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A Technical Note

Effectiveness of a writing system using a Computerized Long-Range Optical Pointer and 10-Branch Abbreviation Expansion

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Abstract—Many individuals with limited abilities require specialized technological writing systems. These individuals and the clinicians and engineers who work with them need information regarding the effectiveness of various systems. This study developed a methodology for assessing the effectiveness of a technological writing support system and evaluated its success. The Long-Range Optical Pointer and 10-Branch Abbreviation Expansion System developed at the Trace R&D Center at the University of Wisconsin was used. The study applied a single subject research design: a series of AB replications with naturally-occurring baselines comparing data within subjects across behavior, and across subjects. Behaviors assessed included typing rate, efficiency, and accuracy. The results demonstrate the effectiveness of this system with four individuals with severe physical disabilities and one able-bodied person. Among the data collected, typing rates were found to range from 3 to 15 words per minute, with suspected dependency on familiarity with the system. Discussion highlights the potential benefits of this system and the critical requirement to individually assess a person's needs in order to appropriately select and prescribe these types of technology. The need for further application-oriented single-subject research as well as classical human factors research is emphasized.

Key words: *writing systems, abbreviation expansion, word acceleration, alternate input, keyboard emulation, physical disability, spinal cord injury.*

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BACKGROUND

Many individuals with severe physical disabilities are unable to write or can only write very slowly. Persons with high level quadriplegia, for example, may lack upper extremity function and the ability to use a standard keyboard. Therefore, they must access the keyboard with a single switch input system, a mouthstick, or a headwand. These access methods can be extremely slow or dependent on good head and neck motor speed and range of motion. Consequently, many severely disabled individuals do not have access to a satisfactory writing system. This inefficiency can limit persons with severe disability from normal involvement in competitive educational and employment activities.

Numerous communication systems are available for individuals who are nonvocal (1,2). A major problem is that many are not writing systems. They provide no method of saving and recalling information at a later time because their output is primarily audio/vocal. Other systems which have a printing capability neglect very important qualities of an effective writing system. An effective writing system should be fast; should be able to change or correct text, should be able to reorganize the text; should be portable; should be accessible from various viewing positions; and should enable "free-hand" drawing (13).

In acknowledgment of these requirements, the Trace R&D Center at the University of Wisconsin-Madison developed a long-range optical pointer and

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a 10-branch abbreviation expansion computer program (LROP/10-Branch) (7,8) to incorporate most of these features. The LROP component of the system produces a picture of a typing keyboard on the computer monitor. By focusing a dot from a small flashlight-like pen on the "keys," the keys are activated from a distance. This permits standard and transparent keyboard access for persons with limited range of motion, from any position within reading range of the computer monitors. In the implementation described in this study, a two-monitor version was used. The monitor keyboard was displayed on one screen, and the word processing application on the second. One-screen versions are now available (11,12,14).

The 10-Branch software applies encoding and acceleration techniques which, as described by Gunderson (5), can increase the rate of selecting vocabulary. This component further increases the capability of the system. It is designed to be operated while running standard word processing software and or other standard applications which are character-based.

The 10-Branch abbreviation expansion function is a cued procedure. It applies standard abbreviation expansion concepts with the addition of a constant visual presentation of an expanded word menu to decrease stress on verbal memory. For example, following the "typing" of the letter "R", the computer presents a menu of the most commonly used words beginning with the letter "R" on the upper half of the monitor. Alternately, other words or phrases can be individually programmed for the menu. Selecting the code number (ranging from 0 to 9; hence 10-Branch) for the desired word or phrase with the light pen then selects the complete word or phrase. Use of the system results in a fewer number of input keystrokes in ratio to the number of output

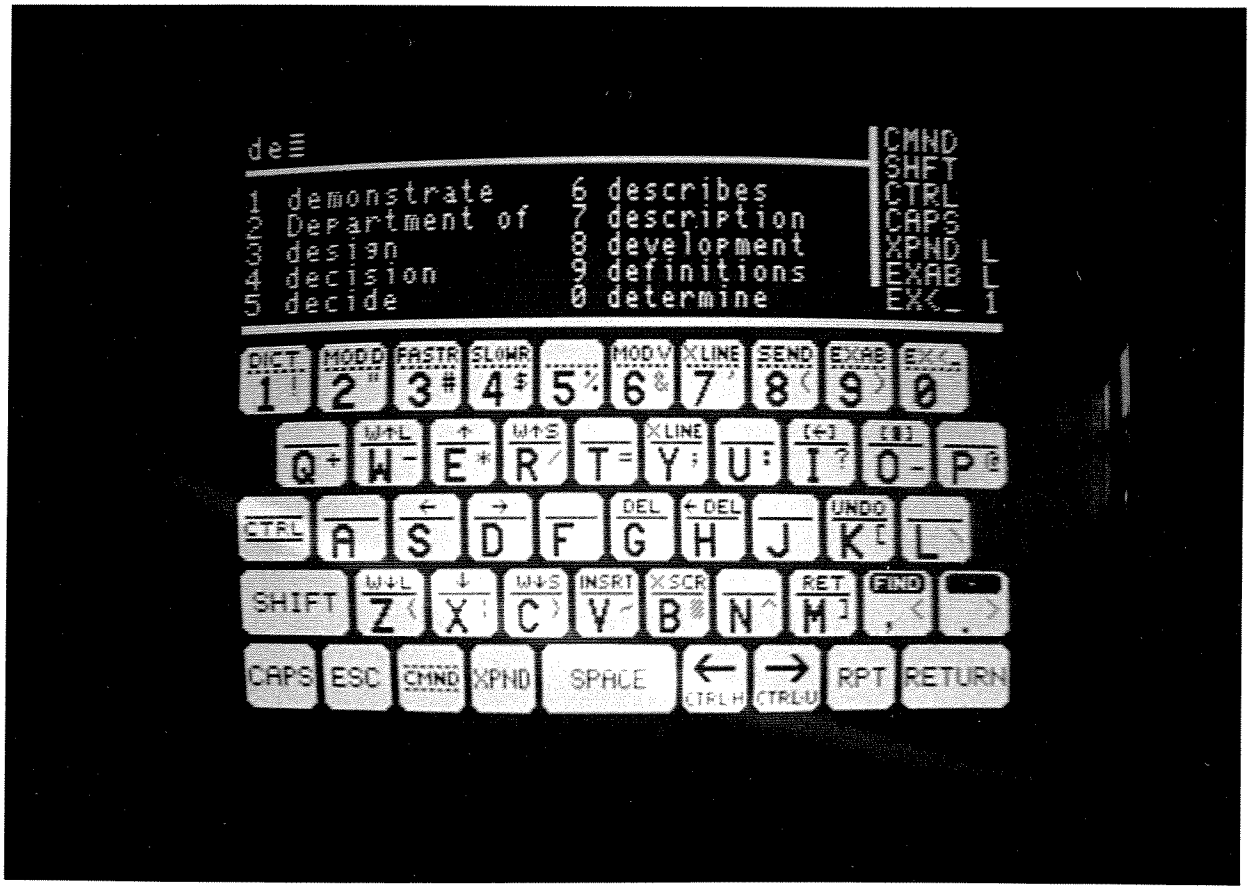


Figure 1.
The LROP/10 Branch display with a "DE" branching menu.

keystrokes. Pointing to the letter "R", selecting "Rehabilitation Medicine," and then the "RETURN" key would require 3 input keystrokes and produce 26 output keystrokes. (In the event that "Rehabilitation Medicine" did not fall under the first menu of 10, the person might type in an "E," displaying the "RE" words: or even one more letter, "H," to access "REH" words. "Rehabilitation Medicine" might more likely be in the third branch. If so, this would have required 5 keystrokes.) **Figure 1** shows the display with a "DE" branching menu.

Besides aiming to increase writing speed and efficiency, the 10-Branch system provides more legible and accurate spelling of words than other writing systems. Compared to handwriting, its computer printout of text is more legible. In contrast with a typewriter, the abbreviation expansion has the unique feature of having correctly-spelled words stored in its abbreviation memory.

THE PROBLEM

The problem is that, while the LROP/10-Branch system seems to have the above-described attributes as a writing system, the actual success of the system has not been empirically documented. Neither descriptive case study nor quantitative information has been published from which to compare its functionality with that of other systems. The purpose of the study was to objectively assess the efficacy of this particular computerized optical pointer and abbreviation expansion system with severely motor-impaired individuals. Its rate of writing, its efficiency, and its accuracy were targeted as qualities for this examination of its functionality.

METHOD

Research design

To investigate the effectiveness of the LROP and 10-Branch abbreviation computer system, an individualized approach was required because of the wide variance in the use of writing systems among severely physically disabled individuals. A design was needed that could describe specific situational needs of individuals and their interaction with this type of writing system. Ottenbacher (9) and Ottenbacher, Johnson, and Hojem (10) have described a variety of designs for gathering and interpreting data as to their clinical significance in therapeutic interventions. Single subject designs applying a series of AB replications have been implemented and are suggested for similar design situations. This type of format, with its naturally occurring multiple baselines, was selected for this study. The naturally occurring baseline comprised Phase A, and the intervention Phase B. These were repeated with subjects, starting at different points in time. Baseline and intervention data were then compared within subjects across behaviors and across subjects.

Subjects

Five adult volunteers comprised the subject population. Four were recruited by telephone from a list of physically disabled individuals in the community known to have needs in writing systems. The fifth subject was able-bodied.

Subject #1 was a 23-year-old spinal cord injured young man with an incomplete C2-3 injury. He was two-and-one-half years post-injury at the time of the study. This subject had no upper extremity function and was nonvocal. Premorbid writing experience included printing and writing, but no typing skills. He was not using any writing system at the time the study was initiated.

Subject #2 was a 53-year-old man, 25 years post-spinal cord injury at the level of C2-3. He had no upper extremity function, fused cervical vertebrae, used a respirator with an external exhalation belt, and vocally communicated proficiently. Dictation transcription was his only current writing system. He was not using any independent writing system.

Subject #3 was a 38-year-old man post-polio. He had no upper extremity function, but excellent head, neck, and trunk motion. He had been using a mouthstick with an electric typewriter as a writing system for many years prior to the study. At the time of the study, he was enrolled as a university student.

Subject #4 was a 40-year-old man 4 years post-spinal cord injury at the C3-4 level. He had no upper extremity function and dictation transcription served as his primary nonelectronic writing system. This subject owned the computerized equipment applied in the study and had become familiar with

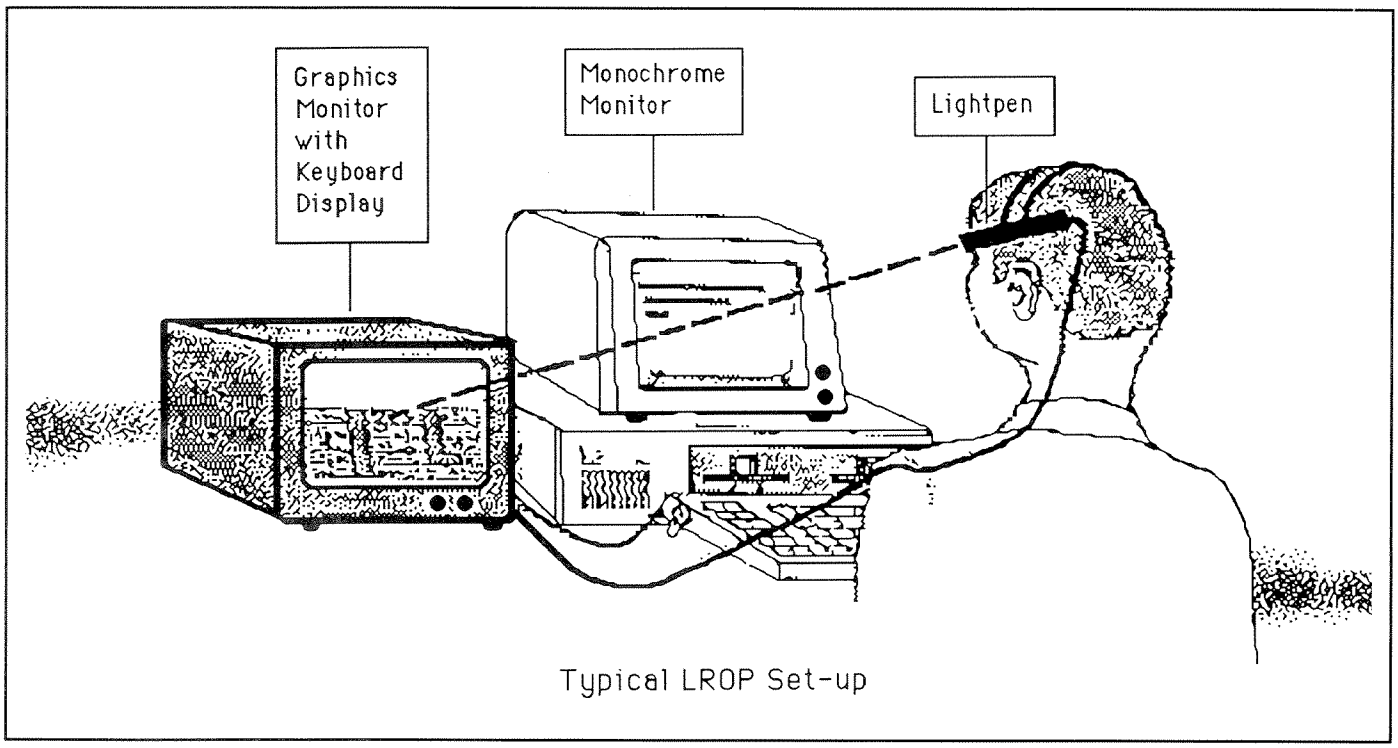


Figure 2.
Typical LROP set-up.

its application over the previous year.

Subject #5 was a 45-year-old able-bodied man with some typing experience and vocation as a university professor.

Instrumentation

The instrumentation used in this study incorporated the LROP and 10-Branch abbreviation format as designed by the Trace Center at the University of Wisconsin-Madison (6). The particular system in this study utilized an Apple IIe computer with disc drive, a Kaypro II, an Epson MX80 printer, and three 19-inch monochrome television monitors (although its standard platform available today is an IBM XT system). **(Figure 2)** Two of the monitors were installed as an additional input system above the bed of Subject #4 to allow use of the equipment while supine in bed. Two of the subjects attached the LROP to their eyeglasses with sticky-back velcro on the sides of the ear pieces. One subject utilized the LROP by attaching the pointer to a specially constructed acrylic dental plate, which allowed the subject to grip the pointer in his mouth and aim using jaw motion. One subject used a headband with velcro to hold the pointer. The able-bodied subject held the pointer in his hand. Each method of holding the pointer was individualized to allow maximal motor control for the individual. Subject #3 also used a personal mouthstick system consisting of a thin wooden dowel with a pencil eraser attachment. This subject typed on an IBM Selectric typewriter.

Procedures

The body of a common letter requesting more information from the manufacturer of a communication device was selected as the text for this study. Approximately 80 percent of the words were programmed into the 10-Branch abbreviation expansion memory to mimic the vocabulary likely to be programmed during this type of application.

Subjects were instructed to "write" as much of the text letter as they could within the 3- to 5-minute time span allocated. These times then remained constant across trials for each subject.

Subjects performed this writing task first with-

out the use of the LROP/10-Branch abbreviation system and then with the system.

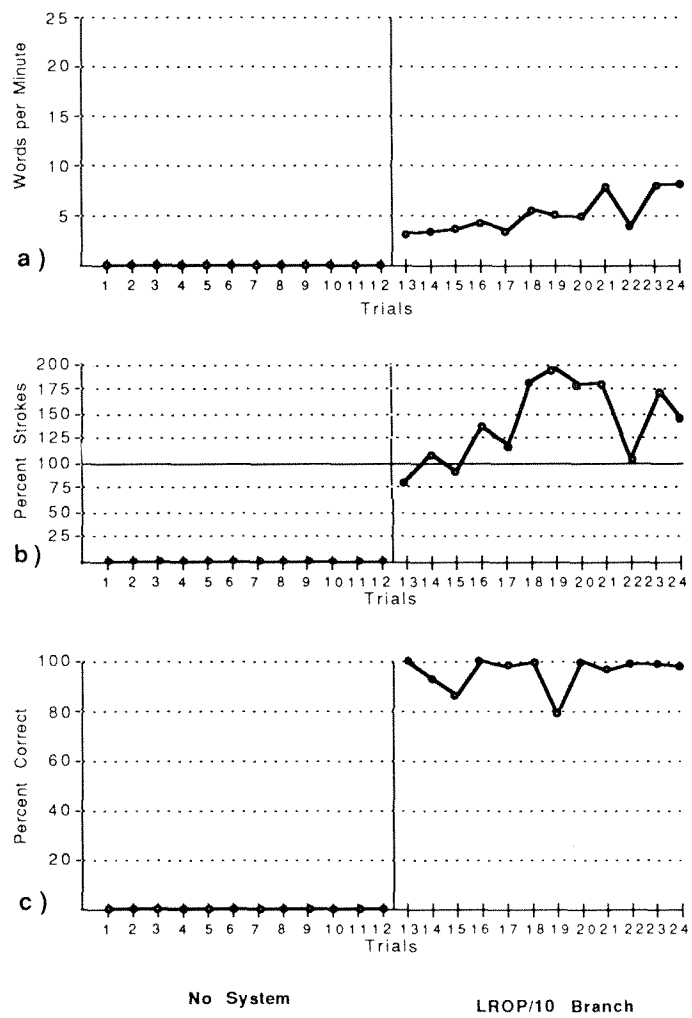
The writing trials were all performed with subjects in the seated position except for Subject #4, who used the computer system while supine in bed. For all subjects, other than the individual who owned the system, training sessions to learn how to use the LROP with 10-Branch abbreviation system were limited to reviewing the steps of running the system, an explanation of the logic behind the 10-Branch abbreviation expansion, and less than six informal trials with verbal cues as necessary to assist the subjects in becoming comfortable with the mechanics of the system. Rest periods, due to limited endurance, were permitted as necessary for the subjects between trials.

Data collection sessions were scheduled over a period of 2 months. Writing trials were all performed during single sessions except in the case of Subject #4. In this case, after a 9-week period a second set of AB phases was added, resulting in an ABAB design for this subject. Since this subject had been acquainted with this writing system for many months, it was believed that a second AB data set would provide additional information regarding learning curve. The general question was whether this subject's skills had plateaued or whether improvements were still being made.

Dependent Measures

Data on quantity of input strokes, actual output strokes, number of characters written, number of characters written correctly, and words written were collected for each subject. Input strokes during use of the LROP were obtained by counting the "beeps" emitted by the Apple IIe for each action entered. Other data were obtained by counts from the hard copy printed or typed during the trials.

Data were integrated into three scores: speed, efficiency, and accuracy. Speed was documented in words per minute by dividing the total number of printed five character sets by the trial length in minutes. Efficiency was determined by dividing the number of output strokes by the number of input strokes, resulting in percentage stroke efficiency. Accuracy was computed in percent by dividing the number of characters correct by the total number of characters printed.



Figures 3a, b, and c.
Speed, efficiency, and accuracy data for Subject #1.

RESULTS

Within Subjects

Subject #1 had a baseline set of behaviors at zero. He had no method of writing available to him. Upon the introduction of the LROP with 10-Branch system, he was able to "write" approximately five words per minute with his rate increasing over trials (**Figure 3a**). One hundred percent efficiency would indicate that he had no effective use of the 10-Branch abbreviation capabilities of the system. As **Figure 3b** demonstrates, he accessed the abbreviation expansion frequently and consistently over the 100 percent efficiency level after initial practice

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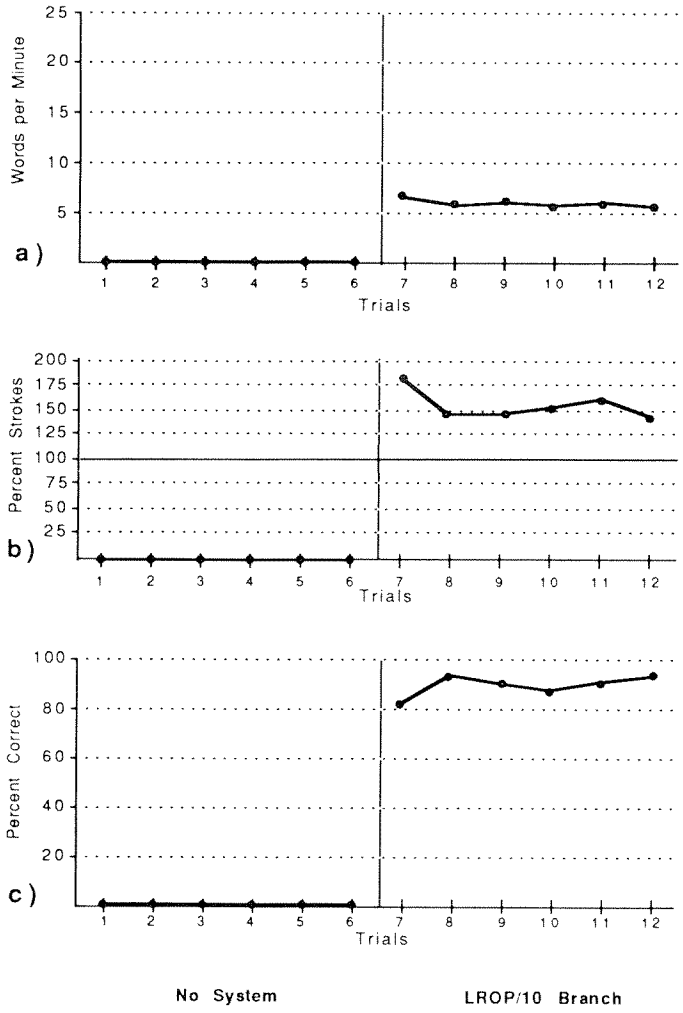
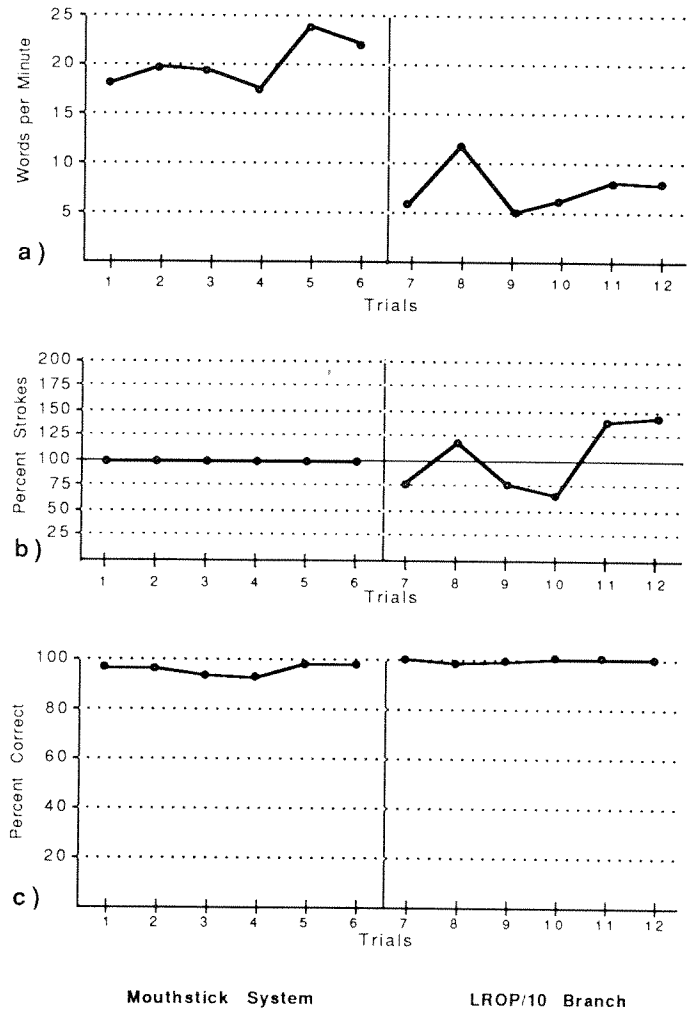


Figures 4a, b, and c.
Speed, efficiency, and accuracy data for Subject #2.



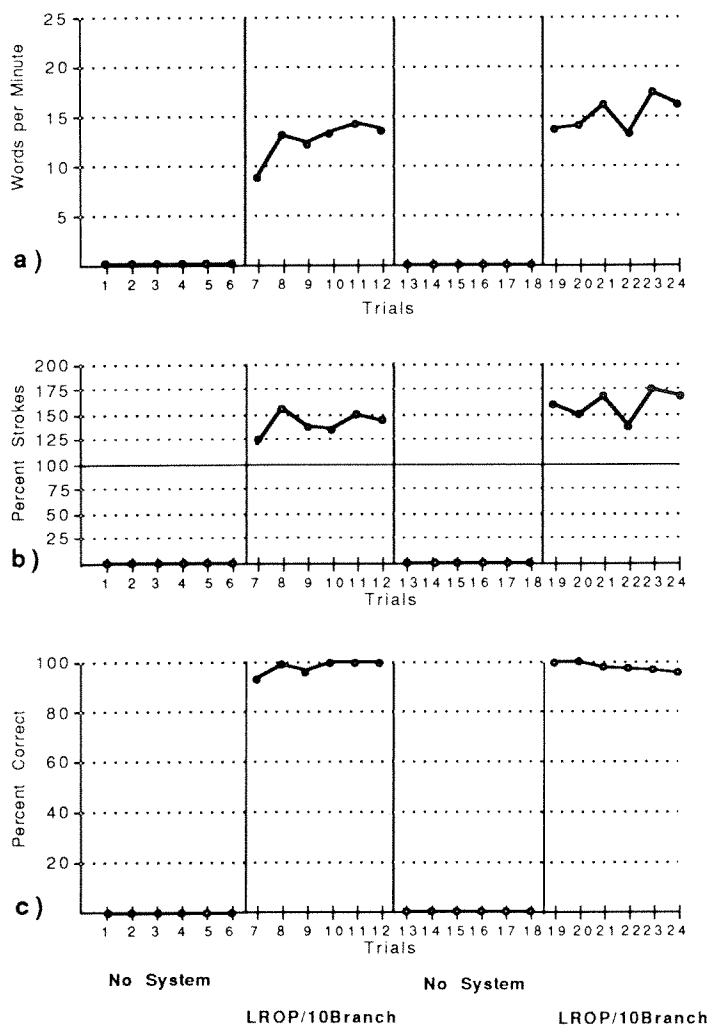
Figures 5a, b, and c.
Speed, efficiency, and accuracy data for Subject #3.

trials. **Figure 3c** shows his accuracy to be primarily above 90 percent while using the computerized system.

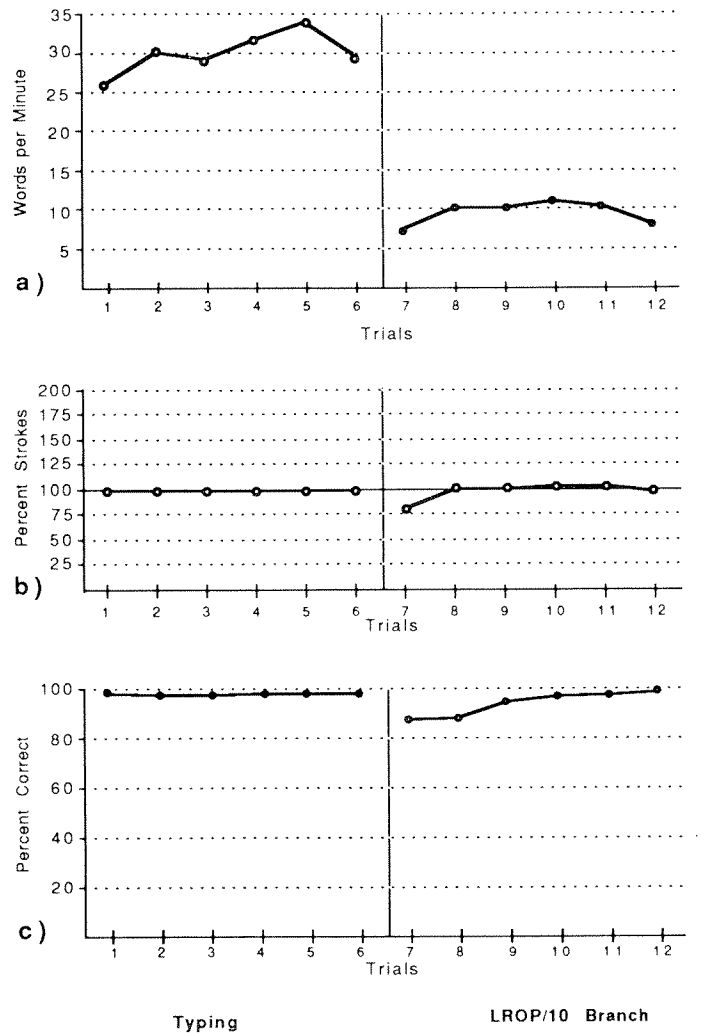
Subject #2 also had a baseline set of behaviors at zero. With the LROP and 10-Branch system, he could "write" about six words per minute (**Figure 4a**). His efficiency was approximately 150 percent (**Figure 4b**). At this level of efficiency, he would obtain one and one-half strokes for every single input stroke. This would functionally translate to printing a whole page by typing two-thirds of a page. His accuracy ran around 90 percent (**Figure 4c**). This indicates approximately one out of ten characters were errors.

Subject #3 used his own mouthstick system to collect baseline data. His typing speed ranged from 17 to 24 words per minute. When using the LROP with 10-Branch abbreviation system, his speed dropped to a range of 5-12 words per minute (**Figure 5a**). Efficiency using a mouthstick is a one stroke in to one stroke out ratio or 100 percent efficient. When using the LROP system, his efficiency made no gains in spite of the potential of the system (**Figure 5b**). Subject #3's accuracy scores for the baseline mouthstick system all resulted above 93 percent. Accuracy scores with the LROP system resulted above 97 percent and with three 100 percent scores. The subject exhibited a high degree of accuracy with both systems (**Figure 5c**).

Subject #4 had a baseline set of behaviors at



Figures 6a, b, and c.
Speed, efficiency, and accuracy data for Subject #4.



Figures 7a, b, and c.
Speed, efficiency, and accuracy data for Subject #5.

zero with a repeat of the baseline behaviors at zero in the second AB series. He averaged 12.5 words per minute during the first B phase and 14.8 words per minute during the second B phase (**Figure 6a**). Efficiency in both B phases achieved over 125 percent for all trials and averaged more than 150 percent in the second B phase (**Figure 6b**). With the exception of the first data point in the first B phase, accuracy scores all placed above 96 percent (**Figure 6c**). Some improvement was noted between B phases in speed and efficiency. Minimal degradation in accuracy was observed.

Subject #5, who had no physical disabilities, had a baseline showing a range of 26 to 34 words per minute. Efficiency was at 100 percent using a typewriter and accuracy seemed fairly level at 98-99 percent (**Figures 7a-c**).

Between Subjects

Data sets across subjects were regraphed for each speed, efficiency and accuracy behavior so they could be viewed together. Data included were from each subject's initial six trials while using the LROP/10-Branch system. (Design phases for Subjects #1 and #4 constituted 12 trials, so for consistency in combining graphs, only the first 6 trails were included.) This provided summaries between subjects.

The graph of speed scores using the LROP/10-Branch system highlights the variance of rates

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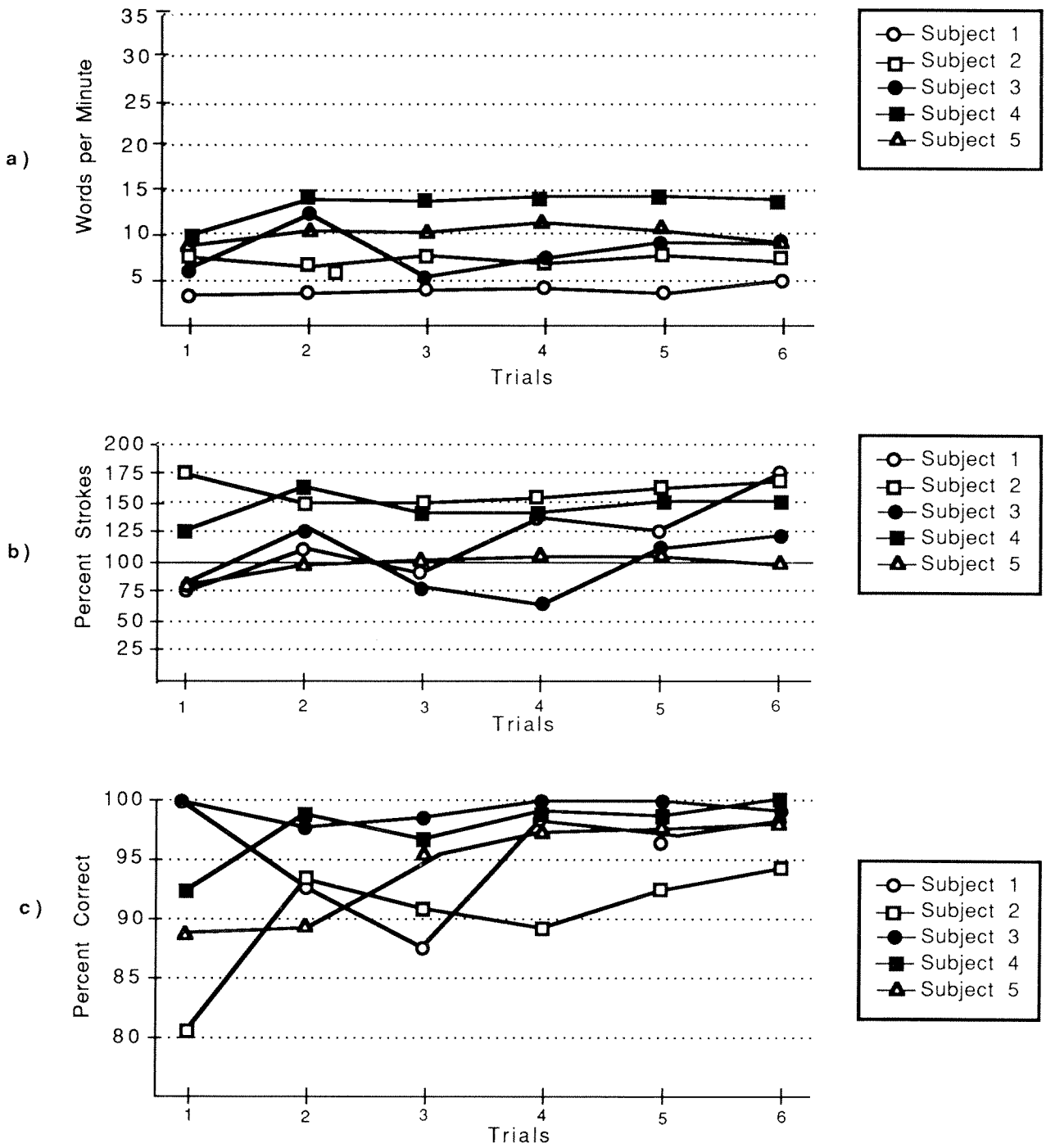

Figures 8a, b, and c.
Composite graphs showing performance by all 5 subjects using the LROP/10-Branch System.

between subjects (**Figure 8a**). It is clear that Subject #4, who was the most acquainted with the system, performed the writing tasks at the fastest rate. Subject #2 scored highest with efficiency scores, indicating that he most effectively applied the 10-Branch abbreviation expansion capabilities of the system, but scored low on rate, suggesting a significant possible interaction (**Figure 8b**). Accuracy scores also revealed high scores from Subject #4, but not highest. Subject #2 scored highest in efficiency, but much lower in speed and accuracy. Again, some interaction is suggested (**Figure 8c**).

Data from the fifth subject was re-examined at this stage. Comparing able-bodied data with that of persons with severe physical disabilities shows that scores from the able-bodied individual scores fell among the performance levels from the physically disabled data sets).

DISCUSSION

The computerized writing system consisted of two major functional components: the LROP, which provided the physical interface between the subjects and the computer, and the 10-Branch abbreviation expansion, which provided the acceleration potential of the word processing. Discussion comments on these two components and their combined use.

It was apparent that the total system provided a method of writing for the subjects who had no independent system available. Although the rate did not achieve the normal writing or typing speed of able-bodied persons, it was clear that the 3-words-per-minute minimal achievement opened communication potentials.

The design of the study limits the ability to state how ultimately effective LROP/10-Branch users can become. The total time subjects used the system in this study was under 2 hours. Thus, the documented speed, accuracy, and efficiency of writing were achieved in a relatively short period of training and experience. Subject #4 demonstrated that experience with the system enabled a speed faster than 15 words per minute. Since this rate was not observed in the timed trials with other subjects, however, it may indicate that proficient use of the system may require a longer period of familiarization and practice. A *post hoc* review of the data, in fact, does suggest that during these brief data collection sessions, graded improvements over time did occur.

Unexpectedly, Subject #3, who had years of experience with his mouthstick system, significantly dropped his rate of writing when applying the LROP with 10-Branch system. This may be due to the more appropriate matching of his own mouthstick interface system to his particular capabilities and limitations. He did have substantial trunk, head, and neck function. It was noted that Subject #3 did not effectively use the 10-Branch abbreviation expansion part of the system. More extensive training may have had a significant impact on his use of this acceleration technique.

It was anticipated that the system would allow a high degree of accuracy due to the correct preprogrammed spellings in the abbreviation expansion memory; however, the study did not provide enough data to substantiate this concept. No data was collected to compare the percent accuracy of able-bodied persons as they commonly type or write

Table 1.
Subject #4. Dictation and LROP/10-Branch Comparison.

Trial	Type of System	Speed (words/minute)	Efficiency (output/input strokes)	Accuracy (correct characters)
1	LROP/10-Branch	8.2	160.5%	96.3%
2	LROP/10-Branch	7.7	145.4%	99.6%
3	Dictation	10.4	<50%	96.7%

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(although the 81 percent to 100 percent accuracy documented in this system may challenge some able-bodied accuracy rates). Subject #3 did provide some data, however, which suggests that the LROP/10-Branch system may permit equivalent or perhaps improved accuracy over typing systems. The LROP/10-Branch system performed somewhat more accurately than the mouthstick system. This seemed to be due to the easy correcting capabilities of the word processor as opposed to the noncorrectable use of the typewriter. Subject #3 also took more time and care to make corrections, which ultimately slowed down his typing rate as related earlier. It was also discovered that, whereas the abbreviation expansion spells correctly, the system inherently increases the potential of spelling entire words incorrectly by selecting the wrong number code abbreviation.

During the study, an additional data set was collected. It was not reported in the results because it was outside the scope of the original study design. However, its information is relevant and worth brief discussion here.

Subject #4, who owned the computerized system, used two writing systems in day-to-day function. He used the LROP/10-Branch and he dictated. Data were collected on speed, efficiency, and accuracy as he "wrote" an entire letter three times. With the first two trials, he used the LROP/10-Branch. With the third trial, he dictated the letter and had it transcribed. Results are charted in **Table 1**.

Words-per-minute in dictation were computed by totaling labor minutes, which included the time Subject #4 dictated, the time of the transcriptionist simultaneously recording the dictation, and the time of a professional typist typing the transcript. Dictation proved to be faster than the LROP/10-Branch system with this method. Most people, however, do not have access to a transcriber and professional typist, and consequently would likely have a decreased dictation rate. Additionally, any corrections needed would require several more steps and added time using dictation. Correction with the LROP/10-Branch would be immediate. Furthermore the speed formula did not include the time accessing a typist, which was a significant time delay.

Efficiency of the LROP/10-Branch was approximately 150 percent. Since the entire text was written and then typed in this dictation format, dictation efficiency was less than 50 percent. Accuracy was comparable between the computerized system and dictation.

For this individual, it seemed that the two systems were very similar in technical quality. Selection of either system in this situation could be dependent on access to a transcriptionist, a typist, the computerized system, the timeline required of the printed material, and the level of independence desired.

Several general observations were made during the data collection process of this study. The capability of using the system in an alternate position (supine) increased the writing time available to Subject #4. The advantage of not being dependent on a seated position for writing seemed significant. This system also used three large 19-inch monitors, which dramatically upstaged the one smaller monitor on the Kaypro II. Any use of the LROP should consider the ideal monitor size for the individual. To become familiar with the system, the subjects had to acquaint themselves with the interactive terminal and certain word processor concepts. This required a deliberate introduction to the system, which must be recognized by others attempting to use the system. It should also be noted that the 10-Branch abbreviation expansion must be programmed. The ten most common words or phrases for each letter code must be individually entered into the program. It is hoped that soon abbreviation expansion systems will automatically be programmed to construct the user's vocabulary from previously entered text and update as desired. The "expand" key was also in an awkward position (adjacent to the "Space Bar" key), which made it easy to inadvertently slip out of the abbreviation typing mode. This underscored the fact that a fair degree of motor control was necessary to operate the system even though limited range of motion was adequate.

Subjective statements by the subjects seem to support some of the basic concepts of this system, at least functionally. Following the study, two of the subjects asked to be set up with similar systems. Today, the three subjects with high spinal cord injury are using abbreviation expansion and long-range direct selection screen-based keyboard systems.

The data in this study raise many further research questions. The two-screen functioning of the system (where the keyboard and application screens are separated) adds an additional perceptual-

motor burden, as users need to point to the keyboard but observe the typing in another location. Comparative research will need to be performed between the two-screen and newer one-screen versions available. Also, rate, efficiency, and accuracy are interactive, as is the LROP input method and 10-Branch acceleration program. This study approached the system as a whole and did not tease out specific interactions. A spectrum of additional human factors studies are required to answer many of the component design issues. For example, when word acceleration is critical, what is the most effective abbreviation-expansion strategy? Is it 10-Branch or others? Are two-screen presentations actually significantly more problematic than one? Does efficiency even matter? Perhaps only rate and accuracy are critical. How fast, efficient, and accurate does a person need to be if functionality is the goal? What are the trade-offs between accuracy, rate, and efficiency? What balance is optimal for what situations?

Careful research into all of these questions is necessary, but extremely difficult. Writing systems tend to be available as functional units. The 10-Branch menu, for example, is displayed on the LROP ScreenKeys. Thus, investigating either 10-Branch or LROP ScreenKeys separately is somewhat artificial. Consequently, two types of ongoing research with writing systems are mandatory. Additional applied single subject designs that examine the efficacy of functional systems are needed, since these designs are best able to scrutinize individual differences of subjects and their particular response to techniques. Secondly, classical research designs must be implemented to investigate specific human factors.

Despite the need for more research, clinical decisions regarding the application of writing systems continue to be made. The LROP with 10-Branch abbreviation expansion writing system is part of a rapidly increasing and improving set of technological devices available to disabled individuals to help them increase their functional independence. Variations of these types of systems are currently commercially available. Number-based branching abbreviation-expansion exists in the ZYGO Notebook (15), EZ Keys (14) and MindReader (3). The latter two provide an active visual menu presentation. Long-range pointers with keyboards are available in ScreenTyper (11), ScreenKeys and OneScreen (14), and Freewheel (12). The system studied in this project seems appropriate for consideration by severely motor-impaired individuals. The LROP can provide direct selection access to a computer with only minimal range of motion required. The 10-Branch abbreviation expansion component can enable individuals to increase their writing rate. The data, however, also clearly show that these types of systems must be carefully prescribed following a full functional evaluation of the particular needs and capabilities of individuals. An individual with proficient use of a mouthstick, for example, may not benefit from this type of system. Clinically, it remains apparent that individually matching a person's needs to writing systems is crucial.

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