Typing With a Two-Hand Chord Keyboard: Will the QWERTY Become Obsolete?

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Abstract —The cognitive and motor difficulties of acquiring a touch typing skill on the present system are analysed. It is proposed that poor cognitive structure is a main source of difficulty in the acquisition of typing skills. Experiments are described with a two-hand chord keyboard designed to provide an efficient alternative to the existing standard QWERTY keyboard. The new system is based upon simpler and more powerful cognitive and motor organization principles. It comprises two panels of five keys, one to each hand. Characters are entered by pressing together combination of keys. The system enables fast skill acquisition, with subjects reaching rates of 30-35 words per minute after 20 h of training. With 60 h of training, subjects can reach entry rates close to 60 words per minute. There is no negative transfer from the new skill to an existing typing proficiency. A cognitive oriented design approach to data entry devices, of the kind applied to the development of the present chord keyboards, appears to have a strong promise in the age of computers.

Introduction

As COMPUTERS proliferate in all areas of our life, the realization of their high performance capabilities in human–computer dialogues is greatly constrained by a technological dinosaur—the keyboard. The logic and design principles of this keyboard, including its most recent standard version, the QWERTY, were established more than a century ago, in the golden age of mechanical engineering [1]. The basic design idea was simple. Take a mechanical arm on a fulcrum, put a letter stamp on the one end and a key on the other. When the key is pressed the arm comes up and stamps the page. The complete configuration followed. Every character had a separate key, leading to a large number of keys organized in rows on a spacious panel. Assignment of letters to keys, which appears random to the modern eye, was also carefully considered by Sholes and his brother-in-law [1]. Letters with high transition probabilities (e.g. Q, U) were placed farther apart to avoid jamming of typing bars. None of the technological constraints that faced our forefathers still prevails. Yet, the keyboard has not been changed.

One may conclude that the design logic underlying the development of the keyboard is well founded from the perspective of human performance theory and the skills required for proficient typing are adequately structured. An extensive body of experimental data which has been accumulated over the years indicates that this is not the case [2]. Although we are frequently amazed by the speed at which the fingers of an accomplished typist fly over the keyboard, it is mainly because we know that touch typing is a highly complex skill. It requires hundreds of hours to master and continuous practice to maintain [2]. It decays rapidly if unused. Consequently, the vast majority of the increasing population of users are poor typists. They type with one or two fingers, at a slow rate, with constant visual supervision.

The miraculous survival of the present keyboard can possibly be accounted for by two other factors. One is the resistance from those users who have already invested the time and effort to acquire proficiency. Over the years there has been a number of attempts to introduce improved keyboards [3]. However, none was widely adopted, possibly because all of them were too similar in their general structure to the existing system. Hence, the acquisition of proficiency on the modified system was apt to interfere with the already established skill of typists. Another contributing factor may have been that the population of keyboard users was not as wide and diversified in age, education and basic abilities as it is today and as it is expected to be in the near future. Therefore, the need and urge for the introduction of changes were not as strong.

In this paper we first examine the possible sources of difficulty in the acquisition of a touch typing skill. The claim is made that a major contributor to this difficulty is the poor cognitive structure of the underlying skill. To illustrate and support our claim, we present data from a comparative study that was conducted in our laboratory with an experimental chord keyboard. We discuss the alternative cognitive principles in the base of the design logic of this system and consider the possible benefits of applying cognitive analysis to the development of data entry devices. While the experiment reported here cannot be considered as a full test of the new system in the applied sense, it does provide an adequate test of two contesting design logics and proposes a new insight into the issues involved.

What are the main elements of difficulty in the acquisition of a touch typing skill? A key requirement for the

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ability to touch type is some internalization of the spatial coordinates of the keyboard and the location of all keys. The aims are to acquire the capability for blind positioning of fingers on their intended letter keys and the knowledge of the movement trajectories of hands and fingers from one key to another. These aims are hard to achieve, because the number of keys is large, there are ten simultaneous operators (fingers) and hundreds of finger trajectories that have to be mastered.

From a theoretical perspective the sources of the difficulty are both motor and cognitive. On the motor side, touch typing requires simultaneous fine control of fingers and production of highly coordinated rapid movement sequences. The cognitive demands are as severe. A large number of associations between spatial locations and verbal codes and an even larger number of routes among these locations have to be memorized, selected and activated on demand. Moreover, there are only few and primitive organization principles that can help students in this massive memory task. An important lesson from the study of memory processes has been that performance under such situations (i.e., the ability to commit to memory and activate upon request), is greatly facilitated if the performer is provided with anchor points and good organizational rules that may enable him to group elementary units into larger chunks. Enhanced performance is also obtained when new elements can be linked with already existing and established knowledge bases.

In the case of the QWERTY keyboard, the only two principles that the performer can draw upon are the arrangement of letters in rows and their assignment to hands and fingers. The arrangement of character keys in 4 or 5 rows facilitates memory, because letters can be grouped and tagged according to their row membership. Similarly, the division of labor between the left and right hand and the assignment of a unique group of letters to each finger, of another set of representation cues. It facilitates both encoding and retrieval of responses. While these principles provide some help, the difficulties in the development of proficiency show that this help is insufficient.

It should be recognized that when we were moved by technology to the artificial environment of the typewriter, we also sacrificed an important correspondence that existed in handwriting: the correspondence between the visual shape of the letter and the movements that are required to produce or copy it. There are no guiding cues in the notation of a text to be typed that may hint at the required movements or the position of the fingers. In contrast, handwriting entails direct copying of the shape of letters. For another comparison, think about music notation. It can be thought of as a primitive sketch of the violin strings, or the keyboard of a piano. When observing notes or chords to be played, the player can derive many spatial cues on the required position of his fingers, or the distance between individual notes. Needless to say that the shape of letters or the structure of words do not convey similar information. Along with the existing keyboard, we have introduced arbitrariness that deprives the performer of important information, without providing sufficient compensations.

Over the years there have been a number of attempts to provide an improved or a better designed typewriter. There were several attempts to propose a different layout of keys that will optimize the load allocation between fingers, or facilitate memory [17], [19]. Most notable was Dvorak's simplified typewriter [15]. However, as has been noted by Norman and Fisher [13], while several of these proposals had some advantage, the basic design logic remained unchanged and the amount of performance improvement was not substantial enough to merit a replacement of the old typewriter.

Another class of attempts were several studies of typing with chord keyboards [3], [14], [16], [18]. A chord keyboard is a keyboard that normally includes a small number of keys (much smaller than a typewriter). Users are typing characters by pressing together different combination of keys (chords). Several of the attempts with chord keyboards proposed interesting ideas and have shown quite a promise in terms of acquisition rate and performance [14], [16]. However, as much as can be judged from the open literature, each of these efforts was short term and limited in scope. Researchers were primarily interested in specific applications, were concerned with technological details and did not pursue a systematic research program with the intention of testing more general theoretical principles that can be offered to the system designer.

In recent years, we have witnessed an active interest in a theoretical understanding of the processing and response foundations of proficient typing, as a model of a highly complex psychomotor skill [10], [12]. In our laboratory, we tried to complement this research of the standard QWERTY by a study of alternative principles that can be used to develop efficient data entry devices. We have been searching for such principles that will simplify and strengthen the cognitive structure of the skill, enable fast acquisition and high levels of performance [5]–[7]. In the present article we describe the results of an experiment that compared typing performance with single- and two-hand chord typewriters for the Hebrew language. Earlier experiments with this system were conducted in the English language at the University of Illinois [6].

The Two-Hand Chord Typewriter

The two-hand chord keyboard is comprised of two separate panels, one for each hand, with five conventional typing keys on each panel (Fig. 1). A letter or a character on each panel is entered by typing a motor chord that is a combination of one to five keys pressed together. With five keys there is a total of 31 possible chord combinations. Twenty six or 22 are sufficient to produce the whole English or Hebrew alphabet, respectively. Additional characters and editing functions are entered by using one of two shift keys to change the mode of the main five keys. Each shift key adds another 31 combinations. In principle, each panel can be conceived to constitute an independent

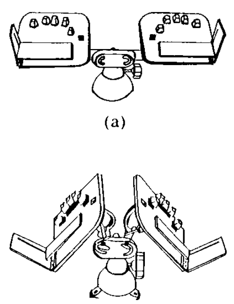

Fig. 1. Two-hand chord keyboard. (a) In horizontal posture. (b) In vertical posture.

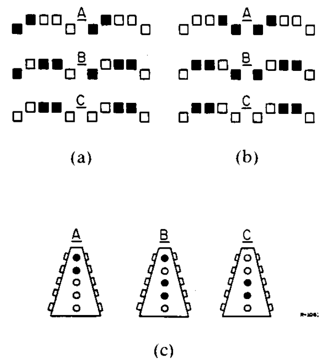

Fig. 2. Three principles of mapping and presenting letter codes to subjects. (a) Spatial configuration. (b) Hand symmetry. (c) Combined.

typewriter. Hence, the system enables parallel typing to the extent of typing two independent texts simultaneously. This is, of course, if the proficient operator can act as a parallel processor.

Letters were mapped onto chord combinations such that the more frequently used letters were associated with easier chords. It should be realized that the 31 different chords vary in their biomechanical difficulty and the perceptual complexity of their created patterns. The latter is important because letter codes have to be committed to and retrieved from long-term memory. We followed the early works of Conrad and of Seibel [3] as well as our own experiments, to order chords according to their difficulty [8].

Another question that was dealt with experimentally during the development of the system, was the best principle to represent the chord associated with the same letter on the right- and left-hand panels. When the panels are placed horizontally side by side (Fig. 1), there are two immediate coding principles for the same letters that come to mind: hand symmetry and spatial congruence. According to hand symmetry the same fingers of both hands will be used to enter the same letter. For example, the thumb and index fingers of each hand are used to enter the letter "A." In contrast, if spatial congruence is applied, the consistency of patterns across panels is preserved. Consequently, the leftmost two keys on each panel are used to enter the letter "A" (see Fig. 2).

Note that the use of one principle creates incompatibilities in terms of the principle that has not been applied. Under hand symmetry, the same fingers are employed to type the same letter on the two panels but the patterns of pressed keys are mirror images of each other. When spatial congruence is applied, the pattern of pressed keys on the two panels is preserved, but different fingers are used to enter the same letter. Thus, hand symmetry is violated. In an early series of experiments we studied the theoretical and empirical implications of adopting each of the two principles [6], [7]. We also compared the performance of a third group that was trained on vertically tilted panels (see Figs. 1 and 2). When panels are tilted to an upright position and the palms face each other, the mapping principles of hand symmetry and spatial congruence unite and all representation conflicts are resolved. That is, there is always a match between the fingers used to type the same characters on both panels and the patterns of pressed keys. The vertical posture also enables a unified and more economical presentation of the codes of letters to the subjects (Fig. 2).

Experimental data showed that higher typing rates were obtained when spatial congruence was used as mapping principle than when hand symmetry was employed. However, performance on the vertical panels was the best of all. Further experimentation showed that the main causes for its advantage were cognitive and not motor [6].

In the following sections we present the results of an experiment that contrasted the learning rates and typing performance of three groups of subjects typing free text. One group was trained with the two-hand chord keyboard, a second group was given a single-hand version, the third group practiced on the standard keyboard. Because our main interest was in the comparison between the chord keyboard groups and the standard system, and in the performance difference between single-hand and two-hand chord systems, both chord keyboard groups were trained with vertical panels, the condition that was found most compatible.

METHOD

Subjects

Fifteen native Hebrew speakers, right-handed, male students at Technion participated in the experiment. None of the subjects had previous experience in typing. Subjects were paid $3.00 per hour for their participation and received an extra $25 bonus for attending all 35 sessions. Subjects were randomly assigned to the three experimental groups. Six subjects were trained on the two-hand machine. Five subjects were trained with the single-hand version (right hand). A third group of four subjects was trained on the regular QWERTY keyboard. Initially, all groups included six subjects, but three subjects dropped out in the course of training (one from the single-hand and two from the standard keyboard group).

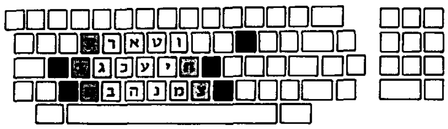

Fig. 3. Learning chart presented to subjects trained on the QWERTY keyboard. Different shades mark allocation of keys to fingers.

Apparatus

The experiment was governed by a PDP 11/34 computer system. The typed text was presented on an ELBIT DS-200, 13 inch terminal and directly recorded onto disk. Letters were 1/2 cm tall and 1/4 cm wide. Subjects sat at a distance of approximately 60 cm (thus, the visual angle for a single letter was approximately half a degree).

Text was typed with three different keyboards, depending on the experimental group. Subjects in the chord keyboard groups used the keyboards with panels in vertical position. The five typing keys on each panel were of the "CLARE" type (resistance 20 g, travel distance 4 mm). Subjects in the single-hand chord keyboard group used only the right plate of the two-hand keyboard. Subjects using the regular keyboard typed on the standard keyboard accompanying the ELBIT DS-200 terminal.

The three experimental groups typed text from printed pages of a popular Hebrew novel. The book was placed in an upright position on the right side of the computer screen.

Procedure

Initial acquisition: In all the experimental groups subjects were presented with charts describing the keyboard. A restricted dictionary of characters was used. It included the 22 letters of the Hebrew alphabet and a space character. Subjects in the chord keyboard groups received charts of the codes (as in Fig. 2(c)) and were asked to commit all letter codes to memory. They were free to try chord combinations on the keyboards and view the typed letters on the computer screen. They were not allowed to begin actual typing before they could type, upon request, all letters on the keyboard, in random order, without error.

Subjects in the QWERTY keyboard group received a keyboard chart describing the standard Hebrew layout of the 22 letters. This was, of course, in addition to the marking of letters on each of the keys on the keyboard. On the chart, all letters that are typed by the same finger in regular touch typing, were colored by the same color (Fig. 3). Similar to the chord keyboard groups, subjects were instructed to first commit letter positions to memory.

Typing free text: Subjects in all groups participated in 35 one-hour training sessions, during which they typed pages from a Hebrew novel. There were three to four sessions a week. Each meeting was composed of 15, three minute trials, interspersed by 1-min rest periods. In each typing segment subjects were given the following instructions: "You should try to type as fast as you can. However accuracy is important. Do not try to trade speed for accuracy." At the beginning of each session subjects were shown their learning curves for speed and error measures up to that meeting.

The group that had trained on the two-hand machine, was instructed to try and alternate hands continually, typing successive letters by right–left alterations. The group which had trained on the regular QWERTY keyboard was instructed to try to perform as in touch typing and type letters with their assigned fingers (as in Fig. 3).

Results

Initial Acquisition

Subjects in both chord keyboard groups were able to memorize the complete set of chords in a period ranging from 30–45 min. This outcome coincides with our previous experience with more than 100 subjects that had been run in different experiments with the present system. There were no appreciable differences between subjects who were given the two-hand keyboard and those who were trained on the single-hand version. In following informal interviews, subjects reported a wide variety of spontaneous mnemonic principles that they used to help them memorize the codes. At the end of the first 45 min they started typing in what, in essence, was a touch typing mode. They referred back to the letter charts on few occasions during the first hour of training and removed them completely thereafter.

Subjects practicing the QWERTY keyboard were able to memorize the position of the set of 22 letters in a similar period, ranging from 30–45 min. However, while typing during later sessions, they continuously used visual supervision to guide their fingers.

Typing Free Text

Fig. 4 presents the learning curves of the three experimental groups during the 35 h of training. These curves are based upon average typing rates (character/min) per session. Error percentages in all groups were low, ranging between 1 and 2 percent throughout training. Our analysis of performance was, therefore, based primarily upon typing rates.

Examination of the learning curves shows that while having similar starting points, the two groups practicing the chord keyboards advanced more rapidly. Up to the 25th session, there was not much difference between the single- and the two-hand chord keyboard groups. In both groups subjects reached the level of 160 letters per minute (about 32 words) and their rate of progress was about the same. In contrast, subjects operating the standard QWERTY reached only a level of 105 letters per minute (about 21 words) and their progress rate was considerably slower. These differences were highly significant. For average typing levels, the comparison between the two-hand condition and the QWERTY yielded $t(8) = 5.526$, $p < 0.0005$. The comparison between the single-hand group and the QWERTY condition, $t(7) = 3.537$, $p < 0.005$.

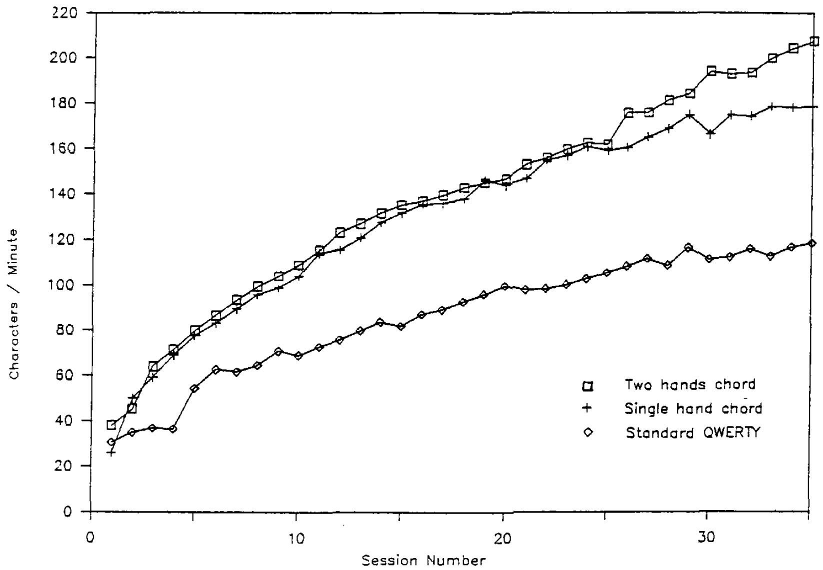

Fig. 4. Learning curves of three groups of subjects typing free text on single-hand and two-hand chord keyboards, and on standard QWERTY.

Differences in rate of progress were compared by computing the slope of the curves in the preceding five sessions (sessions 20-24). The slope values for the two-hand, single-hand and QWERTY groups were, 3.83, 4.36, and 0.85 letters per session, respectively. An analysis of variance for these values showed that the overall effect was significant, $F(2/12) = 7.39$, $p < 0.008$. Duncan post analysis comparisons indicated that the two chord keyboard groups did not differ from each other but both were significantly different from the group operating the QWERTY.

The 25th meeting seems to had been a break point between the groups trained with the chord keyboards. The rate of learning of the single hand group decreased while the two hand group continued its fast progress. As a result, there was a build up of difference in the average typing levels. With additional 5 h, at the 30th meeting, subjects in the two-hand group reached the level of 194 letters per minute (about 39 words), while subjects in the single-hand group reached only the level of 166 letters per minute (about 33 words). This difference was statistically significant $t(9) = 1.855$, $p < 0.05$.

At the end of training, 35th meeting, subjects in the two-hand group typed at an average level of 208 letters per minute (about 42 words) and progress was still continuing at a fast pace.[1] Subjects in the single hand condition reached only the level of 178 letters per minute (about 36 words). Subjects using the standard QWERTY typed only 118 letters per minute (about 24 words) and their rate of progress at this point was considerably slower. The analysis of variance of these differences was highly significant, $F(2/12) = 22.35$, $p < 0.0001$. Duncan post analysis paired comparison showed that all groups differed significantly from each other.

Differences in learning rates were compared by computing the slope of the curves for the last ten sessions (sessions 26–35). The respected average slope values were, 3.63 for the two-hand group, 1.86 for the single-hand group and 0.85 for the QWERTY. The analysis of variance of these values was again highly significant, $F(2/12) = 16.96$, $p < 0.0003$. However, this time the Duncan postanalysis comparison showed that while the rate of progress of the two-hand keyboard group was significantly different from the rates of the single-hand and the QWERTY groups, the difference between the latter two did not reach statistical significance.

Two of the subjects in the two-hand chord keyboard group continued their training up to 50 h. Their typing level at that point was 51 words per minute. One of them continued up to 60 h and reached a rate of 59 words per minute (295 letters). For both subjects, error percentages remained constant at their low 1-percent level.

Discussion

The Chord Compared With the Standard Keyboard

Before a detailed interpretation of the experimental results is attempted, it seems desirable to reiterate the point that the present experiment was not intended to be a comprehensive test of a chord keyboard application. Rather, it meant to contrast design logics with an emphasis on the cognitive foundations of these designs.

[1]We compared the differences between the two-chord keyboard groups both at the 30th and the 35th meetings, because two subjects from the single hand group dropped after the 30th meeting. Their data points for meetings 31–35, were extrapolated using the slopes obtained for their performance in meetings 26–30.

The experimental results indicate a clear performance advantage of both chord keyboard groups over the group practicing the standard QWERTY. At the end of 35 h of training subjects in the two-hand chord group typed at an average speed that was almost twice as fast as subjects in the QWERTY group. More important, their rate of progress at this stage was four times larger. The interpretation of the observed superiority should take into consideration the fact that the typing task was limited to a simple verbal text, which required only the use of letter characters and a space bar. Consequently, the total number of key positions and trajectories of fingers that had to be memorized on the standard keyboard was greatly reduced (Fig. 3). Similarly, the number of different code entries that had to be memorized on the chord keyboards was also reduced.[2]

It is clear, therefore, that subjects in all groups were trained on a simplified version of their respective keyboards and were given a relatively simple data entry task. Another factor that should not be overlooked is that the overall duration of training was relatively short. A training period of 35 h, when compared with the years of experience of a professional typist, can be considered to constitute no more than an initial stage of training. Nevertheless, the differences in performance among the three groups were pronounced. Moreover, when weighing and extrapolating the possible influence of the limiting factors, there is no reason to think that the simplification of the typing task and the short duration of training were more beneficial to subjects in the chord keyboard groups. We hence submit, that the observed differences are representative of the expected relative differences between the systems in the performance of more complex typing tasks, with longer periods of training. We shall examine the reasons for this claim in the following sections.

What are the differential features of the chord keyboards that facilitated learning and performance, when compared to the standard keyboard? One possible feature is the basic unit of typing. The elementary unit of the standard keyboard is a single key of a letter, located within a large group of otherwise similar keys. The equivalent unit in the chord keyboard is a chord, which is a spatial pattern mapped onto the exhaustive set of the five keys on the panel (6). This represents a significant difference. Spatial patterns are organized percepts that are easier to recognize and memorize and have many internal redundancies that facilitate their reconstruction. They are much easier to identify and memorize than isolated elements in an unorganized array (single keys) [20]. By analogy think about the difference between the difficulty of perceiving and memorizing a list of single letters compared with a list of words. We have evidence from several recent experiments to show the pronounced contribution of the perceptual quality (goodness of figure) of the spatial pattern of chords, to the efficiency of typing the corresponding letters on the chord keyboard [6]–[8]. Given the 23 elementary units that had to be memorized (22 letters + space) and the severe time pressure, urging subjects to type as fast as they could, representation and retrieval of patterns may have been a much easier task than memorizing an array of single keys.

In addition, subjects typing on the QWERTY are required to acquire fingers and hand trajectories, while such a requirement does not exist on the chord keyboard. An important part of the touch typing skill is the ability to move hands and fingers along the required trajectories. Even with a limited set of 23 characters, the amount of travel and the number of different trajectories are quite large. They result in a considerable increase of both memory and motor coordination load in the QWERTY as compared with the chord systems. In the latter, hands and fingers rest on their home keys at all times. This is another factor that contributes to the cognitive and motor simplification of the present chord keyboards. Taken together, the elementary unit of typing and the elimination of the requirement to move hands and fingers, may explain the ability of subjects in the chord keyboard groups, to abandon the use of the letter charts after a short period in the first meeting, while QWERTY subjects continued to depend on visual supervision throughout training.

Single-Versus Two-Hand Chord Keyboard

One of the design uniquenesses of the present chord keyboard is the ability of each panel to function as an independent typewriter. It leads to an obvious question on the difference between the use of one or two hands. Fig. 4 shows very clearly that during the first 25 h of training, the groups using the single hand and the two hand chord keyboards progressed at the same pace. Single-hand subjects showed even a small advantage, which did not reach statistical significance. From the 25th meeting and on, the progress of the single hand group slowed down, while subjects in the two-hand group continued to progress at the same rate as before. Both the initial lack of difference between groups and the later growing advantage of the two hand group are revealing and should be carefully evaluated.

Both from a cognitive and from a psychomotor perspective, the acquisition of a typing skill should be much easier on a single-hand chord keyboard. With a single panel, subjects have only one set of codes to master and there is only one way in which each letter can be typed. In contrast, when the two-hand system is employed, there are two possible responses for each character. Hence, the correct code, the typing hand and the order of using hands have all to be determined for each pair of letters. In addition, the demands on the motor system are considerably increased by the requirement to coordinate the two hand production of simultaneous but different chords.

Thus, the lack of a clear advantage for single hand typing, even during the first period of training, is somewhat surprising. We view two main factors as possible

[2] Given the limits on the cost and duration of a feasible study of typing behavior in the laboratory, the present solution of using a restricted set of characters and a simplified task is a common compromise. It has been adopted by many researchers (e.g. [12]).

contributors to this outcome. One is the nature of the representation in memory of the motor codes for letters. The other is the ability of subjects, operating on the two-hand keyboard, to parallel responses. A series of experiments that was aimed to study the faculties of the long-term memory representation of the motor codes associated with letters, suggested that letter codes for the two hands are stored in a single, general, store [6], [7]. The representation form of codes is argued to preserve the spatial pattern of the produced chord. It is further postulated that in the actual entry of data, the general code of a letter is first retrieved from the general store and the specific hand format is determined at the next step. In the present context, this model is consistent with the finding that the initial acquisition times were not different in the single-hand and two-hand chord groups, because subjects in both conditions are assumed to construct only a single store of letter codes.

But even if the initial process of retrieval is not different in the single- and two-hand systems, there are still the additional requirements, when operating a two-hand chord keyboard, to direct, order and coordinate the execution of two responses simultaneously. We suggest that the degrading effects of these requirements are counteracted by the ability of subjects to parallel or overlap responses. Studies of the behavior of expert typists and accomplished pianists have demonstrated most persuasively that the ability to parallel responses is one of the major assets of the expert (e.g. [2], [9]). A detailed analysis of the time to type pairs of letters (diagraphs) on the QWERTY keyboard, showed that while at the beginning of training the fastest pairs to type are double letters typed by the same finger, with the progress of training there is an increased advantage for letter pairs that are typed by alternating hands (e.g. [10]). Our own data in previous experiments indicated increased savings in typing pairs of letters simultaneously. Some ability to parallel responses was already present after the first 2–3 h of training [6].

Given this experimental evidence, the potential advantage of the two hand keyboard over a single-hand system is apparent. If human operators can parallel their responses, with practice their speed of typing on a two-hand machine could, in principle, be doubled compared to a single-hand panel. In the present period of 35 h, it appears that during the first 25 h, the gains from the ability to overlap responses were sufficiently powerful to combat the added difficulty of the requirement to generate and coordinate two responses. From the 26th hour and on, it is this ability that may account for the growing advantage of the two-hand system over the single-hand.

Higher Level Structure

A full realization of the capacity to use the two hands in parallel, does not depend only on the ability of the typist to process and type pairs of letters. It is important to realize that there are other factors at the higher level of the text structure that may influence the efficient use of the two hands. For example, what is the best way to divide the work between the two hands? In the present experiment subjects were instructed to alternate continuously between hands. That is, to type successive pairs of letters such that the left and right members in each pair will be typed by the left and right hands respectively. Subjects encountered several types of problems in following this procedure. Moreover, the locus of these problems shifted with the progress of skill.

One problem that was reported, was a need to change basic reading and sampling habits. Words and message sequences had to be decomposed into letter pairs. The pair represented a new unit, which was larger than a single letter, yet different from all other well learned larger units such as syllables and words. At the beginning of training this newly introduced unit created conflicts with the natural tendency to focus on single letters. At later stages it interfered with the structure of larger segments, mainly words. The following are two examples of such interferences. One interesting type of error appeared in the typing data of several subjects at about 30 h into training. We revealed a marked increase in the number of times that subjects typed double space instead of a single space between words. A closer examination of this error showed that a double space almost always followed a word with an uneven number of letters and was more likely to follow longer words.

A space appeared to have had for these subjects an independent status. It marked the end of one typing unit and the beginning of another. It was usually entered by the right hand. However, when words with an uneven number of letters were broken into letter pairs, there was only a single letter in the last pair. This pair was, therefore, completed by a space, but another space, the regular one, was then added to mark the closure of the unit and the beginning of a new one, leading to a double space. The word unit, which was of lesser importance at the beginning of training, when subjects operated in a letter by letter mode, became an important factor at the more advanced stage. Note, however, that it was the orthographic and physical structure that were important and not the semantic meaning of the word. To overcome the problem, our subjects tried to develop a strategy by which the last two letters in an uneven word were typed by the same hand. Hence, they started to combine parallel and sequential strategies to overcome a cognitive structuring problem.

Another example of a problem caused by higher structures was reported by one subject at about the same period of 30 h into training. He claimed that he developed specific schemas for some frequently occurring words, which also included the specific assignment of letters to hands. Typing fluency was disrupted whenever he reached one of these words with the inappropriate hand. This type of problem suggests that the initial flexibility of letter assignment to hands which characterize early training, may be constrained in organized word schemas. Such structuring of schemas, confirms again the influence of the word unit as training progresses. Taken together, the three examples demonstrate the importance of evaluating the basic processes of reading and higher-level text elements along with the psychomotor uniquenesses of the new keyboard. The most efficient use of the added flexibility may depend not only on the ability to touch type, but also on the retraining of basic reading and scanning habits, and on the development of the best approach to assure a functional match between the units of the text and the work of the hands.

Will the QWERTY Become Obsolete?

Can we expect the expert level of performance on the new system to compete with the achievements of a proficient QWERTY typist? This is, of course, the most intriguing and natural question to be raised in the present context. At this stage, however, it is also a question that cannot be answered directly. Given the limited period of training and the simplified typing task of the present experiment that were dictated by the constraints of a laboratory experiment, one can only attempt to extrapolate and hypothesize the expected differences between the systems with extended training and a complex task. If we base our predictions on the slopes of the obtained learning curves (Fig. 4), the logical inference is that at least for the following period of training and for the simplified versions of the keyboards, the advantage of the two-hand chord keyboard is expected to increase. The crucial question is what would happen after very long experience and when the set of characters is much enlarged, doubled or even tripled by including digits, punctuation marks, arithmetic symbols and special characters.

To address this issue, let us compare the basic approach to the enlargement of the character set, in the standard QWERTY and in the two-hand chord keyboard. In the QWERTY the increase of the set is accomplished using the same design logic of adding more character keys and expanding the keyboard space. The implication of this approach is a marked increase in the number of key positions and a larger growth in the number of finger trajectories that have to be memorized and touch traveled.

In contrast, the design rationale of the two-hand chord keyboard introduces, at this point, additional and higher level cognitive principles, directed to help subjects to memorize and organize the representation of the added characters, as well as help their retrieval upon demand. To accommodate the additional characters, two functional keys have been added on both sides of the thumb key in each panel. They are used to change the operation mode of the five main keys. The guiding rule is that having acquired the basic inventory of the chords for letters, subjects shall be able to use them to enter all other characters. For example, in the punctuation mode, P types a period (.), C is a comma (,) and Q produces a question mark (?). In the arithmetic mode P types + and M produces −, etc. To enter digits in the Hebrew language, we took advantage of each letter in Hebrew also having a numerical value. Accordingly, the first 10 letters of the alphabet are used to type the digits 1–10. In English we solved the problem by using spatial approximations of finger combinations to Roman numerals (e.g. I, II, III).

There were two leading principles in developing the full character set for the chord keyboard. We either used a strong spatial (pictorial) correspondence to the visual shape of the typed character, or created strong link to a well-built semantic knowledge base. Both principles were shown in a wide body of literature to improve memory and retrieval of information and the conduct of skilled performance ([11], [2], [20]). We therefore claim that, while there is little meaning and a great amount of arbitrariness in the layout of the QWERTY keyboard, the full character set of the two-hand keyboard is easy to learn because it is anchored in compatible and well established knowledge bases. It is, of course, also simpler from a psychomotor viewpoint, because fingers and hands rest on their home keys at all times and no travel is required. From this analysis it is reasonable to speculate that the simplification of the systems in the present experiment should have been more helpful, if at all, to subjects practicing with the standard keyboard, and the differences may have been larger if the full systems were compared.

At this stage, such an expectation is speculative and should be treated with due caution. There is at least one key element of the QWERTY operation that may offset the effects of the discussed advantages on performance, at the very top levels of the typing skill. This element is the potential ability of expert QWERTY typists to move several fingers together and prepare five or six key presses simultaneously [12]. Experienced operators of the two-hand chord keyboard can prepare no more than two responses in parallel. It is possible, therefore, that for the very upper level of expertise, typing speeds will still be higher with a QWERTY keyboard.

How much higher and at what costs of training and maintainance, are empirical questions that are hard to evaluate at this point. The data from our subject that reached a typing rate of 295 characters per minute with only 60 h of practice on the chord keyboard, are encouraging. This is the achievement of an average professional typist after several years of experience [3]. It appears reasonable to suggest that with the chord keyboard one can reach average professional typing rates in a much shorter period. More importantly, the nonproficient user can reach comfortable entry rates, working in touch-typing mode, with only few hours of training.

Aside from conventional text processing tasks, there may be several special applications in which the use of a two-hand keyboard may have a great advantage. For example, in tasks in which a clear division of responsibility between the hands may be highly functional. One such situation is a bilingual data system, say, Hebrew on the right hand and English on the left. Current bilingual machines are very difficult to learn and hard to operate. Another example is a complex alphanumeric coding task, such as the mail sorting systems. Entering letters by one hand and digits by the other may be very efficient.

A final comment is due to the issue of the transfer of technology. We have already mentioned in the introductory section the problems that were encountered by earlier proposed improvements to the QWERTY, due to their potential interference with an already acquired typing skill. In this respect chord keyboards appear to be in a much better position. The components of typing skill on the chord keyboard are sufficiently remote from those involved in typing on conventional keyboards, to preclude major interference and transfer problems. Several of our subjects in previous experiments [6] and in informal explorations, were experienced typists. They did not seem to have an advantage or disadvantage. This is a significant finding. It implies that the proficient typist can add this new skill to his arsenal without worry, while new trainees can be taught the new skill.

Conclusion

We believe that regardless of the question whether the specific keyboard presented in the present article is the optimal solution, there may be substantial gains from the introduction of a cognitive approach to the design of data entry devices. Cognitive considerations were seriously neglected in earlier designs. Chord keyboards of the kind described in this paper, may offer a much superior approach to the design of data-entry devices in the age of computers.

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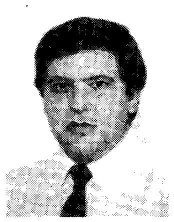

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