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A Cognitive Approach to Brailling Errors

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Abstract: This article analyzes a corpus of 1,600 brailling errors made by one expert braillist. It presents a testable model of braille writing and shows that the subject braillist stores standard braille contractions as part of the orthographic representation of words, rather than imposing contractions on a serially ordered string of letters.

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The topic of errors made when writing braille has not received a great deal of study. When it is discussed, errors tend to be viewed in terms of problems with students' competence in spelling or similar language-arts topics, problems with the system itself, or students' failure to master the system (Koenig & Ashcroft, 1993). What has not yet received focused attention is what these errors reveal about the physical and cognitive processes that underlie writing in braille. The aim of this article is to recast the analysis of brailling errors as the result of generalizable cognitive processes (Mattson & Baars, 1992) that are akin to those that can account for errors in speech (Fromkin, 1973, 1980; Stemberger, 1983) or typing (Cooper, 1983; Grudin, 1981; MacKay, 1993; Shaffer, 1975). This work is not directed at prescriptive aspects of orthography, such as incorrect spelling or rhetoric, that could arguably be attributed to a writer's lack of linguistic competence. Rather, it focuses on accidental slips.

In linguistics, an error (or slip) is defined as an utterance (or portion of text) that differs from its target in some systematic way (Fromkin, 1973, 1980). When the speaker's attention is drawn to what has been said or written, the speaker immediately recognizes that it was not what was intended. Colloquial speech, word play, and colorful language (taboo or otherwise) do not count as slips when they are what the speaker intended.

The same distinction between slips and the lack of knowledge in spoken language can be applied to typing. The following kinds of slips are commonly made by adults who can type well and are probably familiar sights for any proofreader:

Error: Teh quick brown fox did ti again.
Target: The quick brown fox did it again.
(The letters in *the* and *it* are misordered.)

Error: I'm take that fx off my list.
Target: I'm taking that fox off my list.
(The form *take* substitutes for *taking* and an "o" is omitted from *fox*).

Error: He always was sort to a jumpy creature.
Target: He always was sort of a jumpy creature.
(One function word, *to* is substituted for another, *of*).

Errors or slips in any domain tend to be classifiable as anticipations (a unit appearing too early), perseverations (a recurring element), exchanges (or metatheses) of elements, or substitutions of one element for another (such as calling one person by another person's name). Elements can also be deleted, added, or moved. All these sorts of errors have been observed in typing (see Cooper, 1983), and their analysis has been used to examine the underlying processes that are involved in typing on a standard QWERTY keyboard.

This article addresses the following questions:

1. What kinds of errors do braillists make, and in what proportions do these errors occur?

2. How are characters stored mentally by typists and braillists: as shapes in the mind? As finger designations?

3. How are orthographic forms stored in the mind of a fluent braillist? Are contractions stored as part of the word, or is there a contraction process that applies to the string of letters after it is retrieved?

A model of the braille writing process

The following set of ordered components is suggested as a working model for how braille is written. It is used to guide the discussion of the results of the study presented here.

1. Lexical access: Just as is done in spontaneous speech or typing, the forms to be written are located in the mental lexicon.

2. Spell out: Characters (letters and contractions) are serially ordered. It is posited here that there is no separate contracting component. Words are retrieved with their contractions in place.

3. Retrieval of shapes of braille units: Representations of each cell to be written are accessed.

4. Assignment of finger sequences: Serially ordered instructions are created for finger movement.

The steps are necessarily serially ordered. Braille units must be retrieved before the finger movements that are needed to make them can be assigned.

This article deals with spontaneous writing, rather than the transcription of text from hard copy or audiotape. Thus, there is no treatment of the input buffer (Grudin, 1981) that is usual in the literature on typing in which typists transcribe material from printed text.

The relative simplicity of the model of braille writing is intentional, making it possible to examine stages of writing. It is not intended to reflect the processes of learning to write in braille or differences between levels of proficiency; proficiency has been shown reliably to alter the kinds and amounts of errors that are made in typing (Grudin, 1981).

Procedure

The subject, an adult who uses braille daily, kept track of errors that occurred in personal and professional writing. The subject was asked to determine, before beginning to write, whether errors would be collected during that writing session. This determination had mainly to do with the subjective determination of whether recording errors would constitute a burden during that writing session.

The subject is thoroughly conversant with contracted literary braille and computer braille and writes in a highly personalized Grade III braille code (Hayden, 1962) and occasionally in uncontracted braille in languages other than English. The majority of the subject's writing during this time was done on a braille notetaker with a six-key Perkins-style keyboard, and errors collected were made using this equipment. The subject habitually writes with fingers on the prescribed keys. Errors were recorded when noticed either immediately after being written or upon proofreading a document. Along with the error, the target or intended text was recorded. Data were collected intermittently between fall 1998 and fall 2004. Our desire not to impose a burden on the subject and to allow errors to be harvested at the subject's will was the primary cause of the length of time for collecting the data. The process, along with use of the subject's data, was approved by the Institutional Research Board of Bowling Green State University.

Errors and their targets were later transferred to a database and categorized. As is done in speech-error research and typing research, each error was classified according to the unit involved (dot or dots, character, morpheme, word, or sentence). An indication was also made of the type of error that had occurred, such as the deletion, addition, substitution, or movement of material. Many errors in the study seemed to have been detected by the subject; that is, the subject interrupted writing after an error occurred. The fact that errors can be detected as they are written indicates that there should perhaps be a monitor component (not addressed here) that assesses the accuracy of what is being written.

When we report brailling errors here, we observe the following conventions for the sake of clarity and consistency. Each example is presented in six lines. First, the code in which the writer was working at the time of the slip is indicated: Grade III braille, contracted braille, computer braille, or foreign-language braille. The next line shows the error itself in a simulated braille font; below this line, the same text is transliterated into the Roman alphabet. The next two lines show the target in simulated braille and its transliteration. The last line is reserved for any pertinent notes or explanations about the error.

LIMITATIONS

This study, which was based on a single subject, suggests ways in which brailling errors may appear for the general population of braille users and braillists. Looking in depth at one subject's errors is useful, but it must be kept in mind that it is possible that this particular subject's data may not be truly representative of the population of braillists in general. It is also almost certainly the case that braillists of different levels of expertise exhibit different patterns of errors, as may those who use different equipment or those who do not habitually press the keys with the prescribed fingers. Finally, since the subject was asked to collect data only when this task would not constitute a distraction or burden, it is conceivable that the data do not reflect the entire range of the subject's writing or error making.

Results and discussion

OVERVIEW OF THE RESULTS

At the end of the collection period, the corpus contained 1,600 errors. Table 1 summarizes the kinds of errors that occurred, categorized by the unit involved in the error. Here, "character" refers to any configuration of dots within a single cell, regardless of whether it is a letter, part of a contraction, or a whole word standing alone.

The largest category of errors (46.1%) was that of dot errors. If errors that were designated as dot-character (those for which both a dot and a character explanation are possible) are added to this category, the majority of errors (64.4%) were mistakes made at the level of the dot. Character errors were the next largest category (27.7%), followed by errors involving entire words (4.0%). This finding is congruent with the data from typing errors when few whole-word lexical errors are found (Grudin, 1981). The answer to Question 1, then, is that the predominance of the subject braillist's errors occurred at the dot level: the later steps in the model of braille writing and the lowest, perhaps most mechanical, level of writing.

The corpus contained 1,094 errors in standard contracted braille, 387 in computer braille, 107 in Grade III braille, and 12 errors that were committed when the subject wrote in a language other than English. With these numbers, it was not possible to determine which of the braille codes is more vulnerable to error, since which percentage of the time the writer spent working within each code was not known. It is possible to observe two things, however. First, errors occurred in all writing codes; no code seems have been immune to error. Second, we examined the data to see if different kinds of errors predominated in any particular code and found that similar kinds of errors occur within each code in roughly the same proportions.

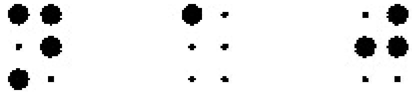
The only apparent anomaly was the relatively high number of lexical errors in the Grade III data (14% as opposed to 3% and 4% in computer and contracted braille). Although no figures exist for this subject's characteristic writing speed in each code, it may be that the subject wrote most quickly (and perhaps with less attention to detail) in the Grade III texts that were intended for personal use only. (For a description of the speed-accuracy trade-off, see MacKay, 1982; see Wells-Jensen, 2007, for a discussion of how different tasks can affect the amount and kind of linguistic errors.)

DOT ERRORS

The majority of errors in the database were those involving units at the character or dot level (*n* = 1,478 or 92%). This finding is congruent with speech-error research, which found that the majority of errors are made with individual sounds, rather than with meaningful units, such as words or parts of words (Nooteboom, 1973), and with research on typing, which found that the majority of errors involve misplaced key strokes, rather than whole words (Grudin, 1981). This finding reflects the fact that there are simply more tasks involving finger movements for the writer to carry out (Levelt, 1989). That is, in most situations, for every word that is selected (one choice), there are a number of letters to be written, and for every letter in braille, there are a number of finger movements that must be correctly coordinated. The predominance of errors at the subcharacter level is one of the main factors that differentiate brailling from typing on a standard QWERTY keyboard; typing in which characters are said to be "atomic"--that is, to have no subcomponents (MacKay, 1993).

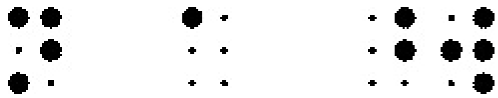
An error is considered to be contextual if it can be said to have been influenced by other material in the string of type. That is, dots, characters, parts of words, or whole words that are present in the string can reappear in nearby cells. Anticipations, perseverations, metatheses, misorderings and some additions are contextual errors. Examples 4 and 5 are contextual. Example 6 is noncontextual.

4. Code: Contracted Braille
Error:



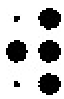
[not] [a] [j]

Target:



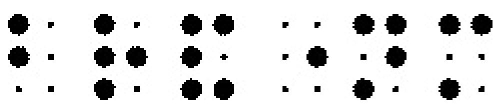
[not] [a] {[dot 4-5][w] (word)}

The dot 2 for the w

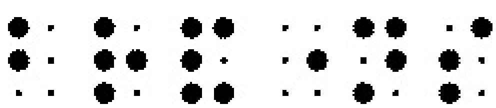


[w] is anticipated and added to the 4–5 prefix.

5. Code: Contracted Braille
Error:



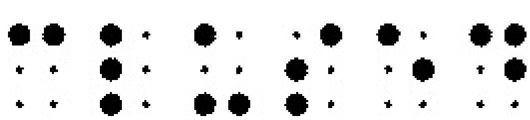
[b][r][and]{[dot 5][n] (name)}[m]
Target:



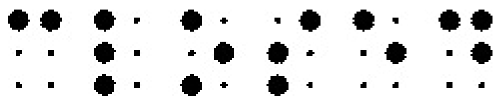
[b][r][and]{[dot 5][n] (name)}[s]

A dot 1, or perhaps the entire left side of the cell preceding the error, perseverates and replaces the intended dot 2 or dot 2–3 combination.

6. Code: Computer Braille
Error:



[c][l][u][s][e][d]
Target:



[c][l][o][s][e][d]

This is a noncontextual error. Dot 6 was substituted for dot 5; there is no dot 6 in either adjacent cell.

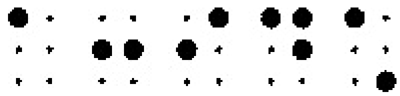
Eliminating errors when contextuality could not be unambiguously determined, we found that 627 (42.7%) were noncontextual and 840 (57.2%) were contextual, indicating that brailling errors tend to be affected by dots in adjacent cells. That is, the subject braillist may tend to make contiguous cells alike by reusing fingers that have just been used.

Of the noncontextual errors, 55.5% were deletions, 33.5% were substitutions, and only 11% were additions. Thus, adding extra dots that are not also present in adjacent cells is relatively rare, reflecting a tendency for fingers at rest to remain at rest. Taken together with the data on contextuality, this finding suggests a kind of "finger inertia" via which each individual finger tends to continue as it is, either moving or at rest.

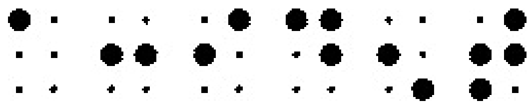
Errors with the whole hand

With contextual errors, the extent to which the entire side of a cell (that is, the part of a cell that requires the use of all three fingers on the same hand) or pairs of homologous fingers (for instance, both index fingers) were anticipated or perseverated together can be determined. Example 7 shows an instance in which the whole hand moved. Example 8 is an instance in which it is not possible to tell with any degree of certainty whether the entire side perseverated together, but a homologous finger-pair perseveration is possible. Example 9 is an error in which, although dots exist in the adjacent cell, it is not possible that a whole hand was perseverated or anticipated.

7. Code: Contracted Braille
Error:

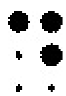


[a][cc][i][d][ch]
Target:

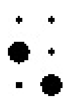


[a][cc][i][d][en][t]

This interrupted error can be accounted for as a perseveration of the dot 1 in the preceding cell. The entire left-hand side of the

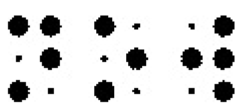


[d] replaces the left-hand side of the cell of the

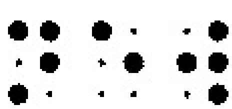


[en] sign.

8. Code: Contracted Braille
Error:

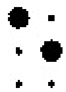


[n][o][w]
Target:

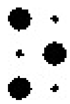


[n][e][w]

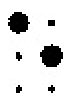
The dot 3 added to the



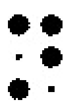
[e] to make



[o] could have come from the preceding cell. It is possible that the entire left hand position (dots 1–3) was perseverated, but since a dot 1 was already present in the

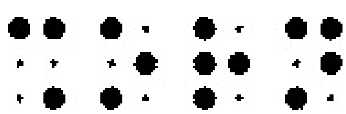


[e], it is impossible to say for sure. It is also possible that the dot 3 or the entire lowest line in the cell 3–6 was perseverated from the

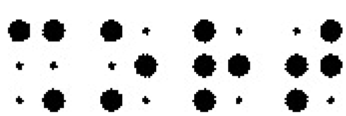


[n].

9. Code: Contracted Braille
Error:

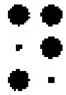


[sh][o][r][n]
Target:

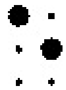


[sh][o][r][t]

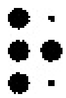
It is possible that the dot 1 in the



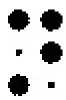
[n] came from the preceding



[e], but since the left side of the



[r] uses dots 1-2-3 and the



[n] uses dots 1-3, the whole hand could not have been perseverated.

In 72.4% of the contextual errors, an explanation of the error can be made in terms of a whole-hand or homologous finger-pair perseveration or anticipation. In roughly three-quarters of this 72.4% (or 54% of all the contextual errors), the whole hand was responsible for the error. Furthermore, when dots were substituted for one another, 77% of them were within the same hand, leaving open the possibility that the errors might have been because of the shape of the hand, rather than of a failure of individual fingers.

Thus, in brailling, although fingers operate individually, hand shape is also a functional unit, suggesting a hierarchical structure of the organization of commands to the hands for the subject braillist. The case for homologous fingers working together to form a unit is less robust. It seems likely that there is some effect of homology in writing braille, but a clear case cannot be made for pairs of fingers as a functional constituent of the character when writing.

For novice typists, homologous fingers often substitute for one another (such as "t" for "y" or "j" for "f") (Grudin, 1981). It is possible that novice braillists' patterns of error may contain more homologous finger intrusions than the current corpus that was collected from an experienced braillist.

Special cases: Out-of-sync errors

Errors like example 10 at first appear uncategorizable.

10. Code: Contracted Braille
Error:

⠗⠉⠣⠝⠛⠑⠑

[r][c][gh][n][g][e][e]
Target:

⠗⠑⠋⠥⠛⠑⠑

[r][e][f][u][g][e][e]

This error can be understood, however, as a series of three right-hand dot anticipations. The right-hand side of the

⠋

[f] (the dot 4) replaced the dot 5 on the right-hand side of the

⠑

[e], creating a

⠉

[c]. (It is also possible that the dot 5 on the right-hand side of the

⠑

[e] was anticipated in the initial

⠗

[r], but this is not detectible, since the right-hand side of

⠗

and of

⠑

are already identical.) Then, the right-hand side of the

⠥

[u], (dot 6) was anticipated, replacing the right-hand side of the

⠋

[f]. Finally, the right-hand side of the

⠛

[g], dots 4-5, was anticipated, replacing the right-hand side of the

⠥

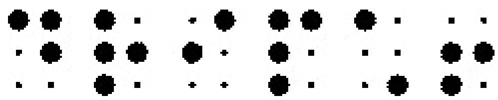
[u] to produce

⠝

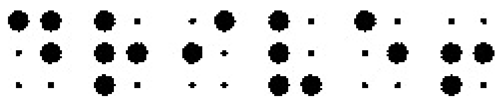
[n]. This error is not unique; there are several similar errors in the existing corpus, such as Example 11, which can be seen as a

double perseveration.

11. Code: Contracted Braille
Error:



[d][r][i][p][ch][!]
Target:



[d][r][i][v][e][!]

Two perseverations

There was no analogous separability of homologous finger pairs within the cell. That is, there was no error in which a pair of fingers was anticipated or perseverated in a series of out-of-sync errors and no errors in which a single dot moved out of sync on its own.

These timing errors, in which a side of a cell (an entire hand) is misplaced by one increment, are analogous to typing errors like that in Example 12 (Shaffer, 1975), in which the two hands get out of sync for a series of key strokes.

12. QWERTY typing
Wne todnw
Target: went down

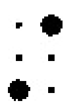
Four sequences of two characters--en, t(space), do, wn--are metathesized.

In studies of errors made by pianists, Shaffer (1981) hypothesized an internal clock that synchronizes the parallel actions of the two hands. The fact that this synchrony can be disrupted in brailling suggests again that the shape of the hand is a subcomponent of the braille cell, at least when writing, and makes it necessary to refine further the model of braille writing to include a mechanism for synchronizing the actions of the two hands.

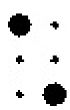
STORAGE OF CHARACTER FORMS

Millar (1997) showed that in reading braille, the density of dots is more important for recognition than is the overall shape of the braille cell. Recognition, however, is a different process than is production, and thus it is necessary to ask how the braille cell is stored for writing. Along with the data already gathered on the constituents of cells, two additional kinds of error, mirrors and raises or lowerings, are pertinent to this problem.

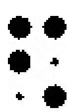
Mirror errors result in characters being flipped so that they are written backward, such as



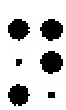
[st] being written as



[ch] or [ed]



being written as



[n]. There were 84 such errors in the corpus, approximately 19% of all character errors. Contextual effects are unlikely contributors to mirrorings; only 25% of the mirrored characters could have been caused by perseverating or anticipating dots or characters from adjacent cells.

Errors that were lowerings or raises of their targets, such as

⠢

[en] for

⠑

[e] or

⠙

[d] for

⠲

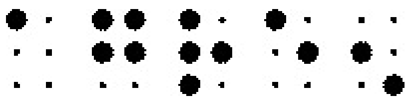
[dd], are also relevant here. There were 60 such errors in the corpus, approximately 14% of all character errors. These errors were almost equally divided between raises (28) and lowerings (32). The six single-dot characters accounted for 45% of the raises and lowerings. They seemed to be affected greatly by dots in adjacent cells, with 81% possibly being influenced by material in neighboring cells. Of the remaining raises and lowerings, only about 25% could have been caused by dots in adjacent cells.

A subset of raises and lowerings could be interpreted as some kind of problem in contraction, rather than in the manipulation of the shapes of characters, since some lowered forms are contractions of analogous letters written in the upper part of the cell, such as 1–4–5

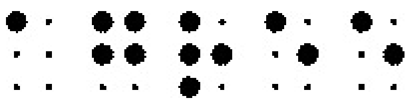
⠲

for [dd]. There is no way to reject this possibility definitively solely on the basis of the data that have been presented so far. However, such an analysis could account for less than half the raises and lowerings in the corpus. Example 13, for example, cannot be a contraction error; it must have had its genesis in the manipulation of shapes.

13. Code: Contracted Braille
Error:

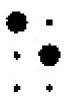


[a][g][r][e][en]
Target:



[a][g][r][e][e]

The last



[e] was written in the lower part of the cell.

If all the raises, lowerings, and mirrors were not caused by contextual effects or failures of contraction, one other possible explanation is that they were caused by the writer manipulating the shape of the cell in his or her mind before assigning fingers to it, suggesting that the overall shape is part of the representation of characters.

CONTRACTION

A central question to researchers on braille is how linguistic units, such as words, syllables, and morphemes, are stored in the mental lexicon. One hypothesis is that forms are stored as serially ordered strings of uncontracted characters. This model stipulates that rules of contraction are applied to the strings after they are retrieved (between steps 2 and 3 in the Model of the Braille Writing Process discussed earlier). An alternative, suggested here, is that, at least for readers who began with contracted braille at a young age, words are stored with their contractions in place, and production moves directly from step 2 to 3 (see Wells, 1995, for a discussion of parallel orthographic representation).

Errors were found that clearly demonstrate that contractions were present as the string was retrieved from lexical memory, rather than being imposed on a previously ordered string. The following error is representative:

14. Code: Contracted Braille
Error:

⠞⠁⠗⠝⠎⠋⠻

[t][a][r][n][s][f][er]
Target:

⠞⠗⠁⠝⠎⠋⠻

[t][r][a][n][s][f][er]

The

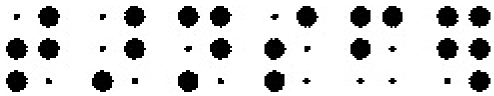
⠁

[a] and

⠗

[r] are metathesized, but the resulting "ar" sequence is not contracted. The [er] contraction is in place, as it should be.

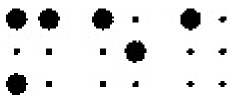
Referring back to the Model of the Braille Writing Process, we can place this error as having occurred at step 2, where the characters are laid out in serial order. Recall that ordering must be done before contraction can occur. Thus, the input to a contraction phase would have been "tarnsfer," which should have resulted in



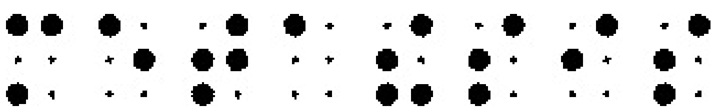
[t][ar][n][s][f][er]

as output of the contraction stage. There are many similar errors in the database. Example 15 is typical.

15. Code: Contracted Braille
Error:



[m][e][a]
Target:

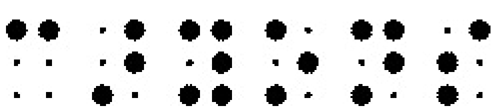


[m][e][t][a][the][s][i][s]

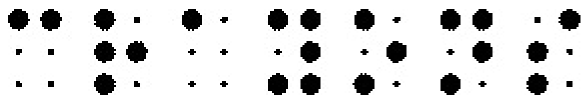
In this interrupted error, the "ta" sequence is misordered, the "t" is deleted, or the "a" is anticipated, resulting in an "ea" sequence. The [ea] sign is not used.

In the corpus of 1,600 errors, there was no error in which letters were misarranged at step 2 and then contracted, as is shown in the following invented example:

16. Invented Error: Code: Contracted Braille
Error:



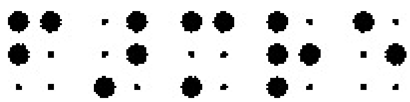
[c][ar][y][o][n][s]
Target:



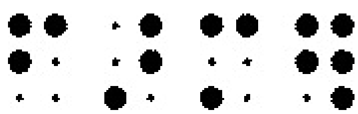
[c][r][a][y][o][n][s]

Similarly, there was no error in which contractions were prevented by misarranged letters, such as a contractable "er" sequence being metathesized, as in the following nonoccurring invented error:

17. Invented Error: Code: Contracted Braille
Error:



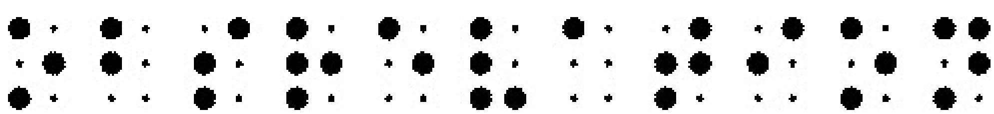
[f][ar][m][r][e]
Target:



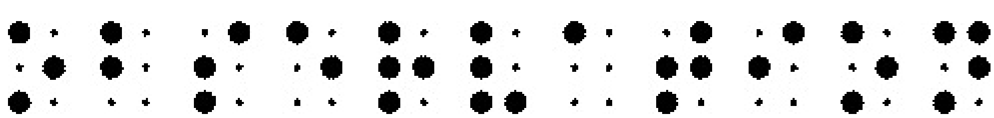
[f][ar][m][er]

In this invented error, the "er" sequence was misordered and thus was not contracted. However, such errors did occur in the computer braille errors, showing that the misordering of characters at step 2 does occur.

18. Code: Computer Braille
Error:



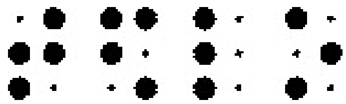
[o][b][s][r][e][v][a][t][i][o][n]
Target:



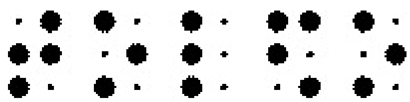
[o][b][s][e][r][v][a][t][i][o][n]

Finally, errors occurred that showed contractions moving together as units, as in the next example.

19. Code: Contracted Braille
Error:



[t][ed][l][o]
Target:



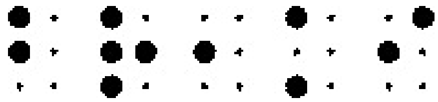
[t][o][l][ed][o]

The [ed] sign moved to replace the first [o].

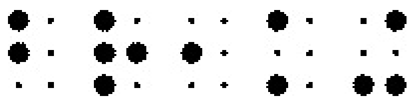
Together, these findings suggest that contractions are atomic--that they are already present in the lexical representations of words and thus that their constituent letters are not available to be metathesized. This is not to suggest that braillists cannot uncontract forms. It is clear that fluent writers of contracted braille know what contractions stand for. Most people, including the current subject, who write on a Perkins braillewriter also type on a QWERTY keyboard, suggesting that they either can and do uncontract stored forms or that they have two parallel orthographic representations, one for brailling and one for typing. In this study, we could not distinguish between these two possibilities. However, informal observation of the subject's QWERTY typing revealed no tendency either to group contracted forms temporarily when typing or to make errors in typing that could be traceable to an uncontraction process.

There are a few errors in the corpus that initially appeared to be failures of contractions. In addition to those discussed earlier (which can be caused by lower-level processes), the corpus contained six errors like the following:

20. Code: Contracted Braille
Error:



[b][r][ea][k][i]
Target:

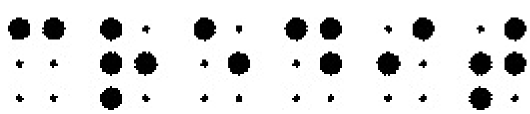


[b][r][ea][k][ing]

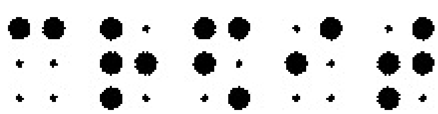
In this interrupted error, the writer apparently began to write "ing," rather than the necessary [ing] contraction.

All six errors that appear to be contraction failures and are not attributable to lower-level processes--such as contextual effects or manipulation of the character--occurred at a regular productive morpheme boundary. There was no error in which a sequence of letters within a morpheme failed to contract, as is shown in the following invented example:

21. Invented Error; Code: Contracted Braille
Error:



[c][r][e][d][i][t]
Target:



[c][r][ed][i][t]

In this nonoccurring type of error, the [ed] contraction that appears within a morpheme was omitted.

We suggest that these errors were due not to misfirings of a contraction stage, but to the subject's frequent alternations between computer braille and contracted braille. It may be that the writer changed codes at the morpheme boundaries or that morpheme boundaries (as well as presumably word boundaries) are points at which it is permissible to change codes. This analysis bears further investigation, but is congruent with recent models of the speech-production system and psycholinguistic research (Levelt, 1989; Wells-Jensen, 2007). We predict that these errors, which are already infrequent, would be even less common in the writing of braillists who do not so frequently use computer braille and contracted braille together.

An amended model of braille writing

The results of this study suggest that some refinements are needed to the model of spontaneous braille writing proposed in the section, A Model of the Braille Writing Process. The steps in the model still necessarily follow one another in serial order, and characters that make up the text to be written proceed through the steps together, making it possible for them to influence one another at various stages. The refined steps are as follows:

1. Lexical access: Just as is done in speech, the forms (words and regular affixes) to be written are located in the mental lexicon. It is necessary to determine which code is being used so that the correct form can be retrieved. Errors at this stage are lexical or morphemic. This is also the stage in which the writer may inadvertently switch codes.

2. Spell out: Characters (letters and contractions) are serially ordered. There is no separate contracting component. Words are retrieved with their contractions in place. Errors at this stage are misorderings of units: metatheses, deletions, or additions of cells or noncontextual character additions.

3. Retrieval of shapes of braille units: Shapes of each cell to be written are accessed. Errors at this stage are mirrors, raises, and lowerings within a cell.

4a. Analysis of the shapes of cells: The shape of each cell is halved to recover the two hand shapes or combinations of fingers that are necessary to write the cell. An incorrectly chosen hand shape may appear as a noncontextual dot error or be indistinguishable from a contextual dot error. Other errors at this stage are anticipations or perseverations of hand shapes to adjacent cells.

4b. Assignment of finger sequences. Taking hand shapes as input, serially ordered instructions are created for the movement of fingers. Errors at this stage are anticipations, perseverations, and metatheses of dots, along with other contextual and noncontextual dot errors. Errors may appear identical to those produced by the previous stage.

5. Synchronization. When writing, the two hands are coordinated so that, in making a character, dots from each hand are pressed simultaneously. Errors at this stage are out-of-sync errors. If the error is located in only one cell, that is, if the hands are recoordinated after only one out-of-sync cell, these errors are indistinguishable from errors at stage 4a or 4b.

This revised model more accurately reflects the way in which the subject retrieved and wrote characters.

Conclusions

This article has examined the process of writing in braille from a purely psycholinguistic perspective. The following is a summary of the main findings from this subject's patterns of errors:

Kinds of brailling errors.
The subject braillist made errors at all levels of orthographic structure: with whole words, morphemes, characters, and single

dots. Low-level processes were responsible for most errors; the most common type of error involved a single dot or dots, followed by errors with characters. Together, these errors constituted 92% of the subject's brailling errors.

Code.
Errors occurred in all codes, and similar kinds of errors occurred in all codes.

Finger inertia.
Fingers in motion tended to stay in motion, and fingers at rest tended to stay at rest. Errors tended to be contextual, that is, affected by material in adjacent cells. Adding dots noncontextually was relatively rare.

Independence and coordination of hands.
Dot substitutions tended to occur within the same hand, rather than across hands. Hands must be coordinated by some synchronizing mechanism to write accurately.

Character storage.
Characters were stored as shapes in the mind. These shapes were retrieved, and from them, hand shapes were determined. Hand shapes were then broken down into individual finger designations.

Contraction.
There was no separate contraction component. Contractions were stored and retrieved as part of the lexical item.

The analysis of writing errors in braille, if more data are collected and analyzed from more subjects, should eventually lead to suggestions for training programs that may target subparts of the system at which errors tend to cluster either for all or for particular writers. Through focused training or even simply raising consciousness, it may be possible to improve writing speed or accuracy or both as students focus their practice on problematic characters or combinations of characters. A better understanding of how braille is written can motivate innovative pedagogy, guide developments in technology, and inform any potential changes to the system of English braille itself.

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