Writing without Graphic Motor Patterns: A Case of Dysgraphia for Letters and Digits Sparing Shorthand Writing

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Abstract

This paper reports the case of a patient (H P) who presents a dysgraphia affecting the production of letters and digits while sparing shorthand writing. HP’s writing impairment is two-fold. On one hand, HP produces systematic letter substitutions affecting exclusively lower-case letters b, p, d, and q. Such confusion is also observed in tasks assessing mental imagery of letters and the processing of visually presented, isolated d letters. This deficit is attributed to a circumscribed disruption of allographic representations. On the other hand, HP can write correctly formed letters and digits but the production of these symbols is slow and non-fluent. This disturbance was investigated by using a digitising tablet to record movements performed in grapho-motor production. The results of the analysis of temporal and kinematic indices suggest that graphic motor pattern of letters and digits are no longer available to this patient, whereas motor pattern is underlying grapho-motor production [..]

Reference


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Writing without Graphic Motor Patterns: A Case of Dysgraphia for Letters and Digits Sparing Shorthand Writing

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This paper reports the case of a patient (HP) who presents a dysgraphia affecting the production of letters and digits while sparing shorthand writing. HP’s writing impairment is two-fold. On one hand, HP produces systematic letter substitutions affecting exclusively lower-case letters b, p, d, and q. Such confusions are also observed in tasks assessing the mental imagery of letters and the processing of visually presented, isolated letters. This deficit is attributed to a circumscribed disruption of allographic representations. On the other hand, HP can write correctly formed letters and digits but the production of these symbols is slow and nonfluent. This disturbance was investigated by using a digitising tablet to record movements performed in grapho-motor production. The results of the analysis of temporal and kinematic indices suggest that graphic motor patterns of letters and digits are no longer available to this patient, whereas motor patterns underlying the production of shorthand seem unaffected. It is suggested that there are two ways for producing spatially well-formed symbols. One route is mediated by graphic motor patterns and the other by a motor planning system that would be used in other tasks involving the generation of 2D trajectories (as in drawing or in tracing unfamiliar symbols).

INTRODUCTION

The fluent production of recognizable letter strings forming words is currently viewed as a multiple-stage mechanism (Ellis, 1982, 1988; Goodman &
Caramazza, 1986; Margolin, 1984; Shallice, 1988). Cognitive models of writing usually differentiate three functionally separate levels: a graphemic level, an allographic level, and a graphic motor patterns level (hereafter GMPs). The graphemic level is conceived as a buffer responsible for maintaining a trace of the grapheme string to be produced during the time necessary for processing these units in lower levels. The allographic level is viewed as a component in which the adequate representation would be selected by determining the shape, the case (lower vs. upper-case) and the type (print vs. cursive) of the letter. Representations processed at this level are thought to be physically or spatially coded. The third stage involves motor representations of the allographs, or GMPs. These representations would supply the information necessary to produce the sequence of strokes corresponding to a specific allograph and are responsible for the fast, fluent and automatised handwriting performance of literate adults. Dimensions such as direction, relative size, and order of strokes would be specified at this level.

Before real-time production, several additional parameters would have to be set: the absolute size and scale would have to be determined and the adequate muscle group would have to be selected so that nerve impulses can be sent to the effector\(^1\). However, to our knowledge, there is no evidence that these latter processes are specific to writing.

Reports of patients presenting post-graphemic dysgraphias provide additional insights in the functioning of these processes. For instance, there is converging evidence that at the allographic level as well as at the level of GMPs, the representations of lower-case and of upper-case letters form two distinct repertoires. Indeed, it has been shown that some patients experience more difficulties in using lower-case letters (Kartsounis, 1992; Patterson & Wing, 1989) whereas others present more important impairments in using upper-case letters (Trojano & Chiacchio, 1994). Within-word case confusion errors have also been reported, thus supporting the hypothesis that a specific process is dedicated to determining this dimension at the allographic level (De Bastiani & Barry, 1989; Katz, 1991). Moreover, access to the allographic store has been demonstrated to be constrained by spatial or visual similarity (Goodman & Caramazza, 1986; Weekes, 1994). Along the same line, access to GMPs appears to be determined by spatial (Zesiger & Mayer, 1992; Zesiger, Pegna, & Rilliet, 1994) and/or by grapho-motor similarity (Lambert, Viader, Eustache, & Morin, 1994). In both cases, the letter substitution errors produced by the patients can be predicted by the similarity between the target letter and the one

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\(^1\)The position according to which the selection of the effector is done after the stages of motor program retrieval and parameter setting is subject to discussion. Some data (Wright, 1990; Zesiger et al. 1994) do not appear compatible with this hypothesis and suggest instead that the selection of the effector is performed prior to these stages.
produced. Letter frequency has also been identified as a relevant variable in accessing GMPs (Black, Behrmann, Bass, & Hacker, 1989).

A closer look at the descriptions of patients presenting a deficit attributed to a loss of or inaccess to GMPs indicates that there are basically two subtypes of disorders. Some patients produce mostly nonphonologically plausible letter substitution errors along with a variable proportion of letter omissions, transpositions and additions (Black et al., 1989; Lambert et al., 1994; Zesiger et al., 1994). In these cases, letters are spatially well formed and the writing process is usually described as fluent. Other patients produce mostly ill-formed letters (i.e. letters containing stroke omissions or additions) or nonrecognisable letters (Baxter & Warrington, 1986; Kartsounis, 1992). In these cases, writing production is reported as being slow and nonfluent. There are also patients in whom both deficits have been described (Papagno, 1992).

In all of these patients, a deficit in allographic representations has been ruled out (or contributes only to a minor extent to the observed disorder), usually on the basis of two criteria: (1) unimpaired performance in tasks assessing letter mental imagery (verbal description of letters of answers to questions like “Is the letter o closed or open”), and (2) preserved capacity to recognise, identify, name, etc. visually presented letters. Note that these criteria are based on two theoretical assumptions that can be questioned: Assumption 1 is that allographic representations are accessible to consciousness (as they can be described verbally). Assumption 2 is that the allographic representations used for output (writing) are the same as those used for input (reading, or, more generally, processing visually presented letters). In the present state of knowledge, there is little empirical evidence supporting these two claims. However, some data indicate that peripheral dysgraphias are at least sometimes associated with letter imagery deficits (Crary & Heilman, 1988) and that impairments affecting the production of letters are at least occasionally associated with symmetrical deficits in processing visually presented letters (Rapp & Caramazza, 1989).

Furthermore, it has been shown in all patients presenting a deficit located at the GMP level that the writing impairment could not be interpreted as resulting from visuo-construcational difficulties that are either absent or not sufficient to explain the writing disability. Finally, it should be noted that these patients’ performance in copying letters and words seems to vary. In some cases, copying is significantly better than writing from memory (Baxter & Warrington, 1986; Kartsounis, 1992), whereas in others, no such dissociation is reported (Papagno, 1992).

This paper focuses mainly on the following question: Is it possible to write spatially well-formed letters without accessing the GMPs? The literature cited earlier has largely been silent on this point. Our contention is that there is more than one way of producing spatially well-formed letters and that the integrity of allographic representations and of visuo-construcational abilities is a
sufficient condition to generate spatially correct—though unskilfully per-
formed—letters. An additional issue concerns the organisation of allographic representations and their role in processing letters. It is addressed through some specific letter substitutions produced by the patient described hereafter.

CASE REPORT

The patient has been described in full detail elsewhere (Mayer, Martory, Annoni, & Landis, 1997). Consequently only a brief description will be presented here. HP is a 59-year-old, right-handed man who works as an insurance agent. He completed college-level education and 1 year at university. On 28 February 1994, he suddenly developed writing and calculation disturbances while working at his office and was admitted at the University Hospital of Geneva.

The neurological examination performed on 1 March 1994 did not reveal any abnormality. The NMR scan (1.6.94) showed an ischemic focal subcortical lesion involving the posterior part of the left gyrus supra-marginalis. HP was assessed in the Neuropsychology Unit in the middle of March. He was well oriented and cooperative. The neuropsychological examination revealed that the patient presented all four elements of a Gerstmann syndrome; acalculia, agraphia, left–right disorientation, and finger agnosia. He was not aphasic and his spontaneous speech was fluent. He was administered a French version of the Boston Diagnostic Aphasies Examination (Goodglass & Kaplan, 1972; Mazaux & Orgogozo, 1982). Oral naming, apart from numbers, was normal. Verbal fluency was good (20 animals in 1 min). Repetition of high and low probability sentences and comprehension subtests were flawless. He scored 10/10 on oral reading and paragraph comprehension. On the shortened version of the Token Test (De Renzi & Faglioni, 1978), he performed 35/36. All the tests dealing with memory (Rey Auditory-Verbal Learning Test, Rey-Oster-rieth Complex Figure, Wechsler Memory–revised) were normal, except the subtests containing digits. There was no frontal sign (Wisconsin Card Sorting Test, Stroop Colour–Word test). Ideational, ideomotor, and constructive praxis were entirely preserved. Figure 1 shows samples of drawings performed by HP. There is no sign of agnosia except finger agnosia. His score on the Wechsler Adult Intelligence Scale was 89 (VIQ: 97; PIQ: 79). His performance in four subtests (arithmetics, digit span, code, and Koh’s cubes) was much poorer than in the others, most likely because of his severe impairment in number processing and in left–right distinction. Finally, he obtained a good score in the Standard Progressive Matrices (42/60, 87.5th percentile).
In the early phase post-onset, HP complained about his handwriting, which he reported as “looking different from before” (see Fig. 2 for pre- and post-onset handwriting samples). He also commented on his lack of efficiency: The writing process was described as “very slow” and “organised letter-by-letter.” At that time, his writing (both spontaneous and on dictation) was characterised (1) by systematic substitutions between lower-case letters b and p (almost all bs were written p and conversely) and between d and q (same phenomenon), (2) by some letter omissions, usually appearing at the end of long words, and (3) by sporadic stroke additions affecting the letter m exclusively (see Fig. 2). Although he could write the French alphabet letters correctly in upper-case (26/26) and most letters in lower-case (22/26, errors on b, d, p and q), his productions were painstaking and slow. The same observations were made when he was asked to write using script letters. On the other hand, his proficiency in shorthand, which he used daily premorbidly, did not appear to be affected by the damage: Shorthand writing was correct, fluent, and fast. The patient did not report changes in his shorthand writing. Additionally, the comparison of pre- and post-onset shorthand samples did not reveal detectable modifications in the shape of the produced symbols. Finally, the copy of lower- and upper-case words was entirely correct (19/19 for 2- to 8-letter words), albeit slow.
HP's writing performance was investigated in further detail 6 months post-onset. By that time, the only two consistent signs shown by the patient were the letter confusions between \(b\) and \(p\) and between \(d\) and \(q\) (hereafter referred as \(b/p \rightarrow d/q\) errors) and the slow rate of production.

**Written Spelling**

Written spelling was assessed by asking HP to write to dictation the 312 words contained in the “Batterie cognitive d’examen de l’écriture” (de Partz, 1994). This test was designed to evaluate the influence of the major psycholinguistic dimensions on writing. Given the fact that \(b/p \rightarrow d/q\) errors appear to be contingent on the presence or absence of these letters in the stimuli, two separate error analyses were performed, one including these errors and one not.

As can be seen in Table 1, both error analyses show that there is no effect of variables such as lexical status, orthographic regularity, syntactical class, degree of imagery, and frequency of the stimuli. Word length seems to affect HP’s written production marginally: The rate of errors per letter is slightly higher in long words than in short or medium ones. Moreover, out of 20 homophones presented in sentences, 18 were written correctly (excluding 7 \(b/p \rightarrow d/q\) errors). Finally, in an additional oral spelling test, HP correctly spelled 10/10 words and 10/10 pseudowords.
The 21 (6.4%) non-\textit{b/p–d/q} errors observed in HP’s productions were mainly letter omissions (e.g. couverture \textit{[blanket]} \rightarrow couvertur, transistor \rightarrow transi-tor). There were six phonologically plausible letter substitutions (e.g. cithare \rightarrow *cythare), one phonologically plausible letter addition (canif \rightarrow *canife), and one homophone confusion (coud \textit{[sews]} \rightarrow coût \textit{[cost]}). Overall, these results indicate that HP’s spelling is largely spared. However, the presence of nonphonologically plausible letter omissions suggests a possible discrete residual dysfunction of the graphemic buffer. Alternatively, it could be suggested that the graphemic buffer is especially stressed due to the reduced fluency of the output.

\textit{The b/p–d/q Errors}

The analysis of these errors was performed on the 312 words of de Partz’s (1994) battery. Overall, these words contain 43 \textit{bs}, 50 \textit{ds}, 63 \textit{ps}, and 2 \textit{qs} (total = 158). Out of these letters, 149 were incorrectly produced. Table 2 shows that letter confusions are specific (they exclusively involve a top-bottom letter reversal and not a left-right shift) and highly systematic. All of these letters are produced by tracing first a circle (and occasionally by superimposing additional circles) and then by adding the up- or down-stroke. It should be noted that HP never corrected these errors spontaneously. However, when asked to read over his productions (words) he was able to detect and correct all of them. Samples of these errors are presented in Fig. 3.

\begin{table}
\caption{Number of Errors per Stimuli Type}
\centering
\begin{tabular}{cccc}
\hline
Lexical status & Words & Pseudowords \\
\textit{(N = 20)} & 3 (14) & 1 (6) \\
\hline
Degree of imagery & High & Low \\
\textit{(N = 30)} & 1 (8) & 0 (13) \\
\hline
Length & Short & Medium & Long \\
\textit{(N = 20)} & 0.001$^a$ (0.09) & 0.02 (0.06) & 0.04 (0.08) \\
\hline
Frequency & High & Medium & Low \\
\textit{(N = 20)} & 0 (9) & 0 (6) & 1 (6) \\
\hline
Syntactical class & Function & Nouns & Adjectives & Verbs \\
\textit{(N = 8)} & 0 (2) & 0 (2) & 0 (2) & 0 (2) \\
\hline
Orthographic regularity & 1$^b$ & 2 & 3 & 4 & 5 \\
\textit{(N = 20)} & 1 (11) & 0 (11) & 2 (8) & 1 (9) & 1 (9) \\
\hline
\end{tabular}
\end{table}

\textit{a}Rate of errors per letter.

\textit{b}1 = the most regular; 5 = the most irregular.
There is a high degree of spatial and motor similarity between the target letter and the produced one: Both are formed by a vertical stroke and a loop and the order in which the vertical stroke and the loop are produced is identical. These confusions could be taken to result from a disruption of either the allographic representations or the GMPs. One criterion that has been suggested to test the integrity of the allographic representations is the mental imagery for

\[
\begin{array}{cccccc}
  a & p & c & q & e & f \\
  g & h & i & j & k & l \\
  m & n & o & b & d & r \\
  s & t & u & v & w & x \\
  y & z
\end{array}
\]

There is a high degree of spatial and motor similarity between the target letter and the produced one: Both are formed by a vertical stroke and a loop and the order in which the vertical stroke and the loop are produced is identical. These confusions could be taken to result from a disruption of either the allographic representations or the GMPs. One criterion that has been suggested to test the integrity of the allographic representations is the mental imagery for

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  y & z
\end{array}
\]
letters. As mentioned before, the assumptions that allographic representations are accessible to consciousness and that tasks of mental imagery for letters directly test the integrity of allographic representations are questionable. Nevertheless, it seems to us that a disruption of letter mental imagery is an acceptable argument indicating that the disorder is located at a level related more to the physical letter code than to the motor code. In this perspective, HP was submitted to several tasks of mental imagery for letters.

**Mental Imagery of Letters**

First, HP was asked to describe lower- and upper-case letters of the alphabet verbally. All descriptions of upper-case letters were adequate (26/26). Twenty-two out of the 26 lower-case letters were correctly described. Letters b, d, p and q were erroneous (b: “A circle on the baseline with a downstroke to the left of the circle” [= p]; d: “A circle ( . . ) with a downstroke to the right [= q]; p: “A circle ( . . ) with an upstroke to the left” [= b]; q: “A circle ( . . ) with an upstroke” [= d]).

Second, HP was asked to name all lower-case letters presenting an opening either at the top (u, v, w, x, y), at the bottom (h, m, n, x), at the left (x), or at the right (c, x). All responses given were correct. When asked to name the lower-case letters that contain an upstroke, he responded: “f, h, the dot of i and j, k, l, p, q, and t”. When asked to name the letters that contain a downstroke, his answer was: “b, d, g, j, and y”.

All together, the data concerning the b/p–d/q errors indicate that the letter mental imagery is strictly parallel to the spatial characteristics of letters produced by HP. This result is compatible with the hypothesis of a selective alteration of allographic representations. As stated in the Introduction, it is usually assumed that allographic representations are used both for input (reading) and for output (writing) (Rapp & Caramazza, 1989). If this hypothesis is correct, it implies that HP should show the same deficit in letter recognition as in letter production and in letter mental imagery. This was tested in the following experiment.

**Letter Recognition**

The 26 letters of the French alphabet were visually presented to HP both in upper-case and in lower-case in two tasks. In the first, the 26 lower-case letters were displayed in front of HP and he was asked to point to the letter that was given by the examiner. The same procedure was used with upper-case letters. In the second task, the letters were presented to HP one by one in a pseudorandom order and HP was asked to name each letter.

Over both sessions, HP gave 100% (52/52) correct responses in pointing to and in naming upper-case letters. With lower-case letters, HP gave 84.6% (44/52) correct responses. The errors exclusively concerned letters b, d, p, and
with the same confusions as those observed in writing and in letter imagery (\(b \leftrightarrow p, d \leftrightarrow q\)).

These data add further support to the hypothesis that the spatial or physical code associated with letters \(b, d, p,\) and \(q\) is disrupted and consequently that these confusions result from an impairment located at the allographic level, this level being common to the processing of visually presented letters, to mental imagery tasks, and to writing letters. Note however that HP’s (altered) performance in letter recognition and naming is partly at odds with his (preserved) performance in reading words and texts and in correcting his own errors. These aspects will be discussed further on.

We will turn now to another characteristic of HP’s writing. Indeed, the hypothesis of a circumscribed deficit located in allographic representations does not explain, in our opinion, why HP’s handwriting production is so slow and painstaking. The patient did not appear to have any difficulty in accessing letter form for the other letters of the alphabet: When writing or when responding to questions about letter imagery, HP did not present unusual latencies. Responses were quickly initiated but letters were traced slowly. In this respect, HP’s behaviour is exactly the reverse pattern of that of patient DK described by Patterson and Wing (1989). The nonfluent production of letters suggests that the pre-compiled, stored motor representations underlying (lower- and uppercase) letter production are either lost or unaccessible. By contrast, the fast and fluent shorthand production seems to indicate that the motor representations mediating shorthand writing are spared. In order to test this hypothesis we performed an analysis of HP’s handwriting movements.

**Movement Analysis**

One way to test this claim would be to compare the quantitative results (movement duration, velocity, etc.) obtained in writing letters and digits with those observed in shorthand production. If the latter is mediated by pre-compiled, stored motor representations and the former is not, variables characterising shorthand production should indicate that movements are faster and more fluent than those produced in handwriting. Nevertheless this simple comparison has its limits. In particular, it would neglect the fact that handwriting motor complexity differs from that of shorthand. In the shorthand system “Sténographic français e Aimé Paris” used by HP, speech sounds are represented by straight lines, curved lines and dots. Consonants are written with full-size symbols and vowels with small ones. Most sounds are represented with only one stroke and a few involve two strokes (generally one long straight or curved stroke with a short bisecting line). In proficient shorthand, only the first vowel of the word is represented and the others are omitted. Moreover, frequently used words are simplified.
Thus, two aspects appear to differentiate shorthand symbols from Latin letters: (1) The number of strokes is higher in letters than in shorthand symbols, and (2) the curvature of strokes contained in letters is higher than that of strokes contained in shorthand symbols. It is known that these two dimensions contribute to motor complexity (Hulstijn & Van Galen, 1988; Meulenbroek & Van Galen, 1990). As far as the number of strokes is concerned, the problem can be circumvented by using shorthand words rather than isolated symbols. Strokes produced in shorthand words can then be compared with strokes produced in isolated alphabetic letters. However, this does not solve the problem of the difference in curvature, which can neither be avoided nor satisfactorily taken care of. For this reason we adopted a different rationale and asked HP to produce alphabetic letters, digits, and shorthand words with his dominant hand but also with his nondominant hand. Indeed, there is both experimental (Wright, 1990, 1993) and neuropsychological (Zesiger & Mayer, 1992; Zesiger et al., 1994) evidence that producing familiar letters and symbols with the dominant or nondominant hand involves the same spatial (or physical) representations of the patterns to be produced (allographs), but that motor representations are effector-specific. In other words, preassembled motor programs are believed to exist only for dominant hand writing. Hence, it may be hypothesised that if the motor programs for letters and digits are lost (or inaccessible), the performance of both hands should be similar: The letter confusion errors attributed to the allographic deficit should be found with both hands and the quantitative measures characterizing the movements produced should indicate that both hands are unskilled. On the other hand, if motor representations for shorthand are preserved, the symbols produced with the dominant (right) hand should be traced quickly and fluently, whereas those produced with the nondominant hand should be trace more slowly and less fluently.

Therefore, HP was asked to produce (1) the 26 letters of the alphabet both in lower- and in upper-case, (2) the 10 digits, and (3) 20 words in shorthand both with the right hand and with the left hand. It was ensured that the words administered in this experiment were correctly formed by asking a stenographer to read them. The same experiment was carried out with three control subjects who were fully right-handed (+1 at Bryden’s laterality questionnaire, 1977), who were female secretaries (C1: 46 years old, C2: 58 years old, and C3: 56 years old), and who had a long practice of shorthand.

The productions were recorded by a ZedPen+ digitising tablet (sampling rate = 200Hz, spatial accuracy = ± 0.127mm) to which a slightly thicker than normal ballpen was attached through a flexible wire. A specific, interactive program was used to process the data recorded with the digitiser. The samples were first filtered (low-pass filter, cut-off frequency = 10Hz). The trajectory and tangential velocity of the samples were subsequently displayed one by one on a monitor. On the basis of geometric (cusps and curvature maxima) and kinematic (velocity minima) criteria, each sample was segmented into strokes.
(see Meulenbroek & Van Galen, 1990, for alphabetic letters; Portier, Hylkema, Meulenbroek, & Van Galen, 1993, for shorthand words). For each stroke, the following variables were computed: duration, trajectory length, average pen velocity, and the number of inversions observed on the velocity profile, a measure known as dysfluency, expressing the degree of continuity or discontinuity of the movement. In adults, the production of a stroke belonging to a familiar letter or symbol is usually characterised by a short duration (100–200msec) and by a bell-shaped velocity profile (involving a single velocity inversion, which means that dysfluency is equal to 1). Conversely, the production of a stroke pertaining to an unfamiliar pattern typically lasts 300–450msec and involves multiple velocity inversions (dysfluency = 3, 4, 5, or higher) (Portier, Van Galen, & Meulenbroek, 1990; Portier, Van Galen, & Thomassen, 1993). It should be stressed that duration and dysfluency are the two most reliable variables allowing discrimination between skilled and unskilled performance. Average velocity can also be of interest, although its major drawback is to be highly dependent on trajectory length. The covariance between velocity and length is a well-known phenomenon termed the isochrony principle, which corresponds to a spontaneous tendency to maintain constant movement duration despite changes in movement amplitude (Viviani & Terzuolo, 1983). Consequently, any substantial size increase in tracing symbols with the nondominant hand can result in an “artificial” velocity increase.

Results concerning HP and the three control subjects are described in Table 3 and samples of HP’s productions and their velocity profiles are presented in Fig. 4. Two-tailed t-tests were computed so as to compare the results obtained by individual subjects in each condition (lower- and upper-case letters, digits, and shorthand words) with the right hand and with the left hand. Inspection of Table 3 reveals that HP does not present the typical right-hand advantage displayed by the three control subjects in the production of lower- and upper-case letters and of digits: His production is characterised by long durations, low velocities, and by a high level of dysfluency whatever the hand used. In two cases, he even displayed a surprising left-hand advantage (on duration for digits and on dysfluency for upper-case letters). This effect could be due in part to the fact that HP’s performance somewhat varied over sessions and that the conditions were pseudorandomly assigned to the first or to the second session. Indeed, unlike normal subjects, HP was tested in two sessions given the time he took to perform each task.

By contrast, like all three control subjects, HP shows a significant right-hand advantage in the production of shorthand words: The right hand is fast and fluent whereas the left hand is slower and more dysfluent. Moreover, it should be noticed that in this latter condition, the raw values of all dependent variables for HP are close to those observed in the three control subjects. This phenomenon appears to be specific to this condition, as HP obtained quite deviant results
<table>
<thead>
<tr>
<th>Subject</th>
<th>Duration (sec)</th>
<th>Length (Cm)</th>
<th>Av. Velocity (Cm/sec)</th>
<th>Dysfluency</th>
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<td></td>
<td>RH</td>
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<tr>
<td>Lower-case letters</td>
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<tr>
<td></td>
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<tr>
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<td>0.30</td>
</tr>
<tr>
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<td>0.67</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>0.14</td>
<td>&lt;&lt; 0.29</td>
<td>0.41</td>
</tr>
<tr>
<td>Digits</td>
<td>HP</td>
<td>0.51</td>
<td>&gt; 0.42</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>C1</td>
<td>0.13</td>
<td>&lt;&lt; 0.23</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0.12</td>
<td>&lt;&lt; 0.29</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>0.13</td>
<td>&lt;&lt; 0.27</td>
<td>0.41</td>
</tr>
<tr>
<td>Shorthand words</td>
<td>HP</td>
<td>0.17</td>
<td>&lt;&lt; 0.28</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>C1</td>
<td>0.15</td>
<td>&lt;&lt; 0.21</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0.16</td>
<td>&lt;&lt; 0.32</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>0.15</td>
<td>&lt;&lt; 0.25</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Significance level of the effects (two-tailed t-tests) are indicated by “<” or “>” ($P < .05$) and by “<<” or “>>” ($P < .01$).
compared to the control subjects in the three other conditions, even for the left hand.

As predicted by the hypothesis stating that allographic representations are common to all effectors, the $b/p-d/q$ confusions were observed both with the right hand and with the left hand, although the letter $q$ was transformed into $p$ instead of the expected $d$ in the nondominant hand condition. Finally, it should be noted that the analysis of additional material (written words both in lower- and upper-case codes, numbers, etc.) provided results comparable to those recorded in the corresponding modalities for isolated letters and digits.

**DISCUSSION**

The patient reported here presents several interesting features: (1) he produces specific and systematic lower-case letter confusions affecting the letters $b$, $d$, $p$, and $q$; (2) his performance in mental imagery for letters and in processing visually presented, isolated letters is the exact reflection of his productions; (3) the writing of lower- and upper-case letters and of digits is spatially correct though unskilfully performed (slow and dysfluent); and (4) shorthand production is both correct and skilful. On the basis of these results, it can be concluded: (1) that HP is affected by a very selective disruption affecting only a small number of allographic representations; (2) that motor representations (GMPs) for letters and digits are either lost or inaccessible; and (3) that motor representations of shorthand symbols and words are preserved. From the two latter

![FIG. 4. Trajectory and velocity profile (cm/sec) as a function of time (sec) of the lower-case letter $n$ and of the word *résultat* (result) written in shorthand produced with the right hand (top panels) and with the left hand (bottom panels).]
statements, it follows that motor representations for letters and digits and those for shorthand symbols and words are represented separately in the subject’s brain. Such a dissociation has already been reported concerning reading (Regard, Landis, & Graves, 1985; Regard, Landis, & Hess, 1985).

These conclusions raise two major theoretical issues: What cognitive architecture is adequate to account for HP’s and other patients’ impaired retrieval of or access to GMPs? and How are the allographic representations organised and what is their role in processing letters?

For the first question, HP’s performance pattern suggests that there is more than one way to produce spatially correct letters. The usual route involves selecting the adequate allograph, activating the corresponding GMP, and transferring this information to the lower motor processes in a so-called graphic code. An alternative route would be used when GMPs are no longer available. In such a case, this spatial information, output of the allographic level, could be interpreted directly by a motor planning system responsible for generating two-dimensional trajectories. This system would compute the trajectory necessary to produce the letters and would transfer this information to the lower motor processes. The use of this route would result in the production of spatially well-formed although unskilfully performed letters.

This trajectory generation system, or 2-Dimensional Trajectory Generator (2DTG), could be used for drawing or for writing unfamiliar symbols with a spatial information input from visual memory. Figure 5 represents a plausible cognitive architecture of the processes involved in producing familiar and unfamiliar symbols. On the basis of this model, HP’s impairment could be located either at the GMP level or in the connections between the allographic level and the GMP level or between the GMP level and the lower-level motor processes. We believe that within this framework and given the current levels of theorising, there is no way to distinguish between these possibilities, since the predictions regarding a total ‘non-access” to the GMPs, those regarding a total “loss” of information within this component and those regarding a total absence of transfer to the lower level are strictly identical. On the other hand, it can be suggested that in HP, the connections between the allographic level and the 2DTG as well as the 2DTG itself are preserved. Indeed, the information from the allographic level can be interpreted by the 2DTG to produce letters and digits and the 2DTG appears to function quite efficiently in producing drawings.

Thus, it appears that a deficit attributed to the GMPs level can result in multiple forms of impairment. The cognitive architecture outlined in Fig. 5 is necessary and sufficient to account for HP’s performance. How does it relate to other cases described in the literature? In particular, is it compatible with patients IDT (Baxter & Warrington, 1986) and LCA (Kartsounis, 1992)? These patients produced mainly aborted letters, “nonletters,” or letters containing additional or omitted strokes. In both patients, allographic representations were
FIG. 5. Schematic diagram of a plausible architecture of the processes involved in the production of familiar and unfamiliar symbols.
reported as being preserved. Yet, if they have impaired retrieval or access to GMPs, why do they not use the 2DTG to write letters? We believe that there are several possible ways of interpreting their performance within our framework. First, these patients may be impaired at the level of the 2DTG (which should affect drawing production). In fact, Baxter and Warrington did report a moderate deficit in constructional abilities in IDT. This deficit does not, however, appear important enough to explain the patient’s difficulties in writing. Moreover, such difficulties are not present in LCA. A more likely interpretation is that these patients also suffer from a disruption of the connection between the allographic level and the 2DTG. An alternative interpretation, perhaps unnecessarily complicated given the present state of knowledge, would be that as long as there is some residual functioning of the GMP level, it could play an inhibitory role on the alternative route mediated by the 2DTG.

The second interpretation, which we favour, also appears to be compatible with the dissociation reported both in IDT and in LCA between writing letters from memory (impaired) and copying them (preserved). It is usually accepted that there are two ways to copy letters and words: a lexical copying mode and a pictorial copying mode (Ellis, 1982; Margolin, 1984). Lexical copying can be seen as involving spelling processes and the usual peripheral processes (graphemic, allographic and GMP levels). By contrast, pictorial copying would involve visual working memory and the 2DTG. Our model would predict the possible use of a “mixed” strategy: Lexical until the allographic level is reached and then mediated by the 2DTG. Indeed, even if both routes emanating from the allographic level are impaired in these patients, it is sufficient for them to have an intact visual working memory and a fairly intact 2DTG to copy letters. However, this would imply that the production of letters in copy tasks is nonfluent. Consequently, knowing that the patient is able to copy or not is not sufficient to decide whether he or she used one route or another. Indeed, it is rather the degree of skillfulness (duration, fluency) that determines whether copying is mediated by GMPs or by the 2DTG system. In this respect, the fact that LCA was reported to copy lower- and upper-case letters “fluently” might suggest that at least part of his difficulties result from an impairment of the allographic representations rather than of the GMPs. Indeed, if the correct shape is supplied, LCA does not appear to be hindered in retrieving the GMPs.

As for the second issue, the selective impairment displayed by HP at the allograph level can be considered as supporting the hypothesis that allographs are represented in clusters sharing similar spatial characteristics, as suggested by Weekes (1994). It is noteworthy that the letters d or q, for instance, are never confused with the (script) letter a despite the fact that they are quite similar to each other except for the size of the vertical stroke. Therefore, it seems that the notion of similarity in the case of allographs extends beyond the general appearance of the letter and that the clusters are organised along axes that remain to be specified. Obviously, one of these axes is the presence of an
upstroke or downstroke. Further research should aim at determining whether the b-d-p-q cluster is special in some respect or if other clusters exist, organised along other axes, as shown by Dunn-Rankin (1968) in letter recognition.

Two additional aspects of the b-p/d-q errors deserve some discussion. The first one is that these confusions are observed in written production, in mental imagery for letters and in the processing of visually presented, isolated letters. These data support the hypothesis of the existence of an allographic level, which would contain spatially or physically specified letter representations and which would be used both for input and for output (Rapp & Caramazza, 1989). However, two aspects of HP’s performance are somewhat at variance with this claim. First, such errors are not observed in HP’s reading of words and texts. Second, this deficit does not prevent HP from being able to detect and correct his own b-p/d-q errors (as long as they are inserted in a word). The following tentative explanation can be suggested: In writing, in letter imagery tasks, and in the processing of visually presented, isolated letters, HP would process each letter individually (recall that HP spontaneously describes his writing production as being “organised letter-by-letter”). Given the fact that the stored allographic representations for the letters, b, d, p, and q are disrupted, HP produces errors with these letters. By contrast, when reading words or when correcting words containing b-p/d-q errors, HP would not necessarily use a letter-by-letter analysis strategy. He could rely instead on the (preserved) word level (or morpheme-level) representations stored in the orthographic lexicon. Thus, the intact performance displayed by the patient in reading and in correcting errors could be due to a lexical influence, which cannot be activated when processing isolated letters.

The second intriguing aspect related to b-p/d-q errors is their systematicity. The performance pattern shown by HP deviates singularly from what is expected if he were globally confused about these letters. Indeed, if these representations were under-specified, one would expect a close to random selection of these letters. For instance, if the representations contained information specifying only that these letters are formed by a circle and by a vertical stroke, one should observe the production of an approximately equal number of the letters b, d, p, and q, whatever the target letter. If the side on which the vertical stroke has to be placed were also defined, it should lead to the undifferentiated production of either b and p or d and q. This is not what is observed in HP. Moreover, letter frequency does not seem to affect the selection of these letters, as HP substitutes almost all occurrences of the letter d by the letter q, which is a less frequent letter in French (2.1% vs. 0.9%, based on Content & Radeau, 1988). In our opinion, the only way to account for the systematics of this phenomenon is to hypothesise that the damage to the allographic level has resulted in a stable reorganization of the b-d-p-q cluster, which involves a shift of at least one defining feature (upstroke vs. downstroke) of these letters.
A final brief point could be raised concerning the fact that the raw values obtained by HP on the duration and dysfluency variables in the production of lower- and upper-case letters and of digits are usually quite out of range compared to those of the control subjects even for the nondominant (left) hand. A priori, this result could suggest the presence of a peripheral motor impairment in HP. However, the fact that the patient obtains results that are fully comparable to those of the control subjects in the production of shorthand both with the right and with the left hand appears to be sufficient to rule out this interpretation. Consequently, this phenomenon could be interpreted as suggesting that the preassembled motor programs, which are in principle specific to the dominant hand, may contribute to some extent to the production of movements with the nondominant hand. It is known that under certain conditions, some transfer of motor skill is possible between the right hand and the left hand (Thut et al., 1996, 1997). Indeed, our data alone are not sufficient to support this claim. In particular, a possible difference in the strategies used by HP and by the three control subjects cannot be set aside, with for example HP being more concerned with producing accurate letter shapes and the control subjects being more focused on efficiency. However, the fact that such a strategic difference is not observed in the production of shorthand words does not seem consistent with this latter interpretation.

In the context of the study of peripheral dysgraphias, the present paper advocates the use of instruments (video cameras as used by Patterson & Wing, 1989, or digitisers as used in this research) that allow measurement of parameters characterising the writing process (i.e. temporal and kinematic variables), instead of being restricted to the observation of the end product (spatial variables), which supplies only a limited range of information concerning the integrity of the processes involved in writing. In fact, it may be possible that a number of patients presenting patterns close to that displayed by HP have gone undetected because they were producing spatially well-formed letters and because their slowness was attributed to a nonspecific effect of brain lesion.

References


