 17)
Mean latency	1987 (SD = 468)	1516 (SD = 294)

IV. Discussion

The aim of this study was to determine whether the timing of motor programming in French adult handwriting production is modulated by morpheme structure. Our results indicate that the suffixed-word production differed from that of pseudo-suffixed words in that the interval at the boundary between the root and suffix was significantly longer than the counterpart interval in pseudo-suffixed words. This difference, which is probably attributable to a processing load resulting from the suffix preparation process, does not occur in pseudo-suffixed words owing to the absence of morphological preparation and the fact that the interval is intra-syllabic. Suffixed words yielded higher latencies than pseudo-suffixed words. This may result from the fact that the system accesses the root prior to accessing the suffix, which is probably more time consuming than accessing one unit only. Pseudo-suffixed words are likely to be accessed directly without any decomposition. This is in line with Orliaguet and Boë's (1993) study on inflexional morphology.

Our results suggest that handwriting production of suffixed words (and possibly other entities) involves morpheme-sized processing units. All inter-letter interval durations were longer at morpheme boundaries than at the corresponding serial position in pseudo-suffixed words. Our results suggest that the movement needed to produce the root is programmed before writing begins, although some movement elements may be prepared on-line. The differences in duration at the morpheme boundary suggest that the motor system prepares the movement needed to produce the suffix during the interval between letters. It would be processed at the interval between the root and its first letter.

In contrast with previous results for typing in German (Weingarten et al 2004) indicating that morpheme effects occur only when syllable and morpheme boundaries coincide, our data indicate that morphemes may even rule out syllable effects. This could be due to the fact that syllable effects in French are highly significant only when the initial syllable of the word contains a consonant cluster. The words we used mainly contained CV syllable initials, thus minimizing syllable effects and (apparently) strengthening morpheme effects. Further research needs to be done with additional suffixed words composed of complex syllable initials in order to test the interaction between syllable and morpheme effects.

It is noteworthy that the results of our experiment are in line with the anticipatory motor programming conception of handwriting postulated by Van Galen's (1991) model. Moreover, our data confirm the concept that supplementary processing loads occasioned by linguistic component programming increase durations. However, Van Galen's model does not regard morphemes as handwriting processing units. Our study revealed that processing of the succeeding morpheme slows down intra-letter string movement by increasing the duration of inter-letter intervals at the morpheme boundary. This rightward incremental fashion and the fact that the system appears to plan the forms of the successive morphemes in a serial order is clearly consistent with the Weaver model of word-form encoding in speech production (e.g. Levelt, Roelofs and Meyer, 1999; Roelofs, 1997). The Weaver model is a theoretical and computational model in which the word-form lexicon is a network of morphophonological nodes and labelled links. The model contains a discrete morphological level (also see Janssen et al 2004) and posits that seriality plays a role in polymorphemic word production. In other words, noninitial word morphemes are planned in serial order and cannot be programmed prior to initial morphemes (Roelofs, 1996).

Morphemes may serve as an intermediate-grained unit between syllables and whole words by virtue of the information they provide on the semantic dimension of words (cf. Kandel et al 2006). Thus handwriting production may also involve activation of a morphemic processing level that stores morphemes as processing units. Morphemes may be decomposed into their syllabic components, either prior to or in conjunction with syllable activation. At this level, syllables may be "deconstructed" into their consonant and vowel constituents and may then serve as input for the allograph module, which may in turn break down the syllables into graphemes for purposes of allograph selection.

Our findings are consistent with (a) neuropsychological data indicating that orthographic representations encode various levels of linguistic information (Caramazza and Miceli, 1990; McCloskey et al 1994), particularly information relating to morphological structure (Badecker et al 1990; Allen and Badecker, 2001); and (b) research on handwriting production indicating that morphologically complex words lead to different processing mechanisms than their monomorphemic counterparts (Orliaguet and Boë, 1993).

However, additional research is needed in the following areas: (a) the possibility of possible applying our results to other languages and the role of the characteristics of these languages on processing; (b) the concrete locus of the morphological effects in a possible model of handwriting; (c) determining whether morphological programming occurs for all types of of words; or whether it is governed by the linguistic properties of individual words, as is suggested by word recognition models (Caramazza, Laudanna, and Romani, 1988); (d) the possible role and processing of inflectional morphology; and (e) how syllables and morphemes can integrated into a unified model (for a discussion of the problems entailed by incorporation of these elements into a single reading model, see Álvarez, Carreiras and Taft, 2001). The Weaver speech production model (e.g. Levelt, Roelofs and Meyer, 1999; Roelofs, 1997) appears to be very promising in this regard inasmuch as it incorporates both types of elements, and is very similar to our own model in a number of ways, particularly in terms of results indicating that non-initial morphemes are subject to serial planning (Roelofs 1996). More work is needed to explore the possible adaptation of these mechanisms to handwriting.

Appendix. Suffixed and pseudo-suffixed words used in the experiment and the consequent word frequencies (pm).

Suffixed words	Word frequency	Pseudo-suffixed words	Word frequency
BLOCAGE	2378.64	BARRAGE	2314.41
BOULETTE	147.24	GOELETTE	142.05
BRUNETTE	178.69	RACLETTE	232.2
CAMIONNETTE	365.92	MARIONNETTE	413.83
CREMEUX	142.54	ONEREUX	1277.51
CUISINETTE	125.94	CHAUSSETTE	150.81
GAZEUX	820.81	ADIEUX	733.88
HERBETTE	69.7	MINETTE	113.06
ILETTE	1.05	BLETTE	21.01
JEUNETTE	23.54	VOILETTE	22.98
LOUABLE	694.23	VOCABLE	710.27
MANCHETTE	420.35	CHARRETTE	451.31
MANIABLE	334.89	CARTABLE	357.31
MIXAGE	777.87	MIRAGE	890.85
ODIEUX	611.23	NEVEUX	600.16
PAYABLE	1149.25	NOTABLE	1940.71
PIERRETTE	907.59	CASQUETTE	893.86
PILLAGE	731.36	PRESAGE	330.48
PLANCHETTE	116.7	EPROUVETTE	175.54
PLIAGE	538.03	POTAGE	418.46
PLUMAGE	325.65	APANAGE	657.67
PORTABLE	5441.84	PROBABLE	5074.94
ROUSSETTE	97.85	SALOPETTE	83.29
SUDISTE	117.19	AUTISTE	137.01
TAPETTE	93.72	SUCETTE	105.7
TIRAGE	4480.11	GARAGE	4647.31
VARIABLE	8535.03	AGREABLE	8296.24

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