A Keyboard to Increase Productivity and Reduce Postural Stress. Paper presented at The Annual International Industrial Ergonomics and Safety Conference, June 8-10 1988 New 0rleans

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A new computer or office machine keyboard has been developed to match hand movements and reduce the postural stress imposed on operators by the Scholes (qwerty) design which engenders fatigue and can lead to pain and disability. The qwerty letter layout has been retained for already trained operators but an alternative efficient new arrangement may be selected. Key tops may be dually or singly designated.

1. INTRODUCTION

As is well known, the physical shape of the Scholes (qwerty) keyboard was established over a hundred years ago within the mechanical limitations of the time. These same limitations also gave rise to the letter layout in which 3 of the 10 most used letters were under the rest position of the fingers. An up, down, or sideways movement had to be made to reach the others before they could be keyed. The delay introduced by this gave sufficient time for the type bar of the previous letter to get out of the way and the arrangement overcame the type bar jamming problem sufficiently for the typewriter to achieve commercial success.

By the mid 1930s most of the mechanical limitations had been overcome and Augustus Dvorak developed a new letter layout with 7 of the 10 most used letters under the fingers. This layout has demonstrated improved performance but has not become widely used. It would seem that the improvement is not enough to justify the retraining effort and it does not address the problems of physical stress associated with the keyboard shape.

The advent of electronic keyboards, mostly in use with visual displays, seems to have highlighted operator stress problems which sometimes occurred with mechanical typewriters. These problems, broadly grouped under the name of Repetitive Strain Injury (RSI), are associated with the over use of particular muscle groups and are found in many occupations. Writer's cramp, Tennis elbow, Cotton picker's arm, are some of the names associated with this type of injury. It also occurs in meat cutting and packing, production and assembly line work in general, to hair dressers and concert pianists. The detail of the injury depends on the actions causing the damage. Medical terms used to describe typical keyboard cases are; Tenosynovitis, Carpal tunnel syndrome, Tendinitis, peritendinitis, and Epicondylitis. Unfortunately none of these conditions respond quickly to a simple cure and much medical doubt surrounds the best mode of treatment. Prolonged rest seems to be the only effective answer at present. The result is that often the most productive and conscientious operator is forced to stop working altogether, which is a personal career disaster, a severe productivity loss to the employer and a financial loss to the insurance company in meeting compensation claims. Sometimes the onset of RSI from keyboards is rapid (complete disability within a week), but more often it builds up slowly over months or even years.

The symptoms are increasing aches and pains, and / or numbness and tingling in fingers, wrists, arms, shoulders, or neck. There may also be weakness or swellings in hands and arms. These symptoms, when presented, should be regarded seriously and at least some action taken immediately to change the work pattern or load if permanent damage is to be avoided.

Quite apart from clinical levels of RSI damage actually occurring, a surprising number of keyboard operators do put up with mild aches and pains in their daily work. If they complain, they are usually told that they are not sitting properly or have strained themselves in some other activity. While both these comments and others similarly dismissive may be true in some cases, too many occur for them to be ignored. For example, in the offices of the "Engineering Computers" magazine, 14 of the 17 regular keyboard users suffered such pain. So large a percentage can only mean a job related stress. The only common item was the keyboard. Following research in 1974 into the disproportionate amount of ill health in Telex operators in the Australian Postal Service, Professor Ferguson of Sydney University concluded that the stress from keyboard operation was the prime cause [1]. Similar work in Japan [2] and more recently in West Germany [3] has supported this. In 1984 the Australian public Service reported that 1000 of its 5984 operators were suffering in this way.

The fact that operating a qwerty keyboard can cause pain must mean that an initial stage of tiredness and fatigue has been passed through. From this it follows that to many operators the occupation is at least unpleasant, often painful, and sometimes dangerous. These characteristics of the design can hardly be expected to promote job satisfaction and productivity.

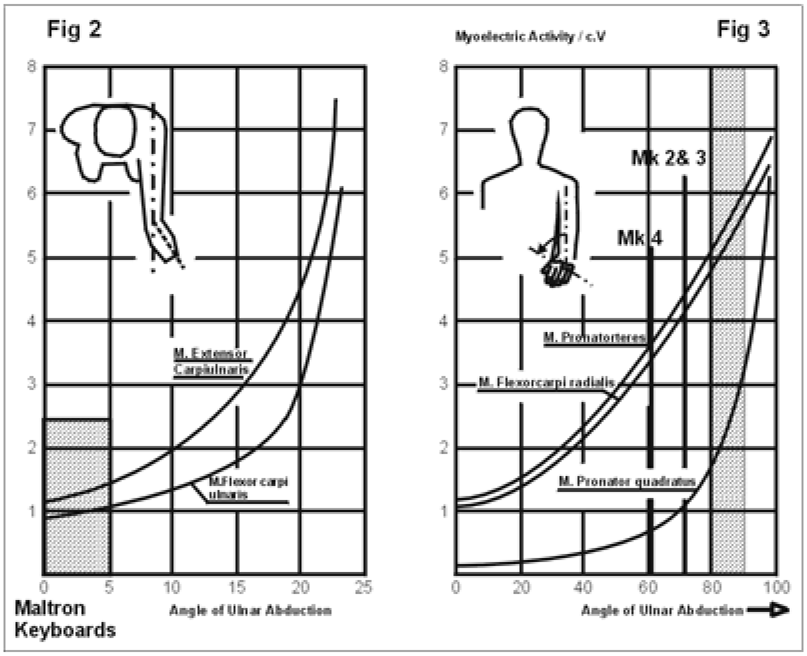
The need for a better keyboard has been realised for many years and alternative designs have been proposed [1,4,5]. Some have been primarily letter layout changes, others have considered the physical problems [6,7,8,9]. In 1976, Professor Ferguson's paper indicating that wrist abduction was the main problem, together with other papers and articles, were brought to my attention by Lillian Malt. From our study of these we decided to try and create a new fully ergonomic design. It was to address the physical stress of wrist abduction, take into account the differing lengths of fingers and be based on movements which can be made easily without strain. It was also to make the most of modern electronics to offer a new letter layout based on a computer analysis of letter use sequences and frequencies. Electronics had made it possible to separate the keys from the printing mechanism opening the way for a three dimensional shape, and permitting key memories to be switched instantly. This allowed the qwerty layout to be selected by already trained operators who would still have the benefit of the new shape.

2. ABDUCTION

The outward turning of the wrists, sometimes to an extreme extent as shown in Fig. 1, requires a sustained muscle tension in the arms to hold the hands in the normal typing position. This tension is partly relieved by slightly raising the shoulders, but this in turn often leads to fatigue and pain across the back.

Fig1. Hand abduction at a conventional keyboard

By experiment we found that only by splitting the key board and separating the two parts by approximately 25cm between centres, could the abduction angles be reduced to zero for average adults, while at the same time keeping forearms nearly parallel in the minimum strain position. Although small angles do occur, this separation also seemed acceptable to children and men with wide shoulders. This design decision was subsequently confirmed by the work of P. Zipp et al [3]. Fig. 2 shows the change of myoelectric activity controlling muscle tension as the abduction angle is varied from 0 to 25 degrees. The operating area shown by the dense shading illustrates the activity needed by the qwerty design. The reduction achieved by the 0 - 5 degree range of the Maltron is clearly shown.



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3. HAND SHAPE

The shape of a relaxed hand is easily seen by allowing the arms to hang loosely by the side. In this condition the fingers usually curve through a quadrant. The shorter fingers follow tighter curves so that the line of the ends of the three outer fingers does not make a right angle with the axis of the forearm. The resulting angle is usually about 20 degrees different and is about the same as the inward inclination of the forearms in the minimum strain position mentioned above. The result is that the line of the centre row of keys is nearly straight across the keyboard. If the hand is now raised until the forearm is horizontal, easy finger movements are seen to be arcs of about 90 degrees pivoted on the first knuckle. These movements then define the shape of the keyboard in the front to back direction, but since fingers are not all the same length the key heights and arcs must vary to suit. The division of the keyboard into two key groups with a wide gap in the middle provides an opportunity to consider making more use of the thumbs. Operating with the relaxed hand shape allows thumb movement to cover a significant area without the need to move the fingers from their "home row" key positions.

It was decided to take advantage of this and move the "Return" key to the right thumb alongside the Space key so that the long little finger stretch of the qwerty keyboard was no longer needed. This action on the qwerty keyboard, as well as the strain, usually causes loss of finger location and time waste in repositioning the hand. From a logical basis this "Return" key change makes sense since the thumb is immediately available to operate at the end of a word when either a "Space" or "Return" keystroke is needed. Experiment also showed that each thumb could easily access up to 8 or 9 keys. This opened the way for a complete reappraisal of the positions of computer cursor and function keys.

4. PRONATION

Normal keyboard operation requires the hands to be turned to the horizontal palms-down position and, as in abduction, this is usually near or at the anatomical limit. Fig. 3 shows the curves of myoelectric activity for the range of movement from palms vertical to horizontal, with the qwerty range shaded. From the point of view of minimum strain, an accordion style keyboard would be the best solution, but such a shape would hardly be acceptable in an office environment. The curves show the importance of reducing pronation as much as possible. In the relaxed hand shape, the shorter outer fingers cause the hands to turn out a little, so the Maltron design uses this effect to reduce pronation to an extent which operators have noticed and welcomed. The 70 degree operating line of the Mark 2 and 3 designs has been drawn on the figure. These designs and the results achieved were the subject of a paper I presented in 1985 [10]. The 60 degree line achieved by the new Mk.4 design is also drawn on the figure. This shows further improvement and a significant reduction of stress from the qwerty levels.

5. KEYBOARD DESIGN

The first design, based on the principles discussed above, was brought into use in 1977 and satisfactory operation confirmed the design philosophy. Trials showed that there was a significant drop in fatigue and an improvement in accuracy. A keyboard of this time is shown in Fig. 4. It was designed to work with an IBM mag card word processor and displayed the Maltron letter layout. The three dimensional shape and the thumb groups are clearly shown.

Fig. 4 - Mark 2 Maltron Keyboard

The right hand finger group shows the two rows of keys for the index finger raised to allow for its shorter length. A similar allowance for the little fingers can be seen on the left hand group.

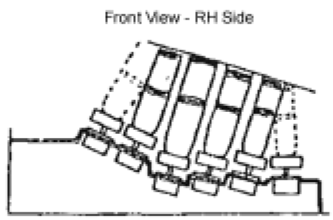
A particular feature is the pair of palm resting pads in front of each finger group. These are not for use during keying since they would restrict the small amount of hand movement needed to key quickly and accurately, but when there is a pause, or "thinking time" is required, the palm may be lowered to the pad without losing finger position registration. This action allows the finger actuating muscles to relax and promotes the flow of blood in them to remove, or at least delay, the onset of muscle fatigue. The pads have proved to be a significant innovation. The centre key of the right hand row of the right thumb group is the "Space" key, with the "Return" key to the immediate left. The white keys are for controlling word processing functions and their positions were determined from an analysis of frequency and action. The centre of the left hand row of the left group is a "Space" key in the qwerty mode which changes to the next most used key "E" when in the Maltron mode with "." adjacent.

Fig. 5 - Mark 3 Maltron Keyboard

Since extra keys could not be fitted to the earlier model, the advent of the IBM PC (with number pad and 10 Function keys) called for a new design. The Mk.3 keyboard, developed to be plug compatible with the IBM PC and keyboard compatible clones, is shown in Fig. 5. It can be seen that the essential features have been retained but the moulding has been modified to give a central flat area for the number pad and room for the Function keys along the back. Behind these is a holder for a Function key designation strip which can be easily changed to suit the software in use. To the left of the Function keys is the qwerty - Maltron changeover key to give immediate selection of the preferred letter layout. On this model small red qwerty letters were engraved above the larger Maltron letters. Coloured LEDs at the changeover key showed the set in use.

At this time a general philosophy was developed to put all right hand symbols on the right and left hand on the left. This was then extended to cursor keys and other functions. The idea was that actions going forward in the work would be on the right and those going backwards would be on the left. The "Up" and "Left" cursor keys were therefore placed on the left thumb along with "Home" and "Back Space Delete". On the right thumb were the "Down" and "Right" cursor keys together with "End" and "Delete". Placing the "BS Del" key in the left thumb group above the "E/Sp" key has proved very satisfactory as a conscious error can be corrected immediately. Since the "Control" and "Alt" keys may be needed with a key from either hand, these keys are duplicated and may be selected by either thumb. To make thumb operation of the "Space" and "E/Sp" keys easier, they have been enlarged to double size so that pressing with the side of the thumb, as many operators prefer to do, poses no risk of striking two keys at once.

Pressure from West Germany a few years ago for keyboards with home row heights not more than 30mm above the table, made keyboard manufacturers design short key modules. As these became available, it was decided to redesign the Maltron to use these keys to meet the 30mm requirement as far as possible within our concept and at the same time to see if pronation could he further reduced.



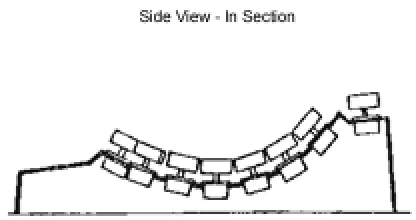


Fig.6 Tilted keys Fig. 7 Arc of movement

Figs 6 & 7 - Roll mouse over to enlarge.

If the relaxed hand and forearm is laid on a table, it can be seen that when the finger ends lie in a vertical plane roughly across the axis of the forearm, the fingers slope outwards at about 20 degrees from the vertical. Because the outer fingers are shorter, the back of the hand shows pronation reduced to the 60 degree region. To take advantage of this and still have the right feeling of comfort at the finger ends, it was decided to tilt the keys outwards to match the slope angle as far as possible.

To meet some difficulties in making a moulding, a compromise at 15 degrees was accepted for the 3 outer fingers but with the keys for the index finger raised to suit its shorter length and tilted at 20 degrees. Figs. 6 and 7 show a section along the home row of the right hand and a side view of the little finger outer column of keys. [11] At the same time, to meet the needs of male operators, the key group spacing was increased to 28cm and the key spacing was increased slightly. This design is shown in Fig. 8 below, where it will be seen that attention has also been given to industrial design aspects of the product to enhance the appearance. Comments from some qwerty operators who found that they needed to look at the letters when adapting to the new shape have been accepted and the old layout is now engraved in equal sized letters coloured yellow, with the Maltron letters in green. When required, either qwerty or Maltron letters alone can be fitted. The electronics will still provide both layouts so that an operator who has learnt to touch type Maltron will still be able to use an apparently qwerty keyboard and vice versa.

In recent years visual problems in connection with VDUs have been studied intensely and any form of glare is known to be a cause of strain. Light reflected from the keyboard to the screen or the operator's eyes, although not in the line of sight, will reduce the screen contrast and contribute to such strain. Also, when the operator looks down at the keyboard, a higher light level from it will cause iris adjustment which has to be changed again as soon as screen viewing is resumed. Since the screen background is usually dark, a dark keyboard will be beneficial in both respects. To meet this, Maltron keyboards, as shown in the figures, are normally made of dark material with a fine grained surface to give minimum reflection.

Fig. 8

6. QWERTY OPERATION

Since the Maltron shape removes abduction and reduces pronation stress, it can be expected that an improved performance will be obtained from the use of a Maltron keyboard. The flat typewriter style keyboard has been around for so long that a severe cultural shock occurs when an entirely new shape is presented as an office machine keyboard. This is especially so for trained operators who find the different physical layout of key positions to be confusing. Some gentle encouragement may be needed to help to overcome initial reluctance and to practice sufficiently to develop new reflexes. The problem occurs because the sense of key position derived from practice on the flat keyboard is no longer correct. This is a passing phase. It has been demonstrated that in as little as 25 minutes, normal speed can be attained. While this may be exceptional, it can certainly be achieved in a day or so.

To help with further improvement, an adaptation training course is supplied with the keyboard. Results show that a 20% improvement in speed is easily accomplished, with a substantial reduction in errors and fatigue as expected.

7. MALTRON OPERATION

The development of a new letter layout is a major task and for the Maltron keyboard was carried out by Lillian Malt in 1976-77. She presented this work at the PIRA Symposium in September 1977. [12] The following extracts from her paper, which may not be readily available, give some idea of the factors considered. "The uneven stretches caused by the diagonal slope of the rows of keys on qwerty result in uneven reach and distance movements, and this together with the letter layout which reinforces language confusions and induces errors, adds to learning difficulties and training time. Of course there are many highly skilled and accurate keyboard operators. They are only a small proportion of the total number of people who learn to use a keyboard and their skill has taken longer to achieve and required greater effort. These difficulties all add to the cost of providing training both in our educational and training establishments, and in industry."

"Siting characters on the keys is a complex matter, and to arrive at an optimum layout many variables require consideration: motion economy principles related to hand and finger movements; finger strength and flexibility; the human neuromuscular structure. All these factors are included, as well as language restraints, such as letter confusions which result in common spelling errors and then appear as common keying errors, and allowance for statistical frequency of letters, single and in combinations of di- and tri-graphs, especially those in the commonest words."

"For accurate keying and for ease of learning, letter layout should take account of cybernetic requirements related to language. Highest source of error in reading and in spelling is located in vowels and vowel graphemes. On the qwerty layout the highest source of error is on the vowels "e" and "i".

Dvorak's layout, mentioned previously, has all the vowels adjacent to one another on the centre (home) row of the left hand. The analysis in his book [4] shows that vowel errors are 49% of the total. So it seems clear that this type of arrangement should be avoided. Again from Lillian’s paper: "If vowels are strategically placed so that they do not appear on adjacent keys, nor on the same finger and same row on the two hands, neural confusion may be avoided. This would provide the best possibility for accurate keying".

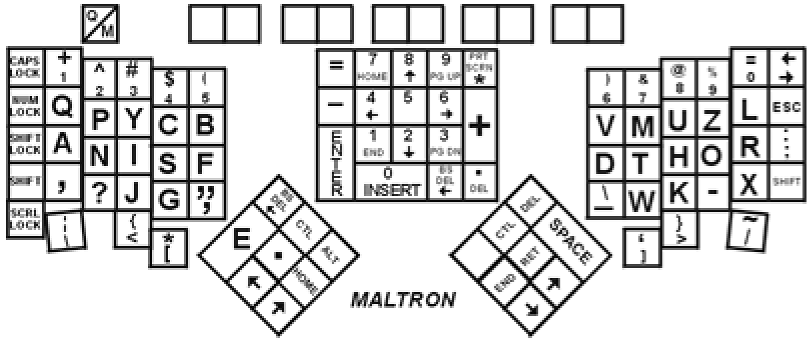


Fig. 9 Maltron layout for PC style keyboard

Fig. 9 - Maltron layout for PC style keyboard.
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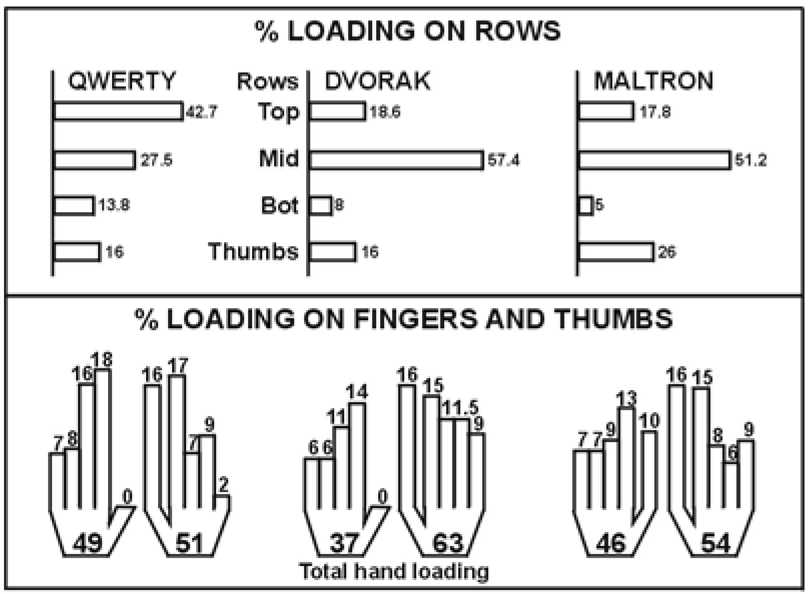

Fig.10 Finger and Hand Loading Diagram

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The Maltron letter layout, developed in accord with the above principles, is shown in Fig. 9. Fig. 10 is a loading diagram showing the amount of work done on the rows and by the fingers and hands for the three different letter layouts. The two operations which slow down keying are; the successive use of the same finger, since a finger cannot be used again as quickly as another one, and a "hurdle", ie. the need to move a finger to the row above or below from an already bottom or top position and so cross over the home row before striking the key. Thumb keys are included as "home row" in the tables below. Based on the figures from an analysis of a million words of English language [13] the table of Fig. 11 shows the number of times each of these occurred for the three letter layouts. The very clear advantage of Maltron can be easily seen. The placing of the letter "E" on the normally unused left thumb is the main reason for the big improvement. The great reduction in Maltron hurdles over qwerty supports the new shape in further reducing the total work load and stress. Trials also indicate that the combined effect reduces learning time to about a quarter of the usual period and errors to one tenth.

Keyboard	SFSU	IR	H	IR	IFSS				% LAW	% CW
					LH	IR	RH	IR		
Qwerty	273450	1	82200	1	12.27	1	13.73	1	43.6	51.9

Maltron	24826	11.0	321	256	4.9	2.5	5.50	2.5	77.9	90.5

SFSU = Single finger successive use IR Improvement Ratio

IR = Improvement ratio H Hurdles

IFSS = Index finger sideways stretch

% LAW = % letters keyed on home row for all words

% CW = % letters on home row for the 100 commonest words (these = 47% of all language input)

Fig. 11 Table showing improvements due to change in letter layout, based on data from Lillian Malt and H Kucera [12] & [13]

8. CONCLUSION

The Maltron keyboard, when used in either mode, addresses the physical stress problems of keyboard operators and shows a sufficient improvement to justify general adoption. The fact that the design requires only a few hours of adaptation practice by already trained operators to achieve much more comfortable working conditions, and at the same time offers a significant improvement in productivity, should appeal to both operators and employers.

ACKNOWLEDGEMENTS

I have much pleasure in acknowledging Lillian Malt's inspiration in indicating the need for a new keyboard and her considerable work in the creation of a letter layout to take full advantage of the new ergonomic shape we developed. My thanks also to Dr. P. Zipp and Butterworth R Co. (Publishers) Ltd. for permission to use figures from his paper (Figs. 1,2,3).

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