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An enhanced standard computer keyboard system for single-finger and typing-stick typing

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Abstract—A prototype keyboard system was developed, using off-the-shelf hardware and software, as an inexpensive keyboard-based system to facilitate data entry for single-finger and typing-stick typists. Evaluation established that the system can increase entry rate by 50 percent or more. The underlying concepts may provide a basis for developing other configurations that accelerate and simplify computer keyboard use for persons with a variety of hand impairments.

Key words: *computer keyboard system, hand impairments, macros, single-finger and typing-stick typing.*

INTRODUCTION

The high cost of many potentially useful high technology developments results in their being available to a very limited number of persons. Although many developments enable persons with disabilities to perform critical functions heretofore not possible (e.g., create written communication), their efficiency remains limited compared to the performance of individuals without disabilities. Consequently, where productivity is concerned, persons with disabilities are still left with a substantial handicap which may render them non-competitive. Thus, it is imperative that cost and efficiency be given priority in research and development activities.

The personal computer has evolved into one of the most useful high technology tools for persons with disabilities. It may now be considered a form of megaprosthesis. New uses are emerging daily in treatment, work, educational, and home settings, and considerable effort is being directed toward development of interfaces that enable persons with the spectrum of severe disabilities to benefit from these uses (3,4,8,17). However, the specially-designed and relatively costly input systems for persons with disabilities appear to be considerably less efficient than the standard computer keyboard being used by the typical nonimpaired, 2-handed touch typist. Thus, in word processing and other applications in which input speed is critical, the person with hand impairment may be functional, but is still left with a substantial disadvantage.

The importance of this problem is further underscored by a report published by the Office for Technology Assessment (13) which indicates that there are more than 2.5 million people in the United States with non-paralytic, upper-extremity impairment. When the number of people with impaired hand function stemming from high-level spinal cord injuries and other disabling paralysis is added to that group, there is an indication of the substantial number of people who are impeded in keyboard use.

Because of cost, availability, and related problems with special input devices, the most frequent approach to utilization of personal computers by hand-impaired individuals involves using a typing stick (either hand- or mouth-held), or single-finger

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entry on a standard keyboard. There is an obvious inefficiency in these approaches, although for most of those who are able to utilize the techniques, entry rates are probably competitive with those attainable with available alternative input systems. These problems prompted initiation of a project directed toward reconfiguring the standard keyboard input system to make it more efficient for single-finger and typing-stick typists, while containing cost within more affordable bounds.

This became feasible with the development of memory resident keyboard utility software (e.g., SuperKey[1]), which enables key reassignment without special costly hardware or hardware modification for IBM-PC's and compatible computers. Additionally, the widespread availability of low cost IBM-type computer keyboards contributes to the practicality of this approach to keyboard adaptation.

KEYBOARD DESIGN

Review of keyboard design-related research and observation of single-finger and typing-stick typists revealed 5 significant factors affecting keyboard use: a) the distance the finger or typing stick must travel; b) the speed at which the stick or finger can be moved; c) the time spent locating the keys to be pressed; d) interruptions evoked by the need to figure out how to expedite simultaneous keypress combinations; and, e) the number of key strokes required for some functions (6). These 5 factors provided the focus for reconfiguration efforts.

An IBM PC-type keyboard and keyboard utility software (SuperKey), having a combined cost of approximately $100, provided the basis for the system. SuperKey was most suitable for meeting the software needs of the project because of its low cost and its capacity to support a variety of keyboard input functions, including complete keyboard layout reassignment and alteration of simultaneous keypress commands to a sequential mode. A flattened "target-like" arrangement was used as the primary guideline for the key reorganization. Within this framework, previous research suggested clustering the most frequently used letters in the center, with others arranged in order of decreasing frequency toward the periphery (3). The logic of this approach rests on the concept of a "minimal distance" keyboard or scanning board configuration, which emanated from efforts to develop more efficient alternative input devices by limiting the distance the input medium must travel (4,10,11,17).

Additional effort was made to keep letters which frequently occur together in close proximity to each other in accordance with research findings (17). The work of Solso and Juel (15), and Solso and King (16) provided the usage frequency data required for reassignment of key position according to the minimal distance concept. Their data were derived from the Kucera and Francis assemblage of words, which comprise a corpus of more than a million words selected from written English prose (7). This is the largest sample constructed for language analysis and is relatively recent (2,14). The data derived from these works, and used in rearranging the keys, are contained in **Table 1** and **Figure 1**.

The key caps were physically removed from the keyboard and relocated to keep their character labels consistent with the changes. Based on the data, the most frequently occurring letter is E, and it was used as the center of the keyboard arrangement. Although it has been suggested that the space bar and ENTER key are actually the most frequently depressed (17), they were not reassigned to other locations. Because the space bar runs across almost the entire keyboard, and is in close proximity to several keys, there would be little accomplished by moving it. This assumption is supported by the work of others (6). The RETURN key was not included among those considered for movement, because appropriate frequency-of-use data was not found, and because the use of the RETURN or ENTER key is diminished by most word processing programs which now include "word wrapping" or automatic returns when the end of a line is reached.

Ultimately, the layout in **Figure 2** evolved. It can be seen that the letter E is actually located nearer the bottom center of the keyboard. Because there are 4 alphanumeric key rows, the alternative would have been to locate it somewhere in the upper center quadrant of the arrangement. This placement was tried, but most users preferred the lower position, and in fact, 2 suggested that near reaches in the bottom 2 rows were easier than far reaches. Consideration of this preference eventually led to the

[1]SuperKey is a product of Borland International, 4585 Scotts Valley Drive, Scotts Valley, CA 95066.

	E	T	O	A	I	N	S	R	H	L	D	C	U
E		57636	3861	26780	19057	77325	75885	139375	122849	50017	72459	37796	5593
T			56058	70665	82986	34716	51937	26698	138812	8130	127	15493	24658
O				2935	28342	75865	24377	71722	20040	26677	13805	32567	35591
A					21352	82189	43063	61307	37057	54323	21577	34575	8378
I						100018	60166	35926	31964	39218	27844	32212	4151
N							17103	6327	1377	2870	48547	13841	17952
S								15281	13453	7205	4713	5866	26849
R									3832	3989	10420	8943	22696
H										592	214	21256	2945
L											12440	5631	17035
D												88	7723
C													10730

	M	F	P	G	W	Y	B	V	K	X	J	Q	Z
E	42256	13895	22970	17358	18450	10152	22920	39318	10976	7477	1694	1638	2127
T	1121	3350	3106	713	2862	7883	605	6	67	1457	1		147
D	32778	57534	19894	8414	21801	7302	11415	9272	3290	593	2304	40	386
A	30368	8694	17573	12983	20897	10069	13941	11914	4899	1587	1269	59	1377
I	23651	17124	8090	15087	14837	1270	6822	17947	6022	1690	150	434	2759
N	1169	1944	228	39395	3598	4555	176	1603	4484	101	374	191	102
S	5925	642	8681	1997	2286	5018	1687	78	3528	3	3		20
R	7058	8849	16628	10627	1659	8786	4999	2218	3561	17	80		34
H	429	83	2999	9791	14883	1701	209	9	165	131	1	18	18
L	1276	4339	10176	2404	1044	17679	8914	1125	1574	20		15	123
D	614	72	32	1132	488	2366	142	612	42		227	67	
C	50	11	11		23	1478	24	1	6003	896			15
U	9138	4224	8832	8098	79	262	11193	170	159	292	2436	4913	142
M		160	8289	269	73	3036	3544	4	67	1			3
F			61	62	65	315	14		114	19	2		1
P				25	94	1020	26	3	61	2395	4		
G					19	632	38	1	79				10
W						340	74		151	13	1	2	6
Y							6048	204	418	84	2		163
B								214	42	2	626		7
V									2	1		1	9
K												17	11
X												7	
J													
Q													
Z													

Figure 1.
Combined forward and backward bigram frequencies.

placement of more alphabet keys at the bottom of the arrangement.

No usage data were available for the numeric, punctuation, and utility keys, but a review of several sample essays and other examples of general written communication in an English textbook suggested that numbers are used relatively infrequently and that the period, comma, quotation marks, and apostrophe are most common. The semicolon, colon, hyphen, and question mark seem to fall in between. This cursory study provided the basis for placement as pictured. It is noted that the numeric keys were located around the periphery of the layout to reflect their low frequency, and the miscellaneous keys were used to fill in the remaining unused positions and appropriately paired to maintain logical combinations.

A final consideration in determining key place-

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Table 1.
Rankings of letters by overall frequency of use and first position use.

Letter	Rank Ordered Frequencies	Overall Use Percentage	Rank by First Position Occurrence
E	577583	12.62	12
T	427179	9.33	7
O	350121	7.65	18
A	348411	7.61	4
I	336166	7.34	14
N	325652	7.11	17
S	297531	6.5	1
R	281881	6.15	9
H	252191	5.51	11
L	188261	4.11	13
D	181054	3.95	8
C	142336	3.11	2
U	124736	2.72	20
M	116574	2.54	5*
F	107219	2.34	10
P	93040	2.03	3
G	89499	1.95	15
W	86563	1.89	16
Y	78749	1.72	24
B	70714	1.54	5*
V	45707	.99	19
K	29838	.65	21
X	9032	.19	26
J	7296	.15	22
Q	4936	.10	23
Z	4316	.09	25

*Estimates for these two letters were essentially the same and they were both ranked fifth.

ment was the likelihood that a letter would be the first of a word. Since words are usually preceded by a space, it was concluded that there would be an advantage to placing letters most likely to begin words near the space bar if consistent with the other placement criteria. To determine which letters were candidates for this placement, the numbers of words beginning with each was estimated from the respective number of pages in *Webster's New World Dictionary* (5).

Another consideration in the enhancement of the keyboard was to facilitate the visual scanning or key-locating process. Observation of typing-stick users revealed that their mode of keyboard entry

```
~  [  ]  3  2  1  V  U  P  6  7  8  +  |
   -  4  Q  M  I  T  S  C  K  Z  9  :
      5  J  G  N  R  E  H  B  Y  X  0
         /  '  F  O  A  D  L  W  ,  .
         ----------------------------
         ----------------------------
```

Figure 2.
Reassigned key positions.

was heavily dependent upon visual scanning, unlike touch-typing, which is predominantly dependent upon kinesthetic feedback (1). Measures were implemented to assist the user in developing a scanning pattern consistent with the target-like arrangement. Generally, English reading/writing people learn to scan from left to right. However, with this target arrangement, it was felt that it would be advantageous if users maintained focus on the center of the keyboard and learned to use this as their reference point, since the layout was designed to concentrate the keyboard activity in this area. To this end, the numbers were arranged to curve around from near the top center of the keyboard in order of occurrence. Thus, as can be seen in **Figure 2**, the numbers 1 through 5 run counterclockwise, and 6 through 0 are arranged in clockwise fashion.

The second measure taken to facilitate scanning and location of the keys was to color code them to highlight the overall pattern, and to provide a discriminable characteristic in addition to the labels on the keys. The "bull's eye" letter E was covered with a red transparency to make it stand out. The numbers were made blue, punctuation marks green, and the miscellaneous letters yellow. The tilde (~) key, which serves as a special function key, was relocated in the upper left corner and made orange. Color coding was accomplished using commercially-produced, transparent, stick-on key top covers, which allowed the character labels to show through. The resultant target-like appearance can be seen in **Figure 3**.

Two approaches were taken to eliminating keystrokes. First, the use of macros, that is, the assignment of words, phrases or other multiple character strings to a defined and relatively limited keying sequence, was incorporated into the scheme. The software provides for the creation of these aids.

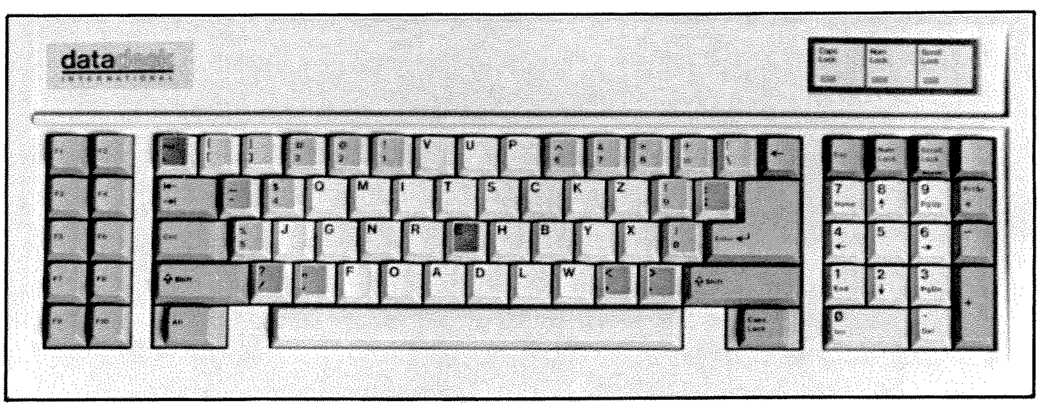

Figure 3.
Reconfigured keyboard.

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Usually macro strings are derived from frequently-typed material, such as a person's signature, which can be assigned to a keying combination like *Alt S*, and thereafter typed in entirety by entering this limited keystroke combination. Because this project was directed at more general usage, a set of macro words was derived from the Kucera and Francis word corpus analysis (7). The frequencies of the 200 most-used words were multiplied by their length to obtain products that reflect the relative number of strokes required by their use when typing substantial amounts of ordinary written English. The 5 words yielding the largest products were utilized for macros. Thus, the following words were assigned a keying sequence consisting of the *Alt* key and an alphabet character (or the *Ctrl* key and the alphabet character to create capitalized macros): *that, from, with, this,* and *which.*

A second means of eliminating keystrokes was derived from the macro concept. Because spacing is usually required after punctuation marks, the macro concept was used to configure the system to automatically insert 1 space following the comma and semicolon. Upon pressing the appropriate punctuation key, 2 spaces are automatically inserted following the period, question mark, and colon. The apostrophe and quotation mark keypress functions were not changed because of their frequent use without trailing spaces.

If it becomes necessary to use these punctuation marks without trailing spaces, one possible solution is to backspace to the desired position after entering the reconfigured punctuation marks; however, the software creates an "undo" key (the orange-colored tilde key mentioned above) which returns the keyboard to its nonmacro state for 1 keypress, and this provides an effective solution.

The final enhancement to the keyboard input system was to utilize the software's "single-finger" mode. This enables entering keyboard commands, which normally would require simultaneous, multiple keypresses (e.g., shift and a letter key to type upper case), to be entered as sequential commands.

EVALUATION

The reconfigured keyboard input system was evaluated in a research study that followed a formal experimental paradigm. Control and experimental groups, each comprised of 3 adults having little or no typing experience, engaged in two 90-minute single-finger typing sessions. Subjects who were inexperienced in typing were used to eliminate the intrusion of negative transfer as a confounding variable (12). The control group was instructed to practice single-finger typing, using a standard IBM-PC keyboard and a word processing program. The experimental group was oriented to the features of the reconfigured keyboard system, and instructed to practice single-finger typing with the altered keyboard and the same word processing program used by the control group. Additionally, all participants were provided with written instructions for their systems to use as needed.

The sessions, scheduled a week apart, involved typing practice exercises contained in a typing instruction textbook (9). During the last 5 minutes of each session, 5-minute proficiency tests were administered to the participants. Following the second session and proficiency test, a debriefing interview was conducted with each participant, and each member of the experimental group was also asked to complete a rating scale developed to obtain their opinions about the value of the enhancements.

RESULTS

The data from the typing tests conducted at the end of the second practice sessions were subjected to statistical analysis. The number of errors was subtracted from each subject's total number of keypress entries to obtain proficiency scores. The mean calculated from the scores of the standard keyboard group was 264.7 (sd = 27.4), and the mean for the reconfigured keyboard group was 409.7 (sd = 29.7). Review of individual scores revealed that all 3 subjects in the reconfigured keyboard group scored higher than the highest score in the standard keyboard group. A t test supports the conclusion that the difference between the means was significant ($p < .005$, $t = 5.69$, $df = 4$). From another perspective, the experimental group rate was approximately 55 percent faster than that of the control or standard keyboard group.

Responses from the debriefing interviews also revealed a notable difference. All 3 subjects in the control group (standard QWERTY-arranged keyboard) reported experiencing finger fatigue during practice, while none of the experimental group members cited this as a problem. Examination of the rating scale data obtained from the reconfigured keyboard group suggested that all of the enhancements contributed positively to their performance, including both speed and accuracy, except the macro words. They attributed problems in using the macros to their inability to quickly learn and recall the keystroke sequences, and suggested that the sequences were "unnatural" or not compatible with the flow of thought and concentration commanded by the typing activity.

DISCUSSION

This limited study suggests that the standard computer keyboard entry system can be enhanced to improve the proficiency of hand-impaired typists. Although the study does not indicate the maximum entry rates which may be attainable by single-finger and typing-stick typists using this reconfigured keyboard system, substantial gains may be realized. Moreover, the study confirms that relatively inexpensive avenues to enhancement do exist.

It is also noted that this keyboard arrangement may not be of benefit to persons using other than a single-finger or typing-stick entry technique. For example, persons using 2 typing sticks or 2 fingers may actually find the arrangement to be a hindrance. Because the activity is concentrated in the middle of the keyboard, 2 or more entry media may collide and interfere with each other. On the other hand, the project outcome supports the notion that it may be possible to discern and create an optimal keyboard arrangement to accommodate any hand-impaired individual and his or her unique residual function. The low cost of keyboards and keyboard utility software, and the flexibility inherent in the software approach to reconfiguration, make the idea plausible.

The key to widespread customizing of keyboard entry systems may lie in the development of analytical algorithms that enable rapid evaluation of various configurations as they are being tried by potential users. Similarly, software designed to analyze unique kinds of material that users will be typing may provide a basis for optimal, individually-tailored key arrangements and macros. Programs that could analyze an individual's text files to reveal their unique usage patterns (including word and letter frequencies), would likely provide a better basis for keyboard rearrangement than general usage material. It is noted that some of these issues are being addressed at Tufts University (11).

Attempts to develop analytical algorithms must be pursued carefully, however. This study, as well as others cited, suggest that to be most effective, reconfiguration must take into consideration a number of human factors that can vary substantially from individual to individual. Included are matters such as visual scanning rate, extremity/digit strength, stamina, dexterity, alternating extremity/digit response time and sequential response time, and cognitive factors such as memory and attention capabilities. Consequently, to be effective, analytical algorithms will have to be able to produce much more than arithmetically-determined key arrangements based on typing or other entry material content and the number of fingers or typing aids used. Each additional critical factor may cause the complexity of the required algorithm to increase geometrically. The most feasible approach may use a moderately encompassing design algorithm, user trial, and an algorithm to analyze system performance.

In sum, the experience gained from this project indicates that there are numerous relatively inexpensive, off-the-shelf productivity enhancements that hold potential benefit for persons with disabilities. However, their optimal use may rest with the development of new assessment and design tools.

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