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ABSTRACT

Vocabulary systems for individuals using communication aids can be broken down into two major types: coverage vocabularies and acceleration vocabularies. Acceleration vocabularies or word sets assume the individual is able to spell and words are chosen which speed up the rate of communication. Acceleration techniques may include sets of most frequently used words or syllables, abbreviation-expansion techniques, word prediction techniques, linguistic expansion, and full sentence storage and retrieval. This paper presents data regarding the coverage power of most-frequently-used-word sets, the effects of word length and keystroke analyses on calculated word set efficiencies, and the effect of different termination and abbreviation strategies. Word set analyses which do not take keystroke analysis into account are shown to be overly optimistic due to the heavily skewed distribution of word length versus usage. A generic abbreviation algorithm is describe l which allows implementation and comparison of other strategies. Fixed-vocabulary, letter-based word prediction techniques are shown to be a form of cued abbreviation expansion with a relatively low motor efficiency. (Author/DB)

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Comparative Analysis of Fixed-Vocabulary Communication Acceleration Techniques

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Principles involved in the formation of acceleration vocabularies are reviewed followed by an analysis of alternate strategies for implementing abbreviation expansion accelleration techniques. Data regarding the coverage power of most-frequently-used-word sets, the effects of word length and keystroke analyses on calculated word set efficiencies, and the effect of different termination and abbreviation strategies are presented. Word set analyses which do not take keystroke analysis into account are shown to be overly optimistic due to the heavily skewed distribution of word length versus usage. A generic abbreviation algorithm is described which allows implementation and comparison of other strategies. Fixed-vocabulary, letter-based word prediction techniques are shown to be a form of cued abbreviation expansion with a relatively low motor efficiency.

KEY WORDS: abbreviation expansion, acceleration, aided communication, prediction, vocabularies, word frequency, word sets

Vocabulary systems for individuals using communication aids can be broken down into two major types: coverage vocabularies and acceleration vocabularies. Coverage vocabularies are vocabularies (picture sets, symbol sets, etc.) which try to provide an individual with a set of "words" or "concepts" with which the individual can communicate. The objective of this type of word set is to try to provide the individual with the ability to communicate most effectively and about the widest range of topics, given the limited word set. These vocabularies are generally provided to an individual who cannot spell, and whose communication is therefore restricted to this particular vocabulary (picture set, symbol set, etc.).

Acceleration vocabularies or word sets, on the other hand, assume that the individual is able to spell. Because the users can spell, they are already able to say anything that they would like. Thus, the words chosen for the acceleration set are not chosen for their ability to allow an individual to communicate their ideas, but rather to speed up the rate at which they can communicate them.

Acceleration techniques can take many forms, including sets of most frequently used words or syllables (Goodenough-Trepagnier & Rosen, 1982; Harris & Vanderheiden, 1980; McDonald & Schultz, 1973), abbreviation-expansion techniques (Vanderheiden, 1984), word prediction techniques (Soede & Foulds, 1986; W. Woltosz, personal communication, 1985) linguistic expansion (Eulenberg & Rahimi, 1978; Galyas & Hunnicutt, 1984), and full sentence storage and retrieval (Baker, 1984; HC Electronics, 1978; Vanderheiden and Grilley, 1975).

Acceleration vocabularies can incorporate the storage and retrieval of entire phrases or sentences. In order for the sentence to be stored in advance, however, it must be known in advance and/or be a phrase or sentence which is very commonly used. This acceleration strategy (prestored phrases or sentences) is most effective for common requests ("I'm thirsty," "I have . . .," "When do we . . .," "Can I have a . . .," etc.) and comments ("I don't like that," "Cut it out," "This is good," etc.). Because of the rapid speed with which these phrases can be called up and played out, they can be used very effectively in situations where a spelled-out or assembled sentence would take too long. They can also be used in places where interjections must be swift in order to have any effect (e.g., communication continuation phrases or emergency situations). Thus, the storage and retrieval of full sentences is a very powerful communication acceleration technique. The vast majority of our communication, however, is of a novel type. That is, the vast majority of what we say every day is not predictable, and cannot be prestored or handled through prestored phrases. For this communication, we must rely on acceleration techniques that help the individual assemble sentences as they occur. It is the "novel communication" acceleration techniques that are the subject of this paper, although the same techniques that are used to call up words can also be used to call up prestored phrases or sentences.

In this paper, the basic concepts and issues will be presented, along with data regarding the impact (pro and con) of various types of acceleration word sets. These discussions are used as a basis for an analysis of several abbreviation-expansion approaches, as well as the relationship of fixed-vocabulary spelling prediction techniques.

Most-Frequently-Used Words Strategy

The first principle underlying most of the acceleration word set techniques is the most-frequently-used words strategy. This strategy focuses on providing the easiest access to those words which are used most frequently. The reason that most techniques are based on this most-frequently-used words strategy is that the normal word usage is very heavily skewed, with a relatively small number of words accounting for most of our speech. Figure 1 shows the word distribution from several major spoken and written word studies. In all of these cases, it can be seen that a relatively small number of words account for a relatively large portion of the communication. Typically, the first 50 words will account for 40 to 50% of the total words communicated even though they account for only 1/2% of a 10,000-word vocabulary. One hundred words would account for approximately 60%, 200 words 70%, and 400 words 80% (Berger, 1967; Horn, 1926; Howes, 1966; Rinsland, 1945; Sherk, 1973).

As can be seen, a relatively small number of words account for the vast majority of word usage. It can also be seen that once beyond the initial couple of hundred words, each additional word adds relatively little. Thus, providing quick access to the first 100 words will have a much greater impact on the person's speed of communication than quick access to the next 1,000 words. As a result, most of the acceleration techniques tend to focus on the most-frequently-used words to optimize their effectiveness.

Consistency of the Words Across Word Studies

A second important factor is consistency across word samples. In examining the above studies, it is interesting to note that a relatively small number of words accounted for a large portion of each of the word samples. What is not clear from Figure 1 is whether it is the same words which appear most frequently in the different word samples. If the same words do appear, then these words could be used within the acceleration technique for an individual with a fair degree of confidence that the words would be this individual's most-frequently-used words as well. If, however, the most-frequently-used words were substantially different within each sample, then the value of this "most-frequently-used words" phenomenon would be greatly reduced. That is, if the most-frequently-used words differed greatly from individual to individual or population to population, then a "standard set" of most-frequently-used words would not exist, and a special set

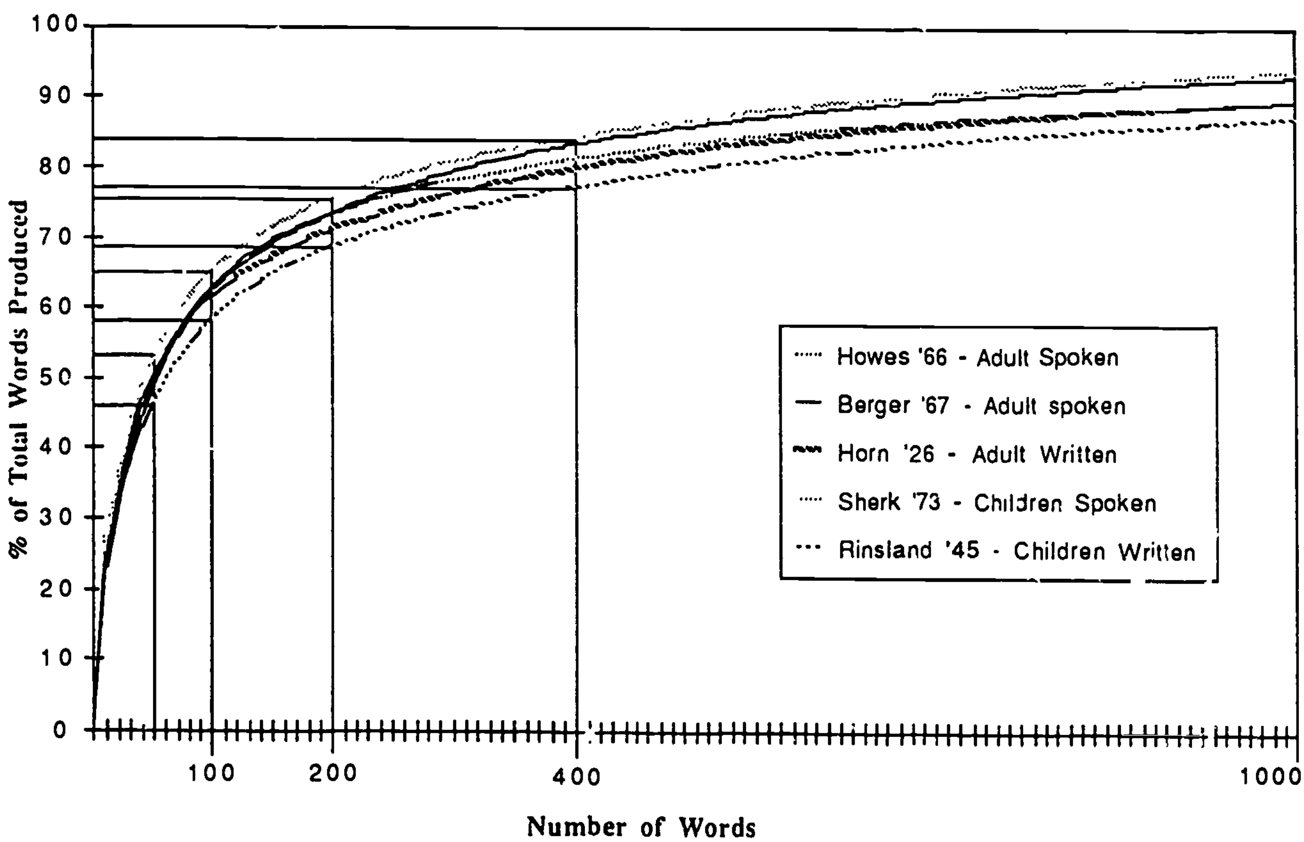


Figure 1. Percent of total words produced which are accounted for by the most frequently used words in that sample.

would need to be calculated for each individual or population.

Research by Vanderheiden, Cress and Kelso (1987) indicates that the most-frequently-used words do differ between studies. However, there is a fair degree of commonality, and a set of 50 to 200 "frequently-used words" can be constructed which will apply across most word samples, with only a minimal loss (*5–8% and less for larger word sets*) in covering power from a custom "frequently-used words" set developed from the specific study(s). Thus, the general principle illustrated in Figure 1 can be used to generate "most-frequently-used words" for arbitrary clients. The expected efficiency, however, would be somewhat less than that shown in Figure 1 in actual daily use.

Effect of Word Length

A third factor that needs to be considered in analyzing acceleration word sets is the effect of word length on acceleration word sets. Since a longer word takes longer to spell than a shorter word, the longer word would be more valuable (based on length times frequency) than a shorter word that was used just as frequently. In fact, a long word which is used less frequently may be more valuable than more frequently used words which are shorter. Table 1 shows how this happens. In this table, the words are ordered by frequency of use, with the most frequently used words first. Ordered in this fashion, the word "because" is the 56th word in the list. However, if we take into consideration the length of the word, and calculate the number of keystrokes that this word represents, we find that it is nearly twice as valuable as the word "up," even though the word "up" is much higher on the list. Since the time it takes to communicate or spell out a message on a communication aid is more a function of the number of letters than the number of words, a "keystroke" analysis would be much more accurate than a simple word frequency analysis. Thus, a word set which was arranged by length times frequency of use would be a more useful tool for acceleration vocabulary than would be vocabulary sets based on frequency alone, such as those of Berger (1967), Beukelman, Yorkston, Pobleto and Naranjo (1984), Horn (1926), and Howes (1966).

The length of words, however, has implications besides just reordering of most-frequently-used word sets. It also has significant effects on the calculated efficiencies of these word sets. Figure 2 shows the decrease in efficiency of most-frequently-used word sets when a keystroke analysis is used rather than the simpler word coverage analysis. For example, if we look at the 50 most frequently used words, we can see that they account for 50.13% of the words, but only 29% of the letters or keystrokes. Similarly, a 100-word set would yield only 38.7% of the characters, versus 63% of the words. A 400-word set would yield only 56% of the characters, versus 81% of the words. Thus, using a keystroke analysis rather than a straight word frequency analysis decreases the apparent covering power of these word sets by between a third and almost a half, depending upon the size of the word set.

This loss can be partially offset by reordering the words, so that the most valuable words (based on length times frequency) are chosen rather than simply the most frequent. This still results, however, in a much lower calculated coverage (Fig. 2).

The reason for this discrepancy between word coverage and keystroke coverage is that the most frequently used words are mostly short words, where the less frequently used words are longer. Figure 3 shows a plot of the length of words as a function of their usage. In this plot, each bar represents 5% of the total word sample of 250,000 words. As can be seen, we have to go beyond the halfway point before we hit an average word length of even 4 characters.

The implications of this are two-fold. First, looking only at the frequency of word use without looking at word length can result in a false positive indication for the value of the words or word sets. To get an accurate picture, the length-times-frequency analysis should be used. Further, for an optimum word set, the words should be reordered after they have been given a length-times-frequency value. However, reordering the word set has little impact on the overall efficiency. The efficiency would only be increased by 1 to 2%.

TABLE 1: Effect of Word Length on Value of a Word in a Wordset

Rank	Word	No. of times this word is used per 1000 words*	Length of word (with space)	Keystrokes used per 1000 words to type this word
1	the	40.5	4	162
⋮				
15	but	9.7	4	38
⋮				
31	up	5.05	3	15
⋮				
47	think	4.14	6	25
⋮				
56	because	3.65	8	29

* Base on Howes (1966) spoken word study

Effect of Scanning Techniques on the Above Calculations

All of the above calculations are made assuming that the alphabet and the words are available on a direct selection panel; that is, that each letter takes the same amount of time to access (one unit), and that the words take the same amount of time to access (one unit). On a scanning panel, the calculations become much more difficult. Each letter of the alphabet takes a different amount of time to access. Thus, the value of a word becomes equal not just to the length of the word measured in letters, but also to the total length of time it takes to select the letters in the word. In order to calculate the amount of time saved by putting a word on a scanning panel, it would be necessary to (a) sum

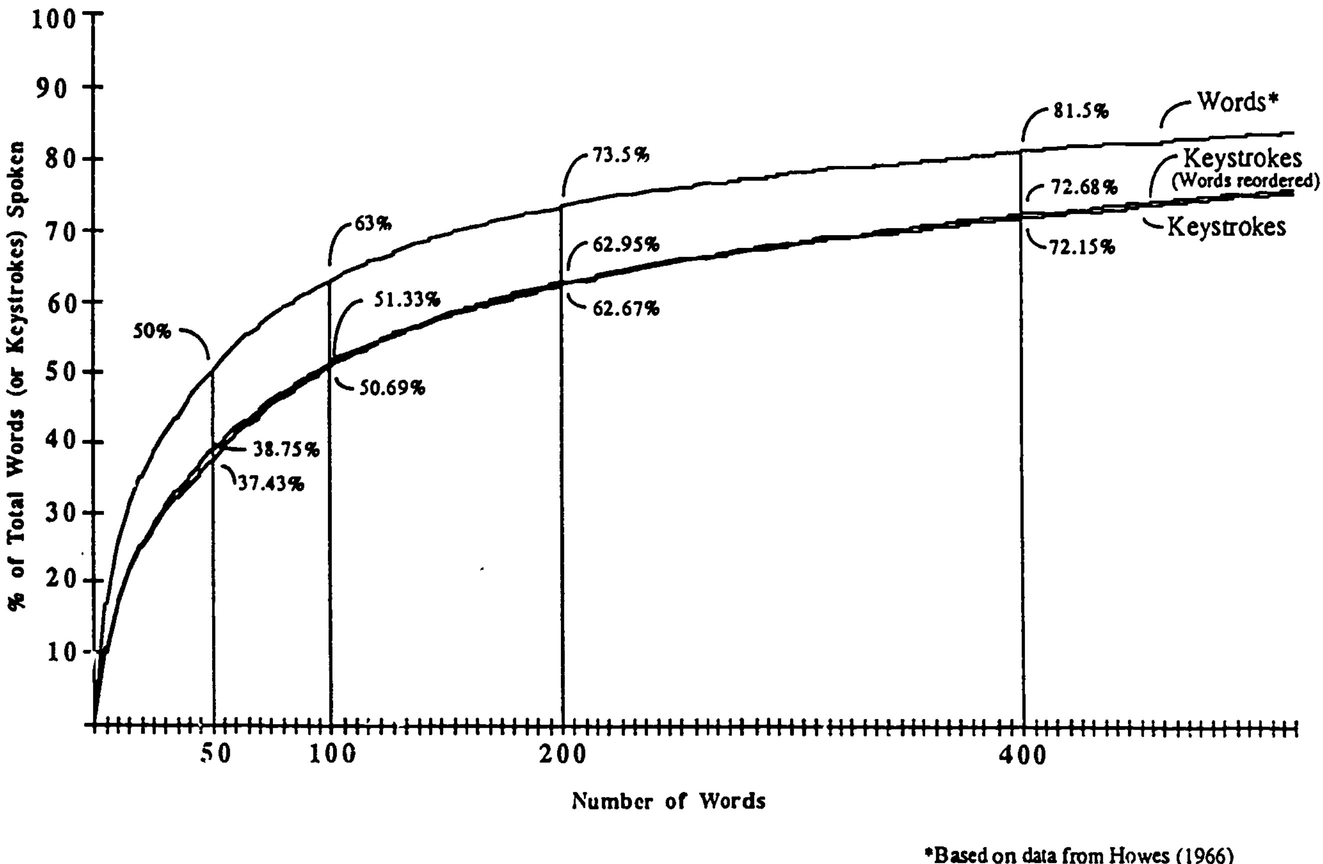


Figure 2. Percent of total words and keystrokes which are accounted for by the most frequently used words.

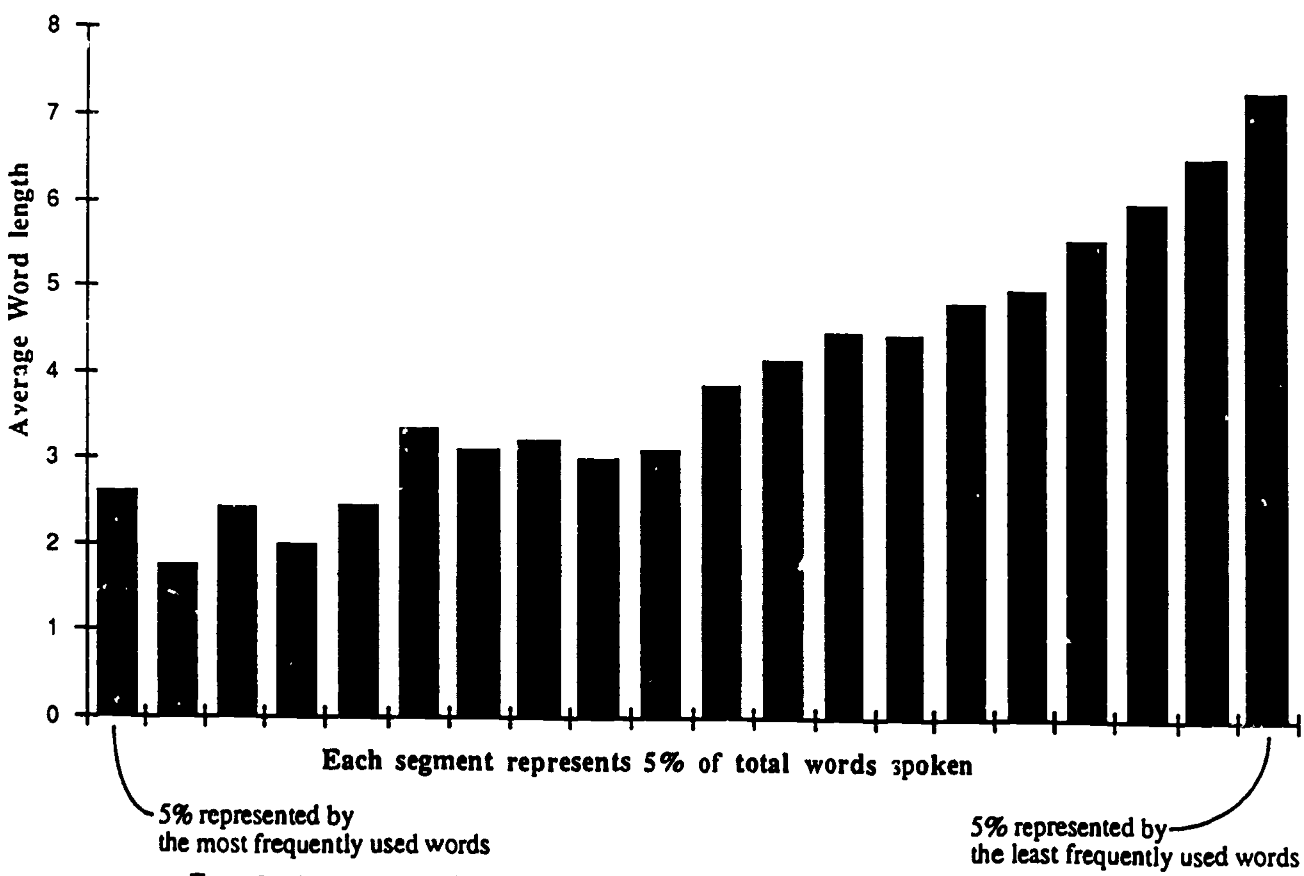


Figure 3. Average length of word versus frequency of use (based on Howes, 1966—spoken).

the amount of time it would take to select each of the letters to spell the word, (b) subtract the time it would take to select the word given its planned location on the scanning panel, and then (c) multiply that result by the frequency of the word. Without going into any more detail here, it is sufficient to say that the rules that go into selecting the optimal words for a direct selection aid are different from and considerably simpler than those that would be used to select the optimal words for a scanning panel. The analyses in this paper should not, therefore, be applied directly to vocabulary selection for scanning panels. The magnitude of the error which would be introduced by doing so is not known at the present time, but is a topic currently being investigated at the Trace Center.

Abbreviation Expansion Techniques

Overview

Outside of the inclusion of words and phrases directly on communication boards or scanning aids, the next most popular acceleration technique is the use of abbreviation expansion techniques. With these techniques, each word in the unit's expansion vocabulary is represented by a smaller set of letters or keystrokes. By having a shorter spelling for each word, it is possible to save keystrokes. These techniques are usually used with electronic aids which automatically look up the shorter spellings and then replace the abbreviation with the fully spelled word. Thus, the individual types a short sequence of keys which is instantly translated into a fully spelled word on the display.

Abbreviation expansion techniques can be used with words, phrases, or entire sentences. As discussed previously, the bulk of everyday communication (in excess of 90%) would still need to be constructed by assembling words, or phrases and words. This discussion is limited to word abbreviations.

Basically, word abbreviation expansion techniques amount to providing an alternate, shorter spelling for the words. In some cases, these shorter spellings are chosen to resemble the original words. For example:

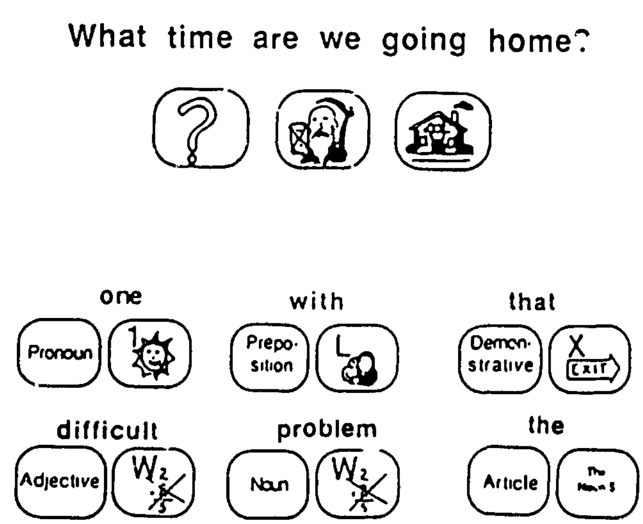
abv. = abbreviation
tn = then
bcs = because

There is no requirement, however, that the abbreviations be spelled in any particular fashion. The word "then" could have been abbreviated to "TI," or for that matter to "QJ." In general, the abbreviations are chosen in order to facilitate learning and recall of the codes. As is discussed later, different abbreviation techniques have varying implications for the efficiency of the overall technique.

Abbreviation expansion techniques are not necessarily restricted to the letters of the alphabet. Words could be represented by any sequence of keystrokes. THN, TI, [ESCAPE][RETURN], or any other sequence of keystrokes could be used to represent a word (or phrase or sentence). In one technique called Minspeak (Baker, 1984), words, phrases, and sentences are represented by sequences of keystrokes or selections having pictures or linguistic characteristics on them. Figure 4 shows Minspeak icons in a three-key sequence which could be used to store and recall the sentence "What time are we going home? Also shown are examples of the sequences of keys which would be used to store individual words. With Minspeak, pictures and grammatical concepts are used rather than letters for the codes for words in order to facilitate the recall of large numbers of abbreviations. Further, since the sequences for some of the words follow grammatical rules and procedures, it would be possible for individuals to figure out the codes for some words from scratch without knowing the code for the word in advance. This would however, require a thorough familiarity with the grammatical constructs used to generate the code.

Efficiency Calculations of Abbreviation Expansion Techniques

Ignoring human perception, cognitive processing, and other cognitive/perceptual factors, it is possible to calculate the theoretical motor efficiency for different abbreviation-expansion approaches using a fairly straightforward process. A calculation which uses the length of the word minus the length of the abbreviation, multiplied by the frequency of use for the word, could be used. As an individual used an abbreviation expansion technique for a long period of time, his ability to recall abbreviations would tend to become more instantaneous and reflexive, in the same way that the keystrokes for a word flow out of a touch typist's fingers. Eventually the typing of the abbreviation would begin to flow as fluently from the individual as the spelling for the word (or perhaps more fluently for very long words). As this occurred, the motor efficiency calculation described would become a fair estimate of the relative efficiency of the technique.



(Graphics and examples courtesy of Bruce Baker, 1987)

Figure 4. Example of Minspeak key sequences for sentences and words.

Until this level of proficiency is reached, however, these theoretically calculated motor efficiency factors need to be substantially adjusted to account for recall and other cognitive/perceptual factors, as discussed below. The length of time it would take to go from looking up abbreviations to reflexive use of abbreviations has not been defined to any degree to date. First-order approximations, however, might be obtained by considering the limit it takes for an individual to learn to use another language fluently. In the case of abbreviations, the individual may actually have a simpler task than learning a second language, since he would only be learning an alternate spelling for the words, and would not have to learn a new syntax, sentence, grammar order, idioms, etc.

Comparison of Abbreviation Techniques

Using the above concepts and techniques, the rest of the paper will explore different abbreviation-expansion techniques in both qualitative and quantitative form. First, the different abbreviation termination approaches are discussed, including relative efficiency issues. This is followed by a discussion of the different abbreviation strategies, with quantitative analysis of their relative efficiencies. Finally, a discussion of the relationship of abbreviation expansion techniques to prediction techniques is presented, along with clinical implications of the analyses. The techniques covered include:

Termination Techniques

- variable-length autoterminating
- variable-length with terminating period
- variable-length with terminating "expand" or "macro" key
- variable-length numeral-terminating (10-Branch)

Abbreviation Strategies

- truncation abbreviation strategy
- idiosyncratic-logical abbreviation strategy
- minimum length arbitrary abbreviation strategy

Prediction Techniques

- fixed-vocabulary techniques
- variable-vocabulary prediction techniques

The most general of the abbreviation strategies is the "*variable-length autoterminating*" abbreviation expansion algorithm (Vanderheiden, 1984). With this strategy, any sequence of characters or keystrokes can be used as the abbreviation. After each keystroke, the system looks up the currently accumulated sequence of keystrokes to see whether it matches any stored abbreviations. If a match is found, then the sequence is removed from the screen and replaced by the expansion (word, phrase, or sentence). With this technique, it is important to avoid using any abbreviations which are identical to the beginning characters for a word. For example, the word "there" might be abbreviated "TH." However, this abbreviation should be avoided since as soon as one began to spell any word which began "TH," the expansion "there" would appear. This problem is easily overcome by either using two letters which do not occur in sequence or by adding a third character such as a period, dash, slash, and so forth (i.e., "TH." or "TH-" or "TH/"). The variable-length autoterminating approach is the most efficient of the abbreviation expansion approaches, due to the fact that all of the other abbreviation expansion approaches are subsets of it, as discussed below. The "QuicKey" technique is an example of the variable-length autoterminating abbreviation expansion algorithm. The algorithm is also used as part of the Minspeak system.

The variable-length, period-termination abbreviation technique is probably the best known. With this technique, any set of characters can be used as the abbreviation without concern for collision with other words or abbreviations. For example, the abbreviation "TH." can be used without interfering with the use of the words "the," "then," "their," and so forth, since none of these words have a period as their third character. This technique has the disadvantage, however, of requiring an extra keystroke (the period) for each abbreviation. Remembering that the most frequently used words are short to begin with, this additional keystroke significantly reduces the efficiency of this abbreviation technique. The exact decrease would depend upon the abbreviations used, but would amount to an approximate 30% decrease in efficiency over the use of a variable-length auto-terminating approach (which did not use a fixed terminating character). The period-termination approach can be seen to be a subset of the variable-length auto-terminating approach by simply putting a period at the end of all of the abbreviations used with this latter approach.

Another common approach is to use some "expand" or "macro" key to indicate that the previous or following character (or characters) should be treated as an abbreviation and expanded. For example, the letter "T" might be preceded or followed by a special "expand" (or "ALT") key which would cause the letter to be looked up and expanded to "the." Similarly, the letters "TH" could be followed by an "expand" key in order to cause them to be expanded to "that." The advantage of this approach is again that any letters can be used for an abbreviation without a fear of collision with other words or abbreviations. The disadvantage is that it again adds one keystroke to each of the abbreviations, and would suffer the same loss of efficiency as putting a period at the end of each abbreviation. This technique can also be seen to be a subset of the variable-length, auto-terminating abbreviation generic approach by simply including the "expand" key as part of the stored sequence of keys which make up the abbreviation.

Another commercially available abbreviation-expansion technique is the "10-Branch" abbreviation-expansion technique (Vanderheiden & Kelso, 1984; ZYGO, 1985). With this technique, all abbreviations consist of a series of letters followed by a number. Allowable abbreviations would be "T7," "TH8," and so forth. This technique also avoids collision with any other abbreviations or words, because of the unique letter-number sequence. In addition, since it uses ten different termination characters rather than one (as with the "period" or "expand" strategies above), an increased number of shorter codes is possible. As a result, the decrease in efficiency is less, but would be in the range of 5 to 10%. Again, this technique can be implemented on a system supporting the variable-length, auto-terminating abbreviation algorithm by using abbreviations which all consist of a sequence of letters followed by a number.

Cued Versus Uncued Abbreviation Expansion Techniques

All of the above techniques can be implemented in either an uncued fashion or in a cued fashion, where the current expansion choices are displayed along with their abbreviations. For example, with the 10-Branch strategy, the 10 abbreviations which could be completed with a single keystroke (one of the 0–9 keys) are always displayed on the screen. Thus, when the letter "T" is struck, the expansions for T0 through T9 are shown on the screen, next to the number which would complete the code for that item. If the person does not want one of these choices and types an "H," the screen would change to display those words whose abbreviations were TH0 through TH9. Thus, if an individual could remember the beginning of the code, the screen would automatically cue them, confirming the beginning and providing the final numeral of the sequence.

The use of cuing can greatly slow down the rate of communication using an abbreviation expansion technique. The abbreviation expansion technique is most useful when the user memorizes the codes and simply types them in. If, in contrast, an individual types a character, then checks a cue display, types another character and then checks the display again, the theoretical abbreviation-expansion rates discussed below would not apply. Thus, while a technique which cues individuals may be a helpful memory aid, it may significantly slow the rate of communication if the individual were to rely on it, especially for commonly used abbreviations.

Abbreviation Strategies

In addition to the abbreviation expansion algorithms discussed above, there are a number of different strategies that might be used to select abbreviations for each word. For example, a contraction strategy might be used, where abbreviations are formed using first and last letters in a word. Another approach is to use truncation, where the beginning of the word is used. If this approach is used, then a final terminating or confirming character is required to differentiate the abbreviation from the actual beginning of other words. Both of these techniques (contraction and truncation) have an advantage because they follow rules. With rule-generated abbreviation strategies, the individual does not have to remember the code, since they can construct the code by thinking about the target word. They have the disadvantage of tending to create longer abbreviations, which significantly reduces the efficiency. There is also a problem with multiple collisions (e.g., two words having the same abbreviation).

At the other extreme is an abbreviation scheme which uses arbitrary letters and/or characters for the abbreviation. With this approach, there is no direct relationship between the abbreviation and the expansion. This technique has the advantage of achieving maximum motor efficiency by using minimum length abbreviations. It has a disadvantage due to the extreme difficulty of learning totally arbitrary codes for any large number of words, thus requiring extensive practice to master a large vocabulary. This approach is primarily useful for establishing the maximum possible rate for abbreviation expansion in a given word set, assuming the individual has mastered the abbreviations. Use of short but arbitrary codes is also a viable technique if applied to a small enough word set. For example, it would not take an individual who is cognitively able to master spelling very long to memorize 10 or 20 arbitrary codes, or perhaps as many as 50. Given the facts that (a) a small number of words accounts for a very high percentage of our word usage, and (b) the most frequently used words tend to be quite short, the use of very short but somewhat arbitrary codes for some of the most frequently used words is a viable approach.

Between these two extremes lies a range of abbreviation strategies which use letters or characters which are conceptually linked with the target word. Salient letters may be used ("BC" for "because"), or characters that resemble the sound of the word ("2" for "two", "U" for "you"), or characters that have other linkages ("X" for "across", or "X" for "no"). In general, these codes would be chosen to be as short as possible and yet easily remembered. Normally, the more frequently used words can use more cryptic codes, since they are used often and remembering the codes is not difficult (and having short codes is very valuable). Less frequently used words generally need to have abbreviations that are more obvious or easily remembered. Abbreviations which are chosen by an individual according to their logic might be termed "idiosyncratic-logical".

Figure 5 shows a comparison of the relative efficiencies of these different approaches, and Table 2 shows sample abbreviations from each approach. The abstract optimized codes show the results if 13 number and symbol keys were to be used for single-key abbreviations, and all of the other 200 words received two-character abbreviations. The alphanumeric optimized assumes that letters and numbers could be used, and that 10 of the number and symbol keys were used in a logical fashion to represent words. The alphabetic optimized used only letters of the alphabet for codes. The trunction approach used the shortest available abbreviation using the truncation technique. Where several words begin with the same sequence, the highest ranking word (length times frequency) was given the shortest code. The word "I" is counted as being three characters long (shift, i, space). The dash (-) is used to visually represent a space in the chart. The asterisk is

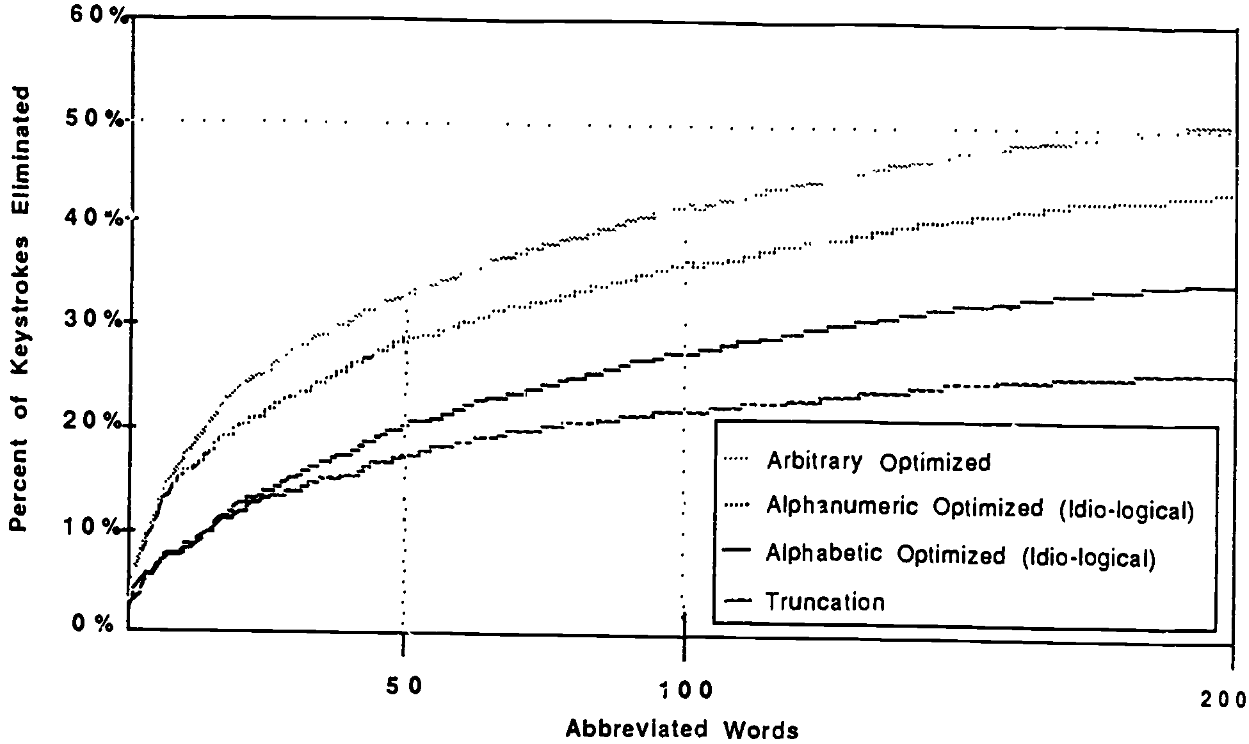


Figure 5. Percent of keystrokes eliminated as a function of vocabulary size for four abbreviation expansion approaches.

used to represent the "EXPAND" or "CONFIRMATION" keystroke for the truncation approach.

The data are based upon the first 200 most valuable words (length times frequency) based on the Howes (1966) study. An excerpt of the data used in this analysis is shown (Table 2). The relative efficiencies of the different techniques would shift somewhat as the number of words in the wordset gets larger. However, the need for a terminating character for the truncation (and similar) techniques will always put them at a significant efficiency disadvantage, as shown in Figure 5.

The Effect of Collisions

Collisions (when the same abbreviation would be useful for more than one word) occur in all abbreviation expansion routines. For example, "TK" would be a contraction for "thank," but would also be an contraction for "tank" or "trick," and for "truck." Although collisions occur with all abbreviation routines, they are more of a problem with truncation and contraction techniques for two reasons. First, words tend to begin and end with similar letter groupings. As a result, truncation and contraction techniques tend to yield a large number of collisions. Second, the general solution strategy when a collision is encountered is to select some other set of letters to represent one of the words. For idiosyncratic (individually selected) abbreviation approaches, this is not a problem. With contraction or truncation schemes, however, this counteracts the purpose of using truncation or contraction in the first place. If some words are truncated by rule but others have special codes, then the individual is left not only having to remember the special abbreviations, but also to remember when to use truncation and when to try to remember a code.

Collision Accommodation

Even idiosyncratic (individually selected) abbreviation techniques can run into collisions. For example, the abbreviation "PN" might be used for the word pencil, since "PN" does not normally occur as the beginning for any word in English. However, there are some seldom-used words, such as "pneumatic," "pneumonia," and so forth, which do start with "pn." One approach to this problem is, of course, to simply select a different abbreviation for the word pencil. However, a second strategy would be to include a "re-abbreviate" key on the communication aid. The "re-abbreviate" key would simply take a word that had been expanded and change it back into its abbreviated form. Thus, the individual would type "PN," the word "pencil" would appear, the individual would hit the re-abbreviate key, and the word would change back into "PN," allowing the individual to continue typing the word "pneumonia." This would add one keystroke to the typing of this seldom-used word ("pneumonia"), but would allow the individual to use the "PN" abbreviation sequence the rest of the time. The re-abbreviate strategy can be used to allow individuals to use a large number of short, very valuable abbreviations which would otherwise be unusable because of the spelling of some infrequently used word.

One of the most valuable applications of the re-abbreviate key is to allow the number keys across the

Table 2: Sample of Abbreviations Used in the Abbreviation Comparison Analysis

BASE WORLIST INFORMATION				Arbitrary - Optimized (18 abve 1 ltr; rest= 2)			Alphanumeric Optimized (idio-logical)			
Ref #	Word	Occurrences per 1000 Wds	Chars per 1000 wds Spoken	KS for Word	KS per 1000	% Elim	Abv.	Keystrokes Saved for This Word	Keystrokes Saved per 1000 Wds	% of Keystrokes Eliminated
1	the·	40.52	162 08	3	121 56	3.07%	3	3	·121.56	3.07%
2	and·	37.96	151.84	3	113.88	2.88%	7	3	113.88	2.88%
3	I·	40.09	120.27	2	80.18	2.02%	I	2	80.18	2.02%
4	that	15.24	76 20	4	60.96	1.54%	tt	3	45.72	1.15%
5	to	25.27	75 81	2	50.54	1.28%	2	2	50 54	1.28%
6	you·	18.9	75.60	3	56.7	1.43%	u·	2	37.8	0.95%
7	they·	14.87	74.35	4	59.48	1.50%	6	4	59.48	1.50%
8	of·	17.59	52.77	2	35.18	0.89%	f·	1	17.59	0.44%
9	it·	17.34	52.02	2	34.68	0.88%	8	2	34.68	0.88%
10	in·	16.77	50.31	2	33.54	0.85%	5	2	33.54	0.85%
11	know·	10.03	50.15	4	40.12	1.01%	k·	3	30.09	0.76%
12	a·	24.15	48.30	1	24.15	0.61%	a·	0	0	0.00%
13	was·	10.91	43.64	3	32.73	0.83%	wz	2	21.82	0.55%
14	well·	8.43	42..3	4	33.72	0.85%	w·	3	25.29	0.64%
15	have·	8.17	40.85	4	32.68	0.83%	v·	3	24.51	0.62%
16	there·	6.74	40.44	5	33.7	0.85%	th·	3	20.22	0.51%
17	but·	9.74	38.96	3	29.22	0.74%	b·	2	19.48	0.49%
18	don't·	6.04	36.24	5	30.2	0.76%	[illegible]	4	24.16	0.61%
19	he·	10.03	30.09	1	10.03	0.25%	h·	1	10.03	0.25%
20	it's·	7.46	37.30	3	22.38	0.57%	i·	3	22.38	0.57%
21	because·	3.65	28.20	6	21.9	0.55%	bc	6	21.9	0.55%
22	so·	9.4	28.20	1	9.4	0.24%	s·	1	9.4	0.24%
23	like·	5.47	27.35	3	16.41	0.41%	lk	3	16.41	0.41%
24	this·	5.45	27.25	3	16.35	0.41%	ts	3	16.35	0.41%
25	just·	5.27	26.35	3	15.81	0.40%	js	3	15.81	0.40%
26	for·	6.38	25.52	2	12.76	0.32%	4	3	19.14	0.48%
27	think·	4.14	24.84	4	16.56	0.42%	thk	3	12.42	0.31%
28	them·	4.94	24.70	3	14.82	0.37%	tm	3	14.82	0.37%
29	all·	6.13	24.52	2	12.26	0.31%	al·	1	6.13	0.15%
30	that's·	4.05	28.35	5	20.25	0.51%	ths	4	16.2	0.41%
31	we·	7.7	23.10	1	7.7	0.19%	n·	1	7.7	0.19%
32	with·	4.5	22.50	3	13.5	0.34%	j·	3	13.5	0.34%
33	about·	3.74	22.44	4	14.96	0.38%	ab·	3	11.22	0.28%
34	they're·	2.67	21.36	6	16.02	0.40%	[illegible]	4	10 68	0 27%
35	yeah·	4 24	21.20	3	12.72	0.32%	ye·	2	8 48	0 21%
36	is·	6.9	20 70	1	6.9	0.17%	8	·2	13.8	0.35%
37	on·	6.84	20.52	1	6.84	0.17%	6	2	13.68	0.35%
38	going·	3 42	20.52	4	13.68	0.35%	gg	4	13 68	0.35%
39	get·	5.01	20.04	2	10.02	0.25%	gt·	1	5.01	0.13%
40	out·	4.98	19.92	2	9.96	0.25%	ot·	1	4.98	0.13%
41	then·	3.98	19.90	3	11.94	0.30%	tn	3	11.94	0.30%
42	people·	2.76	19 32	5	13.8	0.35%	pp	5	13 8	0.35%
43	something·	1.92	19 20	8	15.36	0.39%	sg	8	15.36	0.39%
44	when·	3 82	19.10	3	11.46	0.29%	wn	3	11.46	0.29%
45	had·	4.72	18 88	2	9.44	0.24%	hd	2	9.44	0.24%
46	what·	3.76	18.80	3	11.28	0.28%	wt·	2	7.52	0.19%
47	one·	4.61	18.44	2	9.22	0.23%	L	2	9.22	0.23%
48	got·	4.33	17.32	2	8.66	0.22%	gt	2	8.66	0.22%
49	my·	5.68	17.04	1	5.68	0.14%	m·	1	5.68	0.14%
50	really·	2.38	16 66	5	11.9	0.30%	rly	4	9.52	0 24%
[illegible]	[illegible]	[illegible]	[illegible]	3	9.72	[illegible]	[illegible]	3	9.72	0.25%
197	find·	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0 10%
198	job·	0 77	3 08	2	1.54	0.04%	jb	4	[illegible]	[illegible]
199	us·	1.02	3 06	1	1.02	0 03%	us·	0	0	0.00%
200	own·	0 71	2 84	2	1.42	0.04%	own	1	0.71	0.02%
	AVERAGE			3 21	10 02	0 25%		2 81	8 74	0 22%
	TOTAL			641.00	2003 87	50.59%		561 00	1748 32	44 14%
5	Letters per Word									

		Alphabetic Optimized (idio-logical)				Truncation (fixed vocab prediction)			
Ref #	Word	Abv	Keystrokes Saved for This Word	Keystrokes Saved per 1000 Wds	% of Keystrokes Eliminated	Abv	Keystrokes Saved for This Word	Keystrokes Saved per 1000 Wds	% of Keystrokes Eliminated
1	the·	t	2	81.04	2 05%	t*	2	81.04	2 05%
2	and·	a	3	113 88	2.88%	a*	2	75 92	1.92%
3	I·	I·	1	40.09	1.01%	i*	1	40 09	1.01%
4	that	tt	3	45.72	1 15%	th*	2	30 48	0.77%
5	to	to	0	0	0.00%	to*	C	0	0.00%
6	you·	u	2	37.8	0.95%	y*	2	37.8	0 95%
7	they·	ty	3	44.61	1.13%	the*	1	14.87	0.38%
8	of·	f·	1	17.59	0.44%	o*	1	17.59	0.44%
9	it·	it	0	0	0.00%	it*	0	0	0.00%
10	in·	in·	0	0	0.00%	in*	0	0	0.00%
11	know·	k·	3	30 09	0.76%	k*	3	30 09	0.76%
12	a·	a·	0	0	0.00%	a·	0	0	0.00%
13	was·	wz	2	21.82	0.55%	w*	2	21 82	0.55%
14	well·	w·	3	25.29	0.64%	we*	2	16 86	0.43%
15	have·	v·	3	24.51	0.62%	h*	3	24.51	0.62%
16	there·	th·	3	20.22	0.51%	ther*	1	6.74	0.17%
17	but·	b·	2	19.48	0.49%	b*	2	19 48	0 49%
18	don't·	[illegible]	4	24.16	0.61%	d*	4	24.16	0.61%
19	he·	h·	1	10 03	0.25%	he·	0	0	0.00%
20	it's·	its	2	14.92	0.38%	it *	1	7.46	0.19%
21	because·	bc	6	21.9	0.55%	bc	6	21.9	0 55%
22	so·	s·	1	9.4	0.24%	s*	1	9.4	0.24%
23	like·	lk	3	16.41	0.41%	l*	3	16.41	0.41%
24	this·	ts	3	16.35	0.41%	thi*	1	5.45	0.14%
25	just·	js	3	15.81	0.40%	j*	3	15.81	0.40%
26	for·	fr·	1	6.38	0.16%	f*	2	12.76	0.32%
27	think·	thk	3	12.42	0.31%	thin*	1	4 14	0.10%
28	them·	tm	3	14.82	0.37%	them*	0	0	0.00%
29	all·	al·	1	6.13	0.15%	al*	1	6.13	0.15%
30	that's·	ths	4	16.2	0.41%	tha*	3	12.15	0.31%
31	we·	we·	0	0	0.00%	we·	0	0	0.00%
32	with·	j·	3	13 5	0.34%	wi*	2	9	0.23%
33	about·	ab·	3	11 22	0 28%	ab*	3	11.22	0.28%
34	they're·	[illegible]	4	10 68	0 27%	they*	3	8 01	0 20%
35	yeah·	ye	2	8.48	0.21%	ye*	2	8.48	0.21%
36	is·	is·	0	0	0 00%	is*	0	0	0.00%
37	on·	on	1	6.84	0.17%	on*	0	0	0 00%
38	going·	gg	4	13.68	0.35%	g*	4	13 68	0.35%
39	get·	gt	4	10.02	0.25%	gt	2	10 02	0.25%
40	out·	ot·	1	4.98	0.13%	ou*	1	4.98	0.13%
41	then·	tn	3	11.94	0.30%	then*	0	0	0.00%
42	people·	pp	5	13.8	0.35%	p*	5	13 8	0.35%
43	something·	sg	8	15 36	0.39%	so*	7	13 44	0.34%
44	when·	wn	3	11.46	0.29%	wh*	2	7 64	0.19%
45	had·	hd	2	9.44	0.24%	hd	2	9.44	0.24%
46	what·	wt	2	7.52	0.19%	wha*	1	3 76	0.09%
47	one·	1	2	9.22	0.23%	one·	0	0	0.00%
48	got·	go	2	8 66	0.22%	go*	1	4.33	0.11%
49	my·	m	1	5 68	0.14%	m*	1	5.68	0 14%
50	really·	rly	4	9 52	0 24%	r*	5	11.9	0 30%
[illegible]	[illegible]	dt	3	9.72	0 25%	do*	2	6 48	0 16%
197	find·	ss	1	3 96	0 10%	sh*	1	3.96	0.10%
198	job·	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	7.92	0 20%
199	us·	us	0	0	[illegible]	[illegible]			
200	own·	own	1	0 71	0.02%	ow*	1	0 71	0 02%
	AVERAGE		2 68	7 36	0.19%		1 75	5 18	0.13%
	TOTAL		536 00	1472.38	37 18%		350 00	1035 59	26 15%

top of the keyboard to be used for the most commonly used words. The existence of the re-abbreviate key allows these keys to be assigned to these most frequently used words so that a single keystroke would call up these words. This can yield a significant increase in efficiency, since the 10 most frequently used words account for more than a fifth of the total words that were used, and more than a tenth of the keystrokes in normal conversation (Table 2). Although the number keys would normally be used for typing these high frequency words, the re-abbreviate key still allows the numbers to be accessed. For example, to type a number (e.g., "1956"), one would hit the "1" key (which would cause a word to appear), followed by the reabbreviate key (to collapse it back to a "1") and then type the "9," "5," and "6" keys. This would add one keystroke to the typing of any number (which is infrequently done), and removes one keystroke from the abbreviation for the top 10 words (or 15 words, if the nearby symbol keys are used) each time these highly frequent words are used. The use of this capability with the 10 highest-frequency words alone would increase an individual's communication rate by 12 to 15%, and would increase the efficiency of an abbreviation expansion routine by about 4% absolute (over using 2-letter codes).

Relationship of Prediction Techniques to Abbreviation Expansion Approaches

Prediction techniques are techniques where the communication aid, based upon past events, tries to predict what the individual's next selection (letter or word) is likely to be. There are many different types of prediction techniques. They vary both in terms of what they use as input data on which to base their predictions and what they predict.

In addition to varying the type of data they use for input and output, prediction techniques can either be fixed or dynamic. Fixed prediction algorithms always make the same prediction for the same input. For example, if the individual types "TH," fixed prediction techniques would always guess that the word would be "THE" when the "T" was typed and would guess "THAT" when the "H" was typed. If the individual then typed an "A," the techniques would always guess that it will be "THAN," etc. Fixed prediction algorithms have the advantage that, once the individual gets used to the algorithm, he can anticipate (or predict) what the prediction will be. Thus, the individual can type "TH" and then hit the "YES" key (to accept the prediction) without even having to look up to see that the algorithm has predicted the word "THAT." The system would always predict the word "THAT" for the characters "TH," and the individual can be certain of this.

Dynamic prediction algorithms. on the other hand, continually update and change their predictions based upon the recent history of word usage by the individual. Dynamic systems have the advantage that the predictions would theoretically be more efficient, since they are based upon the individual's actual usage. They have the disadvantage that the user cannot ever predict in advance exactly what the device will offer as a prediction. It may offer the word "WHEN" 30 times in a row as a prediction for "WH," and then suddenly change the prediction to "WHAT." It may then continue to predict the word "WHAT," or switch back to the word "WHEN" the next time "WH" is typed depending on which words the individual has used recently. As a result, the individual must always check after each keystroke (or after each word, depending on the algorithm) to see what the prediction is before proceeding with the next selection. Depending upon the individual's speed in making selections, the way the predictions are presented, the location of the prediction display, and the prediction algorithm, the time lost in checking the predictions may be more than the time saved by not having to spell the entire word.

It can be argued that only dynamic prediction techniques are truly predictive techniques. Fixed prediction techniques are really only cued abbreviation expansion techniques. That is, each word is paired with a unique, fixed sequence of selections which will cause it to be displayed and selected. Although the user can watch the screen where the various words are presented, the user can also just remember the sequence of movements and call the word up and select it without ever looking at the prediction display.

This observation is important, since if fixed prediction is in fact a cued abbreviation expansion technique, it can often be made more effective and efficient by viewing it from this perspective. First, the theoretical maximum efficiency of this fixed-vocabulary prediction technique would be the same as that of the truncation algorithm discussed (and analyzed) earlier. That is, the fastest an individual could go using the fixed-vocabulary prediction technique would be when they knew the predictions so well that they did not need to look at the prediction display. As can be seen from Table 2 and Figure 5, this maximum rate would still fall short of an abbreviation expansion rate. Adding the cognitive and perceptual delays inherent in a display-based prediction technique, the efficiency would be even less. Thus, the only benefit of using a prediction technique over an abbreviation technique would be the elimination of the need to remember the codes.

A Hybrid System

In order to take advantage of (a) the strengths of the fixed, short, reflex-based abbreviation expansion technique with the short high frequency words and (b) the strengths of the cued abbreviation or prediction techniques, with the large number of seldom used words, a hybrid approach may be appropriate for many clients. Such an approach would use fixed, 1-, or 2-keystroke abbreviations for the most frequently used words. Fifty words encoded in this fashion would be fairly easy to learn and would provide the individual with the maximum speed possible for these most frequently used words which account for approximately 50% of the words, or 39% of the keystrokes in normal conversation and writing. For words beyond the first 50 (or perhaps 100), a cued abbreviation and/or prediction technique could be used. With this technique, the individual would begin to spell the word, and have the device cue him with predictions or shorter methods for achieving their desired word. In all cases, the individual could simply spell out the word if he felt that was more convenient.

The exact transition points for moving between one technique and another would be a function of the individual's selection speed, reorientation time, perception rate, etc. For individuals with extremely slow selection time, it may be that prediction software would be appropriate even at a point less than 50 words. For individuals with faster reaction times, a cued but fixed abbreviation scheme may be the most appropriate technique to use for words 50 to 500. This would allow the individual either to use the cuing or to rely on memory for words, but it would obviate the need to pay attention to the cues over time.

In any case, it is clear that a specific technique or approach is not appropriate for all individuals. It also appears that even for a given individual, the optimum system may consist of multiple strategies, in the same way we use multiple strategies in writing and/or making notes for ourselves.

Conclusion

Although various abbreviation-expansion strategies exist, including variable length fixed terminator, variable length auto terminator, numeric terminator, expand key, and macro key approaches, all can be implemented on a generic, variable-length, self-terminating abbreviation-expansion algorithm. With any chosen approach, it is also possible to choose from different abbreviation strategies such as contraction, arbitrary, or idiosyncratic-logical (user-selected) abbreviations. Of these, the arbitrary has the potential for the greatest motor efficiency. This motor efficiency, however, is marginal as compared to the idiosyncratic-logical, and therefore has little merit in practice. The difference between the idiosyncratic-logical and truncation approaches, however, is substantial. Further, the problem with collisions using the truncation approach results in long abbreviations which in some cases are as long as the words they represent. As a result, the idiosyncratic-logical abbreviation approach can be very effective, particularly when used with the shorter, higher-frequency words which make up most of our communication. For words beyond the first 50, 100, or 200, however, memorizing abbreviations may be a problem, even over the long term. In these cases, a cued abbreviation-expansion technique may be most effective. Probably the least cognitively difficult of these would be a cued abbreviation-expansion technique using truncation codes for the abbreviations. Such a technique would look like and behave identically to a fixed-vocabulary word prediction technique. Either single words or multiple expansions (predictions) could be displayed in this fashion. Because of the relative strengths of both of these techniques, the most effective and appropriate approach may be a hybrid of the techniques, with the idiosyncratic-logical approach being used for the shorter, most frequently used words and a cued truncation abbreviation-expansion approach (fixed prediction) for the lower frequency words.

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