Slips of the typewriter key

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ABSTRACT
This article presents an analysis of 500 submorphemic slips of the typewriter key that escaped the
notice of authors and other proofreaders and thereby made their way into the published records of
scientific research. Despite this high selectivity, the corpus is not found to differ in major ways
from other collections of keying slips. The main characteristics of this error type include a predomi-
nance of within-word slips, an elevated rate of noncontextual slips, a heightened incidence of omis-
sions (in particular, masking errors), a high number of adjacent switches, and an uncommonness of
these slips in word edges. In all these respects, slips of the key resemble slips of the pen, although
not slips of the tongue. It is argued that speech errors are shaped by a fully deployed structural
representation, whereas key slips arise under the influence of a weak structural representation. By
implication, speaking is characterized by a hierarchical strategy of activation while typewriting is
subject to the so-called staircase strategy of serialization in which activation is a function of linear
distance. These disparate strategies may be understood as a response of the processing system to
disparate requirements, such as varying speed of execution.

INTRODUCTION

Speaking, writing, and typing are three language output activities that exhibit
some intriguing commonalities. One of the best known of these is the interaction
between utterance planning and utterance length. Sternberg and coworkers (e.g.,
Sternberg, Knoll, Monsell, & Wright, 1988; Sternberg, Monsell, Knoll, & Wright,
1978) demonstrated for both speaking and typewriting that the time it takes to
prepare a sequence of output units increases linearly with the length of this
sequence (i.e., the number of output units). It is to be expected that this correla-
tion also holds for handwriting. On the other hand, there are important dispari-
ties between the output modalities. Apart from the fact that different muscle
systems are involved in motor execution (e.g., tongue movement in speaking
vs. finger movement in typewriting), speaking makes crucial use of a phonologi-
cal code that is much less essential in writing. Lexical representations may be
directly converted into graphemic representations, thus effectively bypassing the
phonological component. A further difference concerns the relationship between
planning and execution. Tannenbaum, Williams, and Wood (1967) found a high
number of short pauses in speaking but a low number of longer pauses in typing.

Finally, mention should be made of the temporal dimension. Speaking is three to four times faster than handwriting (Newman & Nicolson, 1976). As a skill that is acquired comparatively late, the speed of typewriting depends a great deal on proficiency. Highly proficient typists reach a maximum speed of 200 words per minute (Rumelhart & Norman, 1982), whereas the average rate is 30–45 words per minute. Clearly, the normal rate of typing is lower than the usual rate of speaking but not unlike that of writing.

In general terms, typing appears to be more similar to writing than to speaking. Typing and writing make use of the hand, are acquired relatively late or not at all, require some formal instruction to be mastered, are largely based on the prior acquisition of speaking, create a visual–spatial code, and serve almost identical functions, among other similarities. However, there are also some notable disparities. Whereas typing is a discrete activity at the level of the keystroke, handwriting is a more continuous activity (Gentner, 1983) with linkages, overlap, and fuzzy boundaries between adjacent letters, as observed on a much larger scale in speaking. It is therefore not entirely obvious how similar the mental processes underlying typing and writing are.

One way of elucidating the processes of typing, writing, and speaking is by studying the errors arising during these activities. (By errors are meant inadvertent deviations from the producer's intention, so-called slips.) If the error patterns in typing and writing are alike, there would be reason to argue that similar production strategies are employed by the processing system. By contrast, disparate error patterns would be suggestive of disparate processing strategies.

Although a large number of speech error corpora have been amassed, there are not many collections of slips of the pen and the typewriter key. It is no surprise therefore that systematic comparisons of error data from different modalities are at a premium. Even though a few studies have compared slips of the tongue and the pen (e.g., Aitchison & Todd, 1982; Berg, 1997; Hotopf, 1983), no detailed comparisons are available of slips of the pen and the key (or of slips of the tongue and the key, for that matter, with the possible exception of MacNeilage, 1985). It is one of the objectives of the present article to carry out such a comparison.

Previous data gathering efforts have produced at least four corpora of typing errors, three from English and one from Dutch. All of these samples are medium sized, ranging from 300 to 700 items. Naturally, the four corpora differ in terms of the aims, collection procedure, and error classification system. Van Nes' (1976) examination of approximately 300 slips of the key in Dutch was motivated by the practical desire to sound out possibilities of error reduction. Twenty-five typists provided input to his study. Grudin (1983) was mainly concerned with behavioral differences between novice and expert typists and questioned whether the two populations yielded different error patterns. Eight novices and six experts contributed 103 and 598 slips, respectively. On the basis of a single-subject study, Shaffer (1975) looked into the control processes in typing. He furnished detection rates for various error categories and also touched on error correction. Like Shaffer (1975), MacNeilage (1964) related different slip types to different processing stages. A major distinction that he made was between a programming mechanism, which is responsible for serial-order errors, and an

execution mechanism, the malfunctioning of which generates spatial errors (in which a key adjacent to the target key is struck). These properties allow one to keep the two error types operationally distinct, although there is no clear dividing line between high-level (psycholinguistic) and low-level (motor) errors. MacNeilage's work drew on more than 600 slips from five typists.

The widely divergent error categories, as well as their partly nondescriptive nature, hinders not only a comparison of the four collections discussed but also a contrastive analysis of typing and writing errors. Hence, it was deemed necessary to compile a new corpus to which the same set of descriptive categories could be applied as in the investigation of slips of the pen. This corpus of key slips is introduced in the next section.

THE CORPUS

The ensuing analysis is based on a total of 500 typographical errors excerpted from scholarly works published in English and dealing with linguistics and related disciplines.[1] Most of these publications are journal articles or, less frequently, individual chapters of edited volumes. Entire books were not taken into consideration in an attempt to safeguard against potentially idiosyncratic error patterns. A total of 371 sources contributed one slip each, 57 contributed two each, and 5 contributed more than two each.

It was decided from the outset to restrict the investigation to sublexical errors, that is, slips involving units smaller than the word or morpheme. (Lexical slips turned out to be infrequent anyway.) Very few errors were ambiguous between a lexical and a sublexical interpretation. These were either discarded or assigned to the category of noncontextual slips (see below). We included only errors that involved ordinary graphemes. Slips involving punctuation marks and other typographical devices (e.g., capitalization) were ignored. Also discarded were all cases that looked like competence errors, such as those that repeatedly occurred in the same text (especially if the author was a nonnative speaker of English). Slips of the tongue and the pen are defined as performance errors, and the same criterion was applied to slips of the key.

Of course, there is no guarantee that all misprints in the articles scrutinized were caught. It is even likely that some of them were not noticed. In other words, a certain degree of selectivity was impossible to avoid. To keep this selectivity within tolerable bounds, I made every effort to focus on spotting typographical errors rather than on the content of these articles, many of which I had read before and reread for the purposes of this study.

It is clear that the typographical errors under examination here are the remaining few to have survived the several rounds of proofreading to which a scientific article is usually subjected before and during the production process. In most cases, at least two experienced people (the author and the copyeditor) perform an error check. It stands to reason that this proofreading heavily biases the error distributions, to the effect that only those errors make it into the printed version that are most difficult to notice. A highly likely hypothesis is that the grosser the deviation from the intended output is, the easier the error is to detect. The

remaining slips would then be those in which the discrepancy between intended and actual output is relatively minor.

It should be noted, however, that a comprehensive comparison of the distributions of (all types of) self-corrected and uncorrected typing errors has yet to be performed. Van Nes (1976) claimed that he was unable to find any differences in the proportions of error types in self-detected and undetected slips. Evidently, this statement pertains only to the error categories as he defined them. However, not all error classes lend themselves to this conclusion. There is little doubt that some error classes are more readily detected than others. MacKay (1968), for instance, showed that typographical errors that do not change the pronunciation of a word (e.g., *bird → berd*) were more difficult to detect than those that do (e.g., *bird → bord*). Several other studies confirmed the differential detectability of various error classes. However, because detectability data are still lacking for many major categories, the extent of the difference in the distribution of uncorrected and the hard to detect errors examined in this article is not easy to determine exactly. One way of alleviating this uncertainty is to compare the hard to detect data to more balanced corpora. If both data sets generate similar trends, one would be entitled to claim that the distortion introduced by the elimination of easy to detect slips stays within limits.

What is the theoretical significance of a data set that may be biased in the way described here? Clearly, a corpus of hard to detect errors is not a collection of pure production data. Rather, it represents a mixture of productive and perceptual aspects, in that the errors originate in the productive domain but were decimated through the action of a perceptual monitor. The surviving slips may thus be argued to reflect both productive and perceptual constraints. Hence, whatever the theoretical account that may be proposed for these errors, it is inevitably one that cannot neatly separate production and perception.[2] However, this is only a problem to the extent that productive and perceptual representations diverge in critical ways.

RESULTS

The following text gives a survey of the qualitative and quantitative patterns in the error corpus. The classification system is the one that has become standard in the error literature (compare Gentner, Grudin, Larochelle, Norman, & Rumelhart, 1983; Stemberger, 1993). The focus will be on those error types that are of particular relevance to processing issues. Pertinent data from other modalities will be introduced, along with the results for the typographical slips.

An initial observation is that, with one apparent exception (to be discussed below), all errors involved single letters. This finding might seem trivial at first sight, because each letter requires a separate key stroke, which is an independent motor action. However, it is not clear a priori why individual letters should not be integrated into larger units and be dislocated as such.

The first distinction to make is that between contextual and noncontextual errors. An error is said to be contextually motivated when a source unit that is identical to the error unit can be found in its vicinity. When such a source is missing, the error is classified as noncontextual. An example of each error type

Table 1. *Frequency of contextual and noncontextual slips in typing, writing, and speaking*

	Contextual	Noncontextual
Typing	359 (71.8%)	141 (28.2%)
Writing	514 (74.1%)	180 (25.9%)
Speaking	1,845 (85.1%)	324 (14.9%)

follows. For the sake of discretion, the bibliographical source of the misprint is not provided. The error unit is italicized, and the presumably intended form follows the error. As much of the surrounding context is given as is deemed necessary for an adequate categorization and a rudimentary understanding of the utterance. The slash marks the end of the fragment containing the error.

1. it is important to re*b*ember an historical coincidence / for: remember.
2. Then there are special *d*roups. / for: groups.

In example 1 the first <m> of the second syllable of *remember* was replaced with the <b> from the third syllable of the same word. The nearby <b> thus motivates the occurrence of the slip. No such motivation is discernible in example 2 that is therefore classified as noncontextual. Some of these cases represent MacNeilage's (1964) "spatial errors."

Table 1 presents the number of contextual and noncontextual slips in typing, writing, and speech. The written-language data are taken from Wing and Baddeley's (1980) corpus of English pen slips and the spoken-language data from Stemberger's (1989) corpus of English tongue slips.

As Table 1 shows, contextual slips outnumber noncontextual ones in all three output activities. The highest rate of noncontextual errors occurs in typing. However, the difference between contextuals and noncontextuals in typing and writing is not statistically significant, $\chi^2(1) = 0.9$, $p > 0.3$, leading us to conclude that contextuality has the same status in these two modalities. On the other hand, the incidence of contextual slips is significantly higher in speaking than in typing and writing, for typing: $\chi^2(1) = 49.9$, $p < 0.001$; for writing: $\chi^2(1) = 44.1$, $p < 0.001$. Thus, the factors that bring about contextual errors have a more important role to play in speaking than in writing or typing.

The second distinction applies only to contextual slips and turns on the distance between the error and source unit. The most pertinent criterion is whether or not there is a word boundary between them. In the former case, the slips belong to the between-word category and in the latter, to the within-word category, as exemplified in examples 3 and 4.

3. opaque acronyms like FIAT, or some *s*ombination of these / for: combination.
4. Interestingly, there is no eviden*d*e that the length of the name in syllables / for: evidence.

Table 2. *Frequency of between- and within-word slips in typing, writing, and speaking*

	Between word	Within word
Typing	39 (10.9%)	320 (89.1%)
Writing	106 (20.6%)	408 (79.4%)
Speaking	1,605 (87.0%)	240 (13.0%)

Example 3 is classed as a between-word slip because the <s> in the error word *sombination* is assumed to the "same" as the <s> in the prior word *some*. As the source of the slip in example 4 is located in the same word in which the malfunction occurred, it is classified as a within-word error. It is worth noting that the identification of the source element is not always a simple matter. This is because it is not known in advance how far one may go to the left or the right of the error word in looking for the source. An answer to this question presupposes information on the frequency of within-word slips. This information is supplied in Table 2. For the slips of the tongue and the pen, the same corpora are used as in Table 1.

Inspection of Table 2 shows that typing is much more similar to writing than to speaking. Typing and speaking are diametrically opposed. The preponderance of between-word slips in speech is as strong as the preponderance of within-word errors in typing. The corpus of pen slips also exhibits a clear preference for within-word slips, but it is significantly less strong than in the typographical errors, $\chi^2(1) = 15.5$, $p < 0.001$. Not surprisingly, the difference between writing and speaking is significant, $\chi^2(1) = 921.9$, $p < 0.0001$, as is the difference between typing and speaking, $\chi^2(1) = 836.1$, $p < 0.0001$. There thus is a hierarchy of increasing distance between the error and source unit as we move from typing to writing and then to speaking.

The overwhelming predominance of within-word slips in typing allows one to conclude that the interferential effect of graphemes in words other than the error word is rather weak. As a consequence, the identification of such more distant source elements may sometimes be less secure than one would prefer. If the assumed distant source was misidentified, the error would rather be of the noncontextual kind. Fortunately, the number of these uncertain cases is so low that a reclassification would not change the overall error pattern.

At the descriptive level, slips are customarily categorized into three major groups: substitutions, additions, and omissions. All the errors already discussed involve a substitution of one grapheme by another. Examples of an addition and an omission are respectively provided in the following:

5. Thus the in*i*tuitive version of Lounsbury's hypothesis was supported. / for: intuitive.
6. For example, the phonologi_al time node generates more impulses per second[3] / for: phonologi*c*al.

Table 3. *Frequency of substitutions, additions, and omissions in typing, writing, and speaking*

	Substitutions	Additions	Omissions
Typing	217 (43.4%)	83 (16.6%)	200 (40.0%)
Writing	245 (45.5%)	95 (17.6%)	199 (36.9%)
Speaking	2,249 (88.0%)	200 (7.8%)	107 (4.2%)

The error word in example 5 contains one <i> too many whereas the error word in example 6 lacks a <c>. Table 3 reports the frequency of the three error types in typing, writing, and speaking. With respect to slips of the tongue, the substitution data (both contextual and noncontextual) come from Stemberger (1985) and the addition and omission data come from Stemberger and Treiman (1986).

It can be seen from Table 3 that the proportions of substitutions, additions, and omissions are highly similar in typewriting and handwriting, $\chi^2(2) = 1.0$, $p > 0.5$. In both modalities the substitutions are most frequent, omissions somewhat less frequent, and additions least frequent. Speaking is different in three respects: additions clearly outnumber omissions,[4] substitutions are twice as common, and omissions not nearly as common as in typing and writing. The least variation across the three modalities can be observed in the case of additions. The difference between tongue slips and key slips is significant, $\chi^2(2) = 675.7$, $p < 0.0001$, as is the difference between tongue slips and pen slips, $\chi^2(2) = 693.2$, $p < 0.0001$.

The high rate of omission errors in typing calls for a more detailed analysis. Like the other descriptive categories, omissions may be subdivided into contextual and noncontextual ones. Contextual deletions come in two classes. The first is called masking and is defined by an element that blots out an identical unit in the vicinity. Two subtypes of masking may be distinguished: nonadjacent and adjacent (see also MacKay 1969a). In phonology, adjacent masking is commonly referred to as degemination. The other class is called plain contextual omission and involves the deletion of a unit due to structural pressure from a neighboring syllable or word. For example, if a given word begins with a single consonant (C) and a consonant cluster (CC) is erroneously simplified nearby, it is assumed that the C structure of the source word interfered with the CC structure of the error word and led to the production of a singleton consonant. Such a case is documented in example 7. Nonadjacent masking is exemplified in example 8a and adjacent masking in 8b. A noncontextual slip was shown in example 6. Note that example 7 is a speech error not a typographical one.

7. Oh, we p_ant peas every spring. / for: p*l*ant peas (from Stemberger, 1990).
8a. We propose to divide all strategies of lexical simplif_cation in language learning into two groups. / for: simplif*i*cation.

Table 4. *Frequency of noncontextual deletions, masking errors,
and contextual deletions in typing, writing, and speaking*

	Noncontextual deletions	Masking errors	Contextual deletions
Typing	76 (38.2%)	123 (61.8%)	0 (0.0%)
Writing	108 (54.3%)	91 (45.7%)	0 (0.0%)
Speaking	26 (23.0%)	38 (33.6%)	49 (43.4%)

8b. In order to determine whether agram_atic patients appreciate the distinction
   between / for: agram*m*atic.

The dropping of the /l/ in *plant* in example 7 appears to be facilitated by the
fact that the following word begins with a single consonant. This onset structure
was anticipated and left no room for the cluster /pl/, which was consequently
simplified to /p/. The fact that the following word begins with a consonant that
is identical to the onset of the error may also have played a role. The motivation
in example 8a is quite different. The <i> was probably masked by the other
<i>s in the same word. That is to say, the repeated occurrence of the same unit
leads to a processing failure on one of them (see Stemberger & MacWhinney,
1986). A similar account might hold for example 8b.

Frequency information on the three classes of omission errors in the three
modalities can be found in Table 4. The pen slip data are based on Wing and
Baddeley's (1980) corpus, and the tongue slip data are from Stemberger's
(1990) analysis.[5]

Perhaps the most conspicuous result shown in Table 4 is the complete absence
of contextual deletions in typing and writing. While it cannot be ruled out at
this stage of enquiry that the pen slip and key slip corpora are too small to show
an occurrence of such deletions and that larger corpora might show them to be
real, the evidence for their existence is rather weak at the present time. Com-
pared to speaking, the absolute number and percentage of omissions are so high
that one may reasonably expect such errors to have crept in, if they existed. It
could also be that contextual omissions are in the corpora but are not identified
as such. This is not very likely, however. Let us return to example 6 which is
quite typical. There is no "model" in the syntagmatic context for the <c> to
copy. There are only two vowel-initial words (*example* and *impulse*), which are
too far away to make an effect, and there are no vowel-initial syllables. No
matter whether contextual omissions exist or are extremely uncommon in typing
and writing, it is clear that the mechanisms that generate these slips play far
less of a role in typing and writing than they do in speaking.

There is a further radical difference between speaking, on the one hand, and
typing and writing, on the other, that cannot be seen from Table 4. Adjacent
masking errors occur in typing and writing but not in speaking. Although this
difference only serves to amplify the similarity between typing and writing and
the dissimilarity between these actions and speaking, it is of no major theoretical

Table 5. *Directionality of contextual between-word errors in typing, writing, and speaking*

	Masking		Substitution	
	Anticipation	Perseveration	Anticipation	Perseveration
Typing	42 (43.3%)	55 (56.7%)	37 (54.4%)	31 (45.6%)
Writing	28 (41.8%)	39 (58.2%)	111 (65.3%)	59 (34.7%)
Speaking	38 (45.8%)	45 (54.2%)	839 (62.7%)	500 (37.3%)

importance because the phonological system of English prevents such errors from occurring in the first place. Because English lacks consonant gemination, there is no way in which degemination could arise.

Unlike the previous analysis, Table 4 establishes a reliable difference between typing and writing, $\chi^2(1) = 10.3$, $p < 0.005$. Masking errors occur more often and noncontextual deletions less often in the former modality than in the latter. Speaking is significantly different from typing, $\chi^2(2) = 100.3$, $p < 0.001$, and writing, $\chi^2(2) = 70.3$, $p < 0.001$. The rates of noncontextual omissions and masking errors are lower and the rate of contextual omissions higher in speaking than in typing and writing. It is notable that masking errors are similar in their behavior to noncontextual omissions but dissimilar from contextual omissions, given the fact that masking errors and contextual omissions share the same basic motivation (contextual influences) whereas masking errors and noncontextual omissions do not.

Contextual slips may be divided according to the linear order of the error and source unit. When the error unit precedes the source, the slip is called an anticipation; when the error unit follows the source, the slip is classified as a perseveration. An anticipatory key slip is shown in example 9 and a perseveratory one is shown in example 10. Both cases are within-word masking errors.

9. until we reach the point where the category can be inte_preted. / for: inte*r*preted.
10. The Allen work con_luded that men possess and prefer more common names. / for: con*c*luded.

Whereas the <r> in example 9 is masked by the following <r> in the third syllable, the <c> in example 10 is masked by the preceding word-initial <c>.

The directionality of contextual slips can be investigated not only in masking errors but also in contextual substitutions. Table 5 allows us to determine whether there are differences in directionality between substitutions and omissions, as well as among the three output modalities. The typing and writing data were taken from the same sources as before. However, because directionality information is unavailable for Stemberger's masking errors, recourse was taken to Berg's database for masking in Table 5. The substitution errors in speaking are Stemberger's (1989). Note though that these are all between-word slips. All

Table 6. *Frequency of adjacent switches in typing, writing, and speaking*

	$C_1C_2 \rightarrow C_2C_1$	$V_1V_2 \rightarrow V_2V_1$	$CV \rightarrow VC$	$VC \rightarrow CV$	Totals
Typing	14 (14.1%)	17 (17.1%)	40 (40.4%)	28 (28.3%)	99
Writing					
Complete	5 (20.0%)	3 (12.0%)	7 (28.0%)	10 (40.0%)	25
Incomplete	29 (24.2%)	17 (14.2%)	43 (35.8%)	31 (25.8%)	120
Speaking	6 (60.0%)	0 (0.0%)	1 (10.0%)	3 (30.0%)	10

ambiguous slips, which are those in which an anticipatory and a perseveratory source unit could both be identified, were excluded from the analysis.

There is a pronounced difference between masking and substitution in Table 5. Masking errors exhibit a preponderance of perseverations[6] whereas substitution errors have a majority of anticipations. This amounts to a statistically significant difference, $\chi^2(1) = 31.2$, $p < 0.001$. Remarkably, this difference holds true for all three modalities. No directionality difference between typing, writing, and speech errors emerges in either the masking or the substitution category. None of the six pairs of error classes reaches statistical significance.

We now leave the monopositional slips for the bipositional slips. Apart from all omissions taken together, adjacent switches form the most frequent category of typing errors. They make up one-fifth of the entire corpus. Two pertinent examples follow.

11. This inertial a*ps*ect of device-generated material would actually take some pressure off / for: aspect.
12. Note as well that the p*re*severate always substitutes for some segment / for: perseverate.

Example 11 documents the interaction of two contiguous consonant graphemes and example 12 the interaction of a consonant (C) and a vowel (V) grapheme. The interacting units belong to the same syllable in example 12 but come from different syllables in example 11. It is noteworthy that all 99 slips of the key are within-word errors, which means the last grapheme of the prior word and the first grapheme of the subsequent word never trade places.

Adjacent switches allow for the following four possible subtypes: $C_1C_2 \rightarrow C_2C_1$, $V_1V_2 \rightarrow V_2V_1$, $CV \rightarrow VC$, and $VC \rightarrow CV$. The frequency of these subtypes in the three modalities is reported in Table 6.[7] The speech error data are from Berg's corpus.

The most obvious result from Table 6 is the overwhelming difference in the frequency of adjacent switches in typing and writing on the one hand and speaking on the other. Adjacent switches occur with a probability of approximately 1 per 1,000 in the speech error data but with a probability of 1 out of 5 in the keying error data, which is a significant difference, $\chi^2(1) = 1135.3$, $p < 0.0001$. The written data present a similar picture. However, even if all incomplete cases are left out of account, the difference between the genuine switches in writing

and the switches in speaking is still significant, $\chi^2(1) = 179.4$, $p < 0.0001$. As an aside, the difference between completed and incomplete adjacent switches in slips of the pen fails to reach standard levels of significance, $\chi^2(3) = 2.3$, $p > 0.4$, suggesting that most incompletes may indeed be regarded as incipient switches. This, in turn, invites the conclusion that, just as in typing, adjacent switches are also among the most common error categories in writing.

Keying and writing errors do not differ in their distributions across the four C/V categories. Neither the difference between the key slips and the completed pen slips only nor that between the key slips and all pen slips turned out to be significant (both $p > 0.25$). By contrast, the difference between the key slips and the completed typing and speaking slips was statistically reliable, $\chi^2(3) = 13.7$, $p < 0.005$, despite the extremely low number of speech errors per cell. Slips of the tongue are clearly more sensitive to the nature of the interactants than slips of the key. The former prefer like with like interactions ($C_1C_2 \rightarrow C_2C_1$)[8] whereas the latter show no such preference.

The fact that the nature of the adjacent units plays a larger role in speaking than in typing does not tell us anything about the sensitivity of keying errors to the degree of likeness of the interactants. To find out about such a sensitivity, it has to be calculated how often two consonants and two vowels, as well as a consonant and a vowel, interact by chance. The null hypothesis was derived by determining the frequency with which consonants and vowels are immediate neighbors in general language usage. The first 50 words in which an adjacent switch had occurred were corrected, and the transitional probability was calculated at each grapheme boundary. The nine-letter word *centuries,* for example, gives rise to three C–V transitions (<c–e>, <t–u>, <r–i>), three V–C transitions (<e–n>, <u–r>, <e–s>), one C–C transition (<n–t>), and one V–V transition (<i–e>). Double graphemes, as in *recall,* were counted as singles because there is no way of identifying an error in which identical letters exchange places.

All in all, the 50 words yielded 133 C–V transitions, 119 V–C transitions, 70 C–C transitions, and 26 V–V transitions. Thus, the chance level for a like with like interaction is $70 + 26 = 96/348 = 0.276$, whereas that for CV and VC interactions is $133 + 119 = 252/348 = 0.724$. As shown in Table 6, the attested rate of like with like interactions is 0.313 (31 : 99). The calculation of χ^2 reveals that this rate is not significantly above chance, $\chi^2(1) = 0.6$, $p > 0.3$. It may be concluded that like with like interactions occur as frequently as their opposites. These typing slips are thus insensitive to the distinction between consonants and vowels, a result in accord with MacNeilage's (1985) analysis of typing errors.

The next step involved assessing the key slips' sensitivity to word position. It was already ascertained that they respect word boundaries. This sensitivity leads us to ask whether certain word positions are preferentially involved in the malfunction. Word position was defined as follows. In the case of adjacent switches, it is appropriate to look at pairs of adjacent positions. The following five categories were created: (a) word-initial, (b) postinitial, (c) medial, (d) prefinal, and (e) word-final. Categories (a), (c), and (e) serve to establish a possible difference between word margins and the middle portions while categories (b) and (d) help to define how far the word margins extend to the middle of the word. The 99 error words (see Table 6) were reduced to 92 by eliminating all

Table 7. *Frequency of adjacent switches in typing as a function of word position*

Word-initial	Postinitial	Medial	Prefinal	Word-final
3	14	61	10	4

two- and three-letter words (e.g., *to* and *the*) because they do not allow for this five-way distinction. The remaining 92 words contained a total of 809 letters, averaging 8.79 letters per word. This was rounded up to 9 letters or positions (P). Thus, the category of word-initial involves P_1P_2, postinitial P_2P_3, medial P_3P_4, P_4P_5, P_5P_6, P_6P_7, prefinal P_7P_8, and word-final P_8P_9. According to this division, medial errors are about four times more likely than nonmedial ones, whereas all other categories have the same probability of occurrence. The number of errors per category is provided in Table 7.

After normalization, the number of medial errors declines to 15 (61:4). It can now be observed that word-initial and final slips are clearly less frequent than slips in the other positions, $\chi^2(1) = 40.3$, $p < 0.001$. These other positions do not seem to differ much in their proneness to error. Thus, the word edges, defined as the outermost portions, display a marked resistance to error. This finding replicates what Wing and Baddeley (1980) observed in their corpus of spelling errors. However, it contrasts with the strong vulnerability of word-onset sites that is characteristic of English slips of the tongue (e.g., Shattuck-Hufnagel, 1987).

It was noted that adjacent switches have a high frequency of occurrence in key slips. If adjacency is a major characteristic of typing, one would expect nonadjacent errors to be very uncommon. This is, in fact, the case. There are only seven reversals (i.e., nonadjacent switches) and two shifts in the corpus. Refer to examples 13 and 14.

13. This hypothetical mechanism is not a ph*eno*me-to-grapheme conversion / for: phoneme.
14. such that in right-hemisphere pat*n*iets nonverbal processing is more affected than verbal processing / for: patients.

Example 13 exemplifies the exchange of two noncontiguous vowel graphemes from the same word. Case 14 involves an anticipatory shift of the <n>, which skips the two graphemes <i> and <e>. An important difference between the adjacent switches in examples 11 and 12 and the nonadjacent errors in 13 and 14 is their sensitivity to the distinction between consonant and vowel graphemes. While adjacent switches treat these two classes of graphemes indiscriminately, nonadjacent errors either involve two consonants or two vowels but do not allow consonant–vowel interactions. A very similar result emerged from the examination of slips of the pen (Berg, 1997).

There is one subset of reversals that deserves special mention. Not only single graphemes but also double graphemes may be implicated in the error process.

With double letters, one of two things may happen. Either the grapheme that is doubled is replaced by another grapheme, which then undergoes doubling, or the doubling feature itself is misordered. The former subtype was the subject of comment by a number of researchers (e.g., Lashley, 1951; MacKay, 1993; Rumelhart & Norman, 1982) while the latter apparently went unnoticed in the typewriting literature. The two possibilities are illustrated in examples 15 and 16. Examples 15a and 16a exemplify nonadjacent interactions and examples 15b and 16b adjacent ones.

15a.   so as to provide a channel of co*nnu*mication between researchers / for: com-
       munication.
15b.   We went out together at the *eww*kends. / for: weekends.[9]
16a.   and will be able to reject incorrect names pro*ferr*ed by the examiner. / for:
       proffered.
16b.   I believe it is impo*sii*ble to find a situation / for: impossible.

What makes 15a special is that the exchange of <m> and <n> has happened in ignorance of the doubling feature. The quantitative information (i.e., how often a given grapheme is outputted) stays in its original location. Therefore, the <n> is geminated and the <m> is degeminated in the error word. In a sense, 16 is the mirror image of 15. Here, the italicized graphemes preserve their order, but their quantitative specification is exchanged. The "once" feature takes the place of the "twice" feature and vice versa. As a result, the <r> is geminated and the <f> is degeminated in 16a. Viewed together, the slips in examples 15 and 16 exhibit a double dissociation. Qualitative information is severed from quantitative information in 15 and quantitative information is severed from qualitative information in 16. Hence, quality and quantity enjoy a complete representational independence.

    By way of summary, slips of the typewriter key were shown to be constrained by five principal factors: the relatively high incidence of noncontextual errors; the adjacency constraint (minimum distance between target and source unit); the high rate of omissions and, in particular, masking errors; the indifference to the distinction between consonant and vowel graphemes in adjacent switches; and the double dissociation of qualitative and quantitative information. In virtually all respects, key slips behaved like pen slips but unlike tongue slips. As far as production failures are concerned, it may therefore be concluded that very similar processes underlie typing and writing whereas different processes are implicated in speaking. The details of these processes will be worked out in the following section.

THEORETICAL DISCUSSION

The ensuing discussion consists of two parts. The first examines whether the present corpus of key slips is biased, that is, whether there are differences between easy to detect and difficult to detect errors. The second part attempts to draw theoretical conclusions from the empirical analysis. The first subsection is

a prerequisite for the second in that it serves to establish which claims cannot be put down to detection bias and therefore deserve to be treated as constraints for theory construction.

The key slip data: Biased or not biased?

As pointed out in the second section, one obvious method of determining the particularity of a corpus is to compare it to others whose data collection procedures are less selective than in the present case. Perhaps surprisingly, the overall picture that can be gained from a comparison of the available data sets is one of relatively strong homogeneity, thus corroborating the conclusion given by van Nes (1976). Initial support for this hypothesis comes from a comparison of the key slip data with the pen slip data carried out in the preceding section. Let us take contextuality as an example. Typing and writing errors were found to show the same proportions of contextual and noncontextual cases (Table 1). This similarity suggests that the key slip data are not biased because they display the same pattern as the pen slip data, which included all errors, irrespective of whether they were detected by their perpetrators. Unfortunately, the force of this argument is weakened by the following objection. It might be that the similarity between the typing and writing errors is accidentally brought about by the comparison of a biased corpus of key slips and an unbiased corpus of pen slips and that this similarity would disappear if two unbiased corpora were compared. Although this possibility seems rather remote in view of the large number of parallels uncovered, it cannot be entirely ruled out.

A better test is therefore the comparison of corpora of the same error type. How then does the key slip corpus under investigation here compare to other key slip collections? In fact, there is an encouraging amount of agreement. Both MacNeilage (1964) and Grudin (1983) report a low incidence of omission errors in word-initial positions in their corpora. Parallel findings emerge in the present corpus for both omissions and adjacent switches. Grudin (1983) notes that 60% of all omissions are masking errors and that the latter are often perseveratory rather than anticipatory in nature, thereby lending credence to the patterns reported above. A further parallel concerns the preponderance of within-word slips of Shaffer's (1976) and the present analysis. Finally, the foregoing probe concurs with MacNeilage's (1985) claim that consonants and vowels interact freely in adjacent switches. Note that this list of parallels is selective rather than exhaustive.

The conclusion invited by these similarities between the various data sets is that there is reason to regard the present corpus of key slips as a relatively unbiased one. This is not to say, however, that the corpus is not biased at all. There is evidence from the error detection literature to suggest that some slip types may be overrepresented in the present corpus. Shaffer and Hardwick (1969) and Rabbitt (1978) reported that deletion errors are only rarely detected in typing. This difficulty might partly explain the elevated rate of omissions reported in Table 3. MacKay (1969b) found that misspellings involving repeated letters are hard to perceive.[10] On the assumption that handwriting is akin to typewriting in this respect, it may be inferred that masking errors are overrepresented in the data.

Two further claims from the detection literature are worth mentioning, even though it is unlikely that the effects described therein are mainly responsible for the empirical patterns. The frequency of anticipations and perseverations is also a candidate for listener bias. Tent and Clark (1980) showed perseverations to be more difficult to notice than anticipations in speaking. Generalizing from speech errors to typing errors, one might suspect that the actual rate of perseverations is higher than the data suggest. However, this perceptual bias does not appear to play a role in the present context because it is unable to predict the patterns displayed in Table 5, in which substitution errors were found to be predominantly anticipatory and masking errors to be predominantly perseveratory. This difference is difficult to reconcile with a general bias toward ignoring perseverations.

Sloboda (1976) and Haber and Schindler (1981) showed that errors are more difficult to detect when they occur in the middle of the word than when they occur in the word margins. This bias might be held accountable for the asymmetrical distribution of adjacent switches within the domain of the word (see Table 7). However, this does not seem likely because the same pattern was observed in Wing and Baddeley's (1980) spelling error corpus, which was carefully compiled and includes most, if not all, of the errors in the subjects' manuscripts.

To conclude, despite the undeniable existence of perceptual biases, there is little reason to doubt the reliability of the keying error corpus on which the present study is built. These data are reliable as production data: perceptual influences have not distorted the materials to any significant degree. The only area in which reader bias may have left an imprint is omission errors in general and masking errors in particular. However, this influence is probably limited because an elevated rate of this error category was also observed in other more inclusive corpora. Hence, the perceptual bias may have amplified a tendency that is already present in the data and therefore qualifies as a genuine production constraint.

Representation and processing in typing

The following discussion begins with representational issues and then proceeds to processing aspects. As can be inferred from the empirical analysis, the representational system underlying typing is relatively impoverished. The unit that is most clearly relevant in typing is the word. Most error processes take place within the confines of the word and should thus be defined with reference to the word as the pertinent linguistic unit. Because between-word slips are so uncommon, there is little evidence for structures larger than the word at the representational stage at which the errors at the heart of this study occur. Grudin (1983) and MacNeilage (1985) both argued that syllable structure does not constrain typing errors. Neither syllable slips nor syllable-constituent slips such as rime (VC) slips could be found in the present corpus. These two empirical findings suggest that the syllable and its constituents should be denied a role in the production process. However, there is one aspect in the data that calls for a representational level between the word and the grapheme level. It was shown that keying errors evince a dissociation between qualitative and quantitative

word level   effort

skeleton tier   X X X X X X
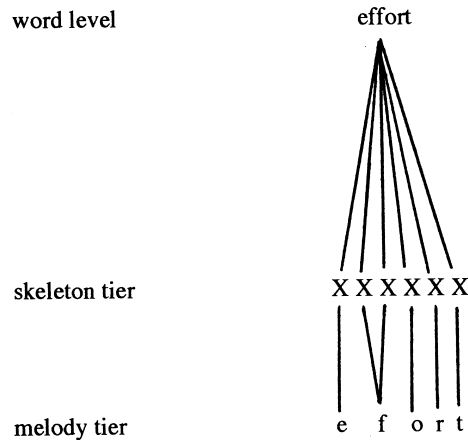
melody tier   e   f   o r t

Figure 1. A fragment of the representational system underlying typing, illustrated by the word *effort*.

information. As the grapheme level is reserved for qualitative information, another level is needed to code quantitative aspects. This is the skeleton tier in phonological theory, which consists of X units (Levin, 1985) and specifies how often a given unit is selected. If it is to be selected once, it is associated with a single X unit; if it is to be selected twice, it is associated with a double X unit. It should be noted that the X tier makes no distinction between consonants and vowels. This is desirable in the present context because most key slips were found to be insensitive to this distinction. The linguistic system underlying typing is graphically represented above for the sample word *effort*.

As can be seen in Figure 1, all graphemes are accorded a single position at the melody tier. The difference between single and double graphemes reduces to whether a grapheme is linked to a "once" or a "twice" node at the skeleton tier. This means that double units at the surface level are represented as single units at a more abstract level. This singleton representation of double graphemes has an important implication. It makes these graphemes indivisible in that one part of the geminate cannot be independently involved in an error while the other part is left untouched. More concretely, the prediction is that an adjacent switch cannot turn $<X_1X_2Y>$ into $<X_1YX_2>$ (see Badecker, 1996; Caramazza & Miceli, 1990; Tainturier & Caramazza, 1996; for a similar claim from dysgraphia). Although these authors state that such cases do not occur in their dysgraphic patients, there is one pertinent error in the key slip corpus:

17.   these effects are introducable only at specific structur*la*ly determined points /
       for: structurally.

The simplest interpretation of example 17 would be to posit an adjacent switch between <a> and <l>. However, this would involve breaking up the geminate

<ll> because only the first <l> would trade places with <a>. Such an error would not be possible if geminates are represented in singleton fashion. Consequently, either the theory has to be radically revised or the error has to be subjected to a different analysis. It is probably unwise to abandon a theory that has proved fruitful in a great many respects on the basis of a unique example. It is preferable therefore to maintain the theory and look for alternative interpretations of the error. One might be to assume that the doubling feature was first deleted (yielding *structuraly* as an intermediate result), then the <a> and the <l> swapped places (yielding the intermediate result *structurlay*), and finally the <l> perseverated and turned up again after the <a>. Such a sequence of events seems quite unlikely, but one can never be sure with singleton errors. There is thus no firm evidence for the claim that typing is representationally different from dysgraphic handwriting. The same dissociations occur in both modalities.

In the present conception, the only function of the skeleton tier is to code the number of times each unit at the melodic tier has to be produced. This might seem an insufficient motivation for the separation between the two tiers, but some such distinction is dictated by the empirical data and is a natural consequence of the widely accepted claim that linguistic units are represented once in the mental network (the "type-only" representation; see Dell, 1984).

A comparison between Figure 1 and the representational system of handwriting as outlined in Berg (1997) reveals a perfect match. Exactly the same representational systems are claimed to underlie handwriting and typewriting. This conclusion is a direct consequence of the fact that the preceding analysis disclosed an almost perfect agreement between the writing and the keying error data. The few differences that were found between the two data sets are unlikely to have a representational origin. Recall the higher percentage of masking errors and within-word slips in typing as compared to writing (Tables 2 and 4). Whatever the ultimate reasons for these differences, the representational system as in Figure 1 is liberal enough to allow for these variations between typing and writing.

Let us now turn to issues of processing. The empirical perspective that is of particular importance here highlights the disparity between slips of the tongue and slips of the key, in particular the heightened rate of noncontextual, within-word, and omission errors, as well as adjacent switches in typing. Perhaps the single most important constraint on typing errors is the adjacency constraint. It strongly supports the conclusion that the "viewing window" in typing is quite small (i.e., that the number of elements that are concurrently active is rather low). As a result, the only elements that can interact are those that are relatively close to each other. To account for the high frequency of adjacent switches, it has to be assumed that adjacent units are more strongly activated than nonadjacent ones. A more general enunciation of this principle would hold that the closer two elements within a planning unit are, the higher their coactivation. This is the essence of what Berg (2001) termed the staircase strategy of serialization, which is reproduced in Figure 2.

The current unit is the one that is in the process of being selected. In the error-free case, its activation level is higher than that of any other unit preceding or following it. The further away the neighbors are from the current unit, the
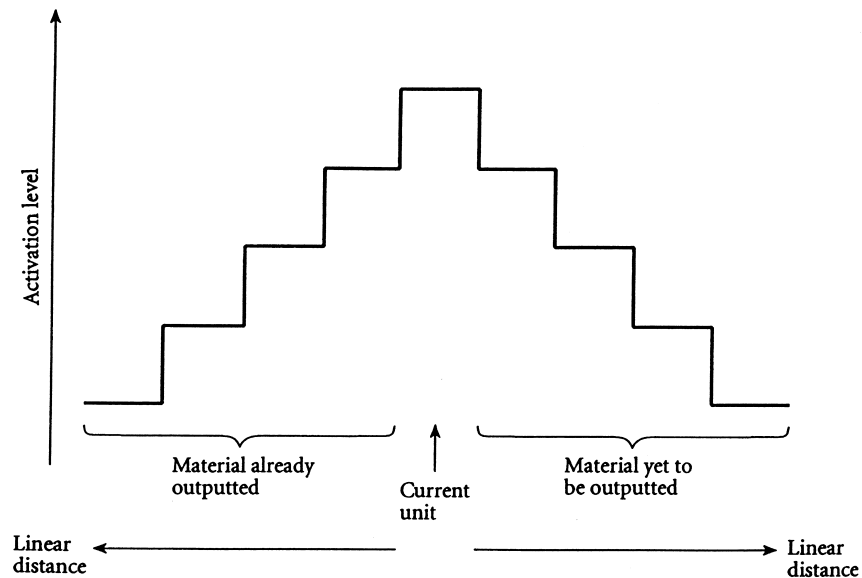
Figure 2. The staircase strategy of serialization.

lower their activation levels, and hence their potential of interference. The staircase strategy thus captures the predominance of adjacent switches and the uncommonness of between-word slips. The latter category can be explained by an exceptionally high level of activation in a neighboring word due to noise or a higher degree of advance planning, which is an occasional enlargement of the viewing window.

The small viewing window accounts not only for the correlation between error frequency and the linear distance between the interacting units but also for the high rate of noncontextual slips. Contextual errors have a crucial dependence on a viewing window, within which linearly ordered elements are simultaneously activated. The smaller the viewing window is, the smaller the number of competitors from the same utterance, and consequently, the lower the probability of contextual error. A small viewing window thus predicts a relatively low number of contextual slips, as is actually observed in the keying error data. The fact that contextual slips still outnumber the noncontextual slips in typing (Table 1) suggests that the constituents of a planning unit are not only activated in parallel but also to a similarly strong degree to the effect that within-word competition is relatively high.

At first sight, the large number of omissions does not readily fit the picture. This error category cannot be accommodated by either the staircase strategy or the small viewing window. It apparently requires a different processing mechanism. It is a standard assumption in linguistics and psycholinguistics that the production of a linguistic unit involves attaching this unit to a structural position (e.g., Goldsmith, 1990; Itô, 1988; Roelofs & Meyer, 1998; Stemberger, 1990).

If no such association takes place, the unit fails to be produced. The association process is driven by the activation levels of the slot and the filler. When both have reached a certain threshold at the same time, they undergo linking. There are thus two ways in which an omission error may come about. Either the grapheme or its placeholder fails to attain the requisite level of activation. Although both possibilities are equally probable a priori, it would be more consistent to assume that it is difficult to activate the units at the skeleton tier. The skeleton tier is part of the structural representation, and we have seen that the structural representation in typing (as well as in writing) is impoverished (i.e., it has neither syllable nor syllable constituent nodes). Further evidence for a weak structural representation comes from the fact that contextual deletions do not occur in typing (see Table 4). The explanation for speech errors like case 7, for example, is that the malfunction did not originate at the melodic tier but rather at the syllable structure level at which a structural element (a CC onset) was ousted by another structural element (a C onset). If there is no such structure in typing, such keying errors cannot occur, as is presumably the case. In conclusion, the high rate of omissions is hypothesized to be brought about by a weakness of the structural representation,[11] in particular, the skeleton tier, which makes the attachment of graphemes to placeholders rather more vulnerable.

Slips of the tongue are vastly different. They are characterized by a predominance of contextual and between-word errors, as well as substitutions and exchanges. All four characteristics can be ascribed to a fully developed hierarchical representation. Such an elaborate structural representation entails a larger viewing window that secures the parallel activation of the constituents of syntactic phrases and even sentences. As a consequence, the phonemes from different words can easily interact. Opportunities for contextual slips abound with a larger viewing window. The fully deployed structural representation assigns certain labels to phonemes such as "word-onset consonant." This increases the similarity between relatively distant phonemes and allows them to interact, in exchanges, for example. Because the skeleton tier as part of the structural representation is readily available, there is only a small chance that the association process between its units and those of the melodic tier fails and that, by implication, an omission error results. If an omission arises in speaking, it is structurally motivated in the majority of cases (Table 4).

It may be concluded that speaking is under the sway of a hierarchical strategy of serialization, whereas typing is under the control of the staircase strategy (see also MacKay, 1993). However, these two strategies should not be construed as mutually exclusive. The difference between them is one of degree, not of kind, given that the unfolding of structural representations is a gradual process (Berg & Abd-El-Jawad, 1996). It follows that the difference between slips of the tongue and slips of the key is also a gradual one, and this is in fact confirmed by almost all the tables in the data analysis section (even if the empirical differences are of a rather drastic nature). This is to say that slips of the tongue are also subject to the staircase strategy (see Berg, 2001) and that slips of the typewriter key may also be subject to the hierarchical strategy. This can be seen in such late errors as between-word slips, which arise at a moment in time when the structural representation has reached a certain hierarchical level. Between-

word slips are therefore expected to exhibit structural effects, and indeed they do! They are typified by a heightened number of interactions of graphemes from structurally similar positions (Shaffer, 1976).

CONCLUSIONS

It has emerged from the preceding analysis that slips of the typewriter key are largely indistinguishable from slips of the pen. By implication, the psychological processes underlying typing and writing are highly similar. The differences that exist between the two modalities (e.g., the linking of the letters in handwriting vs. the complete discreteness in typewriting and the absence of an allographic level in typewriting vs. its presence in handwriting) appear to lack any high-level processing consequence. Hence, the near identity of the psycholinguistic processes underlying typing and writing is arguably occasioned by the similarities between the two modalities. Three possible causes are their common use of a spatial code, their similar speed of execution, and their freedom from articulatory constraints.

Slips of the key were found to exhibit a number of particularities, which were claimed to be reducible to weak structural representations. The postulation of a single common cause for these characteristic traits appears to imply that they must always co-occur. However, this implication is a nonsequitur. There are various levels of structural representations; and even if they are all structural in nature, they enjoy a certain independence and may therefore be separately affected. Precisely this dissociation can be found in real life. Table 4 shows a relatively high incidence of deletions in the typewriting data, as well as in Wing and Baddeley's (1980) handwriting data. In contrast, the number of deletions is fairly low in Berg's (1997) self-produced pen slips, even though his corpus is highly similar to the other corpora in all other respects. Thus, there is a clear dissociation between the frequency of omissions and that of within-word slips, for example. The next step would be to explore how pervasive this dissociation is and under what conditions one of the empirical effects emerges in the absence of another.

NOTES

1. The entire data set is available upon request.
2. Note that it is not totally clear whether even a sample of uncorrected errors is a pure production corpus. The possibility cannot be ruled out that the slips that are outputted represent only a fraction of the total number of errors made because the internal monitor may have intercepted errors before they were outputted. In that case, no set of error data would be purely production based, and the present corpus would not be too different from the corpora previously examined in the relevant literature.
3. The space between the <i> and the <a> in the error word does not occur in the original text. It was introduced here only to mark the location of the deleted grapheme.
4. Because the information gleaned from Stemberger's published analyses is not complete, a second speech error corpus was consulted for comparison. Berg's (1988)

     sample of German slips of the tongue also contains more additions than omissions, thereby confirming the reliability of the data in Table 3.

5. The totals of deletion errors in speech in Tables 3 and 4 are not identical (107 vs. 103). In all probability this is due to the fact that the numbers were taken from different analyses that are based on nonidentical subsets of data.

6. There is a potential relationship between the predominance of perseveratory maskings and the fact that the second (later) item in a sequence containing two nonadjacent identical elements is more difficult to recall than the first (Jahnke, 1969).

7. Unfortunately, an interpretative difficulty arises in the analysis of adjacent switches in writing. In the majority of cases, the malfunction was detected and the utterance aborted after the first part of the error. We thus cannot be sure what the second part of the error would have been and, consequently, which classification is the most adequate one. Table 6 therefore contains the rate of both completed and incompleted switches. This descriptive problem does not actually occur in slips of the tongue because interactions of adjacent elements occur very seldom in speaking.

8. The $V_1V_2 \rightarrow V_2V_1$ interactions in speaking are almost completely ruled out because adjacent nondiphthongized vowels hardly ever occur in the ordinary structure of the language.

9. This key slip was collected and kindly placed at my purview by Stefanie Wulff. It is thus the only item presented here that is *not* from my own corpus. It was included because it exemplifies a subcategory that is missing in my data and fits in nicely with the other errors in examples 15 and 16.

10. Note in this connection Crowder's (1968) observation that identical units also create a difficulty of recall. These two aspects might reflect the same underlying phenomenon.

11. This principle might also account for the observation in Table 7 that word-initial errors are uncommon in typing (see Berg & Abd-El-Jawad, 1996, for more details). However, it is not known whether the relative immunity of word-final positions to error can also be explained as a structural effect. It is also not known whether there is a connection between the inverted U curve in typing errors (Table 7) and a similarly shaped curve in tip of the tongue data in which the guesses about the target word's phonological structure are more often correct in the margins than in the middle of the word (Brown & McNeill, 1966).

REFERENCES

Aitchison, J., & Peyton, T. (1982). Slips of the mind and slips of the pen. In R. N. St. Clair & W. von Raffler-Engel (Eds.), *Language and cognitive styles* (pp. 180–194). Lisse, The Netherlands: Swets and Zeitlinger.

Badecker, W. (1996). Representational properties common to phonological and orthographic output systems. *Lingua, 99,* 55–83.

Berg, T. (1988). *Die Abbildung des Sprachproduktionsprozesses in einem Aktivationsflußmodell: Untersuchungen an deutschen und englischen Versprechern.* Tübingen, Germany: Niemeyer.

Berg, T. (1997). The modality-specificity of linguistic representations: Evidence from slips of the tongue and the pen. *Journal of Pragmatics, 27,* 671–697.

Berg, T. (2001). *Linguistic structure and change: An explanation from language processing.* Oxford: Oxford University Press.

Berg, T., & Abd-El-Jawad, H. (1996). The unfolding of structural representations: A cross-linguistic perspective. *Journal of Linguistics, 32,* 291–324.

Brown, R., & McNeill, D. (1966). The "tip of the tongue" phenomenon. *Journal of Verbal Learning and Verbal Behavior, 5,* 325–337.

Caramazza, A., & Miceli, G. (1990). The structure of graphemic representations. *Cognition, 37,* 243–297.

Crowder, R. G. (1968). Intraserial repetition effects in immediate memory. *Journal of Verbal Learning and Verbal Behavior, 7,* 446–451.

Dell, G. S. (1984). Representation of serial order in speech: Evidence from the repeated phoneme effect in speech errors. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 222–233.

Gentner, D. R. (1983). The acquisition of typewriting skill. *Acta Psychologica, 54,* 233–248.

Gentner, D. R., Grudin, J. T., Larochelle, S., Norman, D. A., & Rumelhart, D. E. (1983). A glossary of terms including a classification of typing errors. In W. E. Cooper (Ed.), *Cognitive aspects of skilled typewriting* (pp. 39–43). New York: Springer.

Goldsmith, J. A. (1990). *Autosegmental and metrical phonology.* Oxford: Basil Blackwell.

Grudin, J. T. (1983). Error patterns in novice and skilled transcription typing. In W. E. Cooper (Ed.), *Cognitive aspects of skilled typewriting* (pp. 121–143). New York: Springer.

Haber, R. N., & Schindler, R. M. (1981). Error in proofreading: Evidence of syntactic control of letter processing? *Journal of Experimental Psychology: Human Perception and Performance, 7,* 573–579.

Hotopf, W. H. N. (1983). Lexical slips of the pen and tongue: What they tell us about language production. In B. Butterworth (Ed.), *Language production* (Vol. 2, pp. 147–199). London: Academic.

Itô, J. (1988). *Syllable theory in prosodic phonology.* New York: Garland.

Jahnke, J. C. (1969). The Ranschburg effect. *Psychological Review, 76,* 592–605.

Lashley, K. S. (1951). The problem of serial order in behavior. In L. A. Jeffress (Ed.), *Cerebral mechanisms in behavior* (pp. 112–136). New York: Wiley.

Levin, J. (1985). *A metrical theory of syllabicity.* Unpublished Ph.D. thesis, MIT, Cambridge, MA.

MacKay, D. G. (1968). Phonetic factors in the perception and recall of spelling errors. *Neuropsychologia, 6,* 321–325.

MacKay, D. G. (1969a). Forward and backward masking in motor systems. *Kybernetik, 6,* 57–64.

MacKay, D. G. (1969b). The repeated letter effect in the misspellings of dysgraphics and normals. *Perception and Psychophysics, 5,* 102–106.

MacKay, D. G. (1993). Slips of the pen, tongue, and typewriter: A contrastive analysis. In G. Blanken, J. Dittmann, H. Grimm, J. Marshall, & C.-W. Wallesch (Eds.), *Linguistic disorders and pathologies* (pp. 66–72). Berlin: de Gruyter.

MacNeilage, P. F. (1964). Typing errors as clues to serial ordering mechanisms in language behaviour. *Language and Speech, 7,* 144–159.

MacNeilage, P. F. (1985). Serial-ordering errors in speech and typing. In V. A. Fromkin (Ed.), *Phonetic linguistics* (pp. 193–201). New York: Academic.

Newman, S. E., & Nicolson, L. R. (1976). Speed of oral responding. *Bulletin of the Psychonomic Society, 7,* 202–204.

Rabbitt, P. (1978). Detection of errors by skilled typists. *Ergonomics, 21,* 945–958.

Roelofs, A., & Meyer, A. S. (1998). Metrical structure in planning the production of spoken words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 922–939.

Rumelhart, D. E., & Norman, D. A. (1982). Simulating a skilled typist: A study of skilled cognitive-motor performance. *Cognitive Science, 6,* 1–36.

Shaffer, L. H. (1975). Control processes in typing. *Quarterly Journal of Experimental Psychology, 27,* 419–432.

Shaffer, L. H. (1976). Intention and performance. *Psychological Review, 83,* 375–393.

Shaffer, L. H., & Hardwick, J. (1969). Errors and error detection in typing. *Quarterly Journal of Experimental Psychology, 21,* 209–213.

Shattuck-Hufnagel, S. (1987). The role of word-onset consonants in speech production planning: New evidence from speech error patterns. In E. Keller & M. Gopnik (Eds.), *Motor and sensory processes of language* (pp. 17–51). Hillsdale, NJ: Erlbaum.

Sloboda, J. A. (1976). The effect of item position on the likelihood of identification by inference in prose reading and music reading. *Canadian Journal of Psychology, 30,* 228–237.

Stemberger, J. P. (1985). *The lexicon in a model of language production.* New York: Garland.

Stemberger, J. P. (1989). Speech errors in early child language production. *Journal of Memory and Language, 28,* 164–188.

Stemberger, J. P. (1990). Wordshape errors in language production. *Cognition, 35,* 123–157.

Stemberger, J. P. (1993). Spontaneous and evoked slips of the tongue. In G. Blanken, J. Dittmann, H. Grimm, J. Marshall, & C.-W. Wallesch (Eds.), *Linguistic disorders and pathologies* (pp. 53–65). Berlin: de Gruyter.

Stemberger, J. P., & MacWhinney, B. (1986). Form-oriented inflectional errors in language processing. *Cognitive Psychology, 18,* 329–354.

Stemberger, J. P., & Treiman, R. (1986). The internal structure of word-initial consonant clusters. *Journal of Memory and Language, 25,* 163–180.

Sternberg, S., Knoll, R. L., Monsell, S., & Wright, C. E. (1988). Motor programs and hierarchical organization in the control of rapid speech. *Phonetica, 45,* 175–197.

Sternberg, S., Monsell, S., Knoll, R. L., & Wright, C. E. (1978). The latency and duration of rapid movement sequences: Comparisons of speech and typewriting. In G. E. Stelmach (Ed.), *Information processing in motor control and learning* (pp. 117–152). New York: Academic.

Tainturier, M.-J., & Caramazza, A. (1996). The status of double letters in graphemic representations. *Journal of Memory and Language, 35,* 53–73.

Tannenbaum, P. H., Williams, F., & Wood, B. S. (1967). Hesitation phenomena and related encoding characteristics in speech and typewriting. *Language and Speech, 10,* 203–215.

Tent, J., & Clark, J. E. (1980). An experimental investigation into the perception of slips of the tongue. *Journal of Phonetics, 8,* 317–325.

van Nes, F. L. (1976). Analysis of keying errors. *Ergonomics, 19,* 165–174.

Wing, A. M., & Baddeley, A. D. (1980). Spelling errors in handwriting: A corpus and a distributional analysis. In U. Frith (Ed.), *Cognitive processes in spelling* (pp. 251–285). London: Academic.