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ERGONOMIC KEYBOARDS
-
A COMPARATIVE POSTURE AND USABILITY STUDY

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Summary.

The design of computer keyboards is still characterised by that of mechanical typewriters which were developed over 100 years ago [1]. This 'standard' design imposes postural constraints which may lead to operator musculoskeletal stress problems. Alternative keyboard designs often attempt to reduce these stresses by, for example, keeping the hands in a more neutral position. These are often marketed as 'ergonomic' keyboards. Two of these 'ergonomic' keyboards were evaluated and compared to a 'standard' keyboard which acted as a control in the investigation. The subjective acceptance of the keyboards was also investigated since alternative designs are often rejected by established operators. The results suggest that a split design 'ergonomic' keyboard can help to reduce operator stress problems, by alleviating posture compromises, however the anthropometry of the user is shown to be an influencing factor. The split design 'ergonomic' keyboard was not accepted by the users; it was the design of the non-split design 'ergonomic' keyboard which was favoured and accepted by operators.

Introduction and Background.

The widespread introduction of computers into the workplace over the last two decades has exposed many people to daily interaction with keyboards. This increase in computer usage has lead to operator stress problems related specifically to keyboard tasks, and has generally revived interest in the physical health of the operators. Such stress problems are often casually grouped together under the various 'portmanteau' terms of Repetitive Strain Injuries (RSI's) or Work-Related Upper Limb Disorders (WRULD's), amongst others. Although not medically diagnostic, such terms are widely used to cover more precise musculoskeletal or nerve related injuries which may be caused or triggered by rapid, low-force actions. It is the design of the computer keyboard and its postural constraints that appear to be contributing to such conditions, and therefore as a result there have been many attempts to improve the keyboard design, for example in 1926 Klockenberg [2] proposed splitting the keyboard into two parts to enable the hands to be kept in a more natural position.

Many compensation claims have been made for WRULD's caused by the use of computer keyboards. For example in January 1996, a former Inland Revenue typist was awarded £82,000 after losing her job as a result of a WRULD[3].

The anatomy of the upper extremity permits movement of the hand in two planes only; palmer flexion, or extension when performed in the opposite direction, and ulnar or radial deviation (figure 1, overleaf). The risk of injury increases whenever manipulative

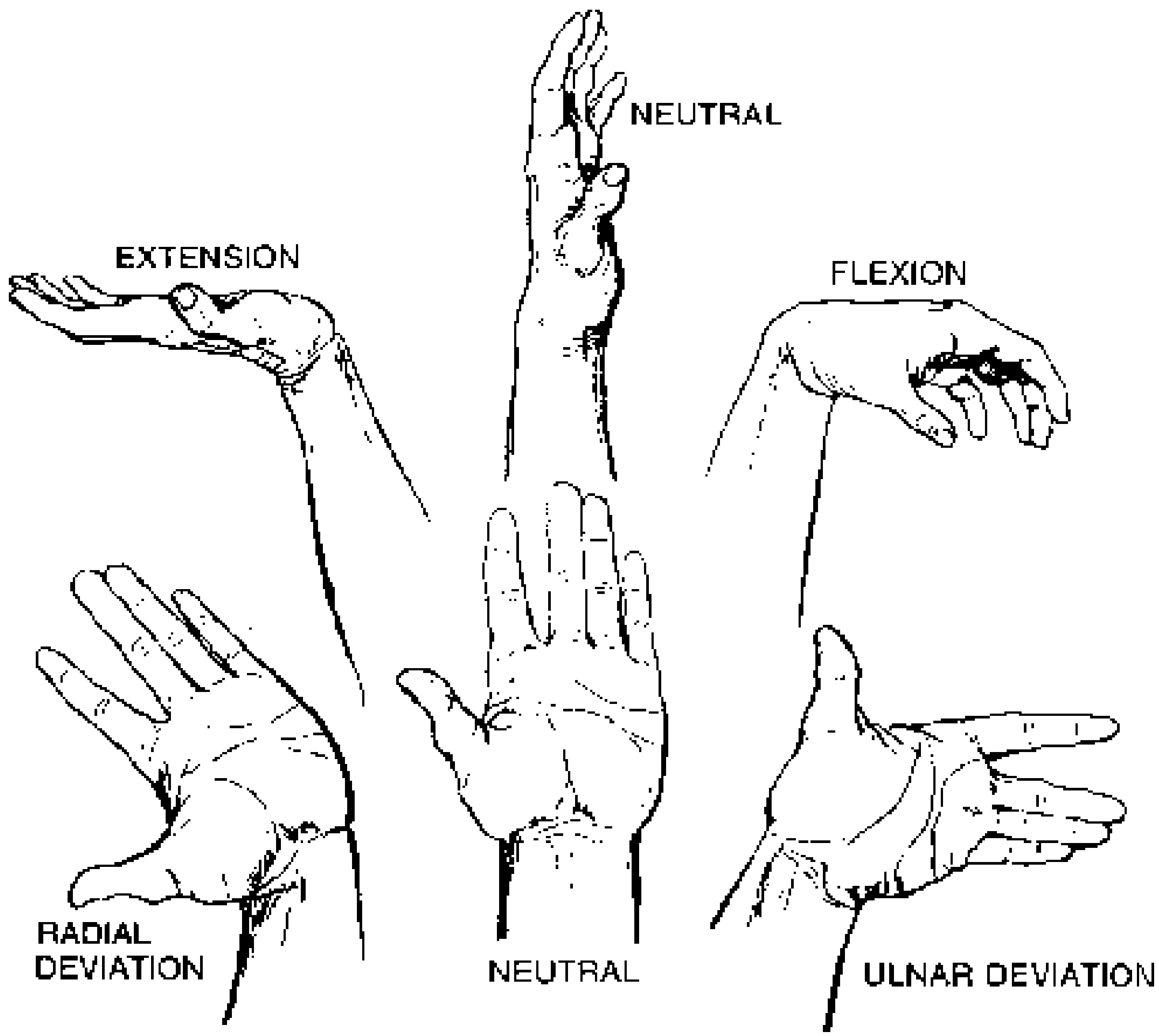

Figure 1. Hand Posture Terminology [10]

manoeuvres, especially forceful ones requiring ulnar or radial deviation, palmer or dorsiflexion, either singularly or in combination with each other, are performed. The forced misalignment of the tendons at the wrist under such circumstances, and their bunching up against each other can increase interstructural forces and thus the friction produced by the muscles operating the hand. Repeated, multiple work stresses over time can result in disease of the forearm or arm becoming clinically evident [4].

It is not possible to operate a conventional computer keyboard with the hands in an neutral position [5]. Due to its design, the keyboard requires the hands to be held in postures of extension, ulnar deviation and pronation. In order to alleviate pronation, users will over-extend the smaller fingers in order to place them on the same horizontal level as the index and middle fingers, or move the elbows away from the side of the body. Both of these compromises create potential isometric muscle contractions in their affected muscles. Furthermore, the shoulder span of users often exceeds the width of the keyboard, therefore it is necessary for them to bend the hands outwards (ulnar deviation of the wrists or wrist abduction) in order to place the unequal lengths of fingers on the home row. These contortions of the fingers require some fingers to be fully flexed and others fully extended, hence reducing the effectiveness of the controlling muscles, and also requiring some muscles to exert static contractions to retain the fingers in these positions. Since the finger muscles do not operate at maximum efficiency when contracted or extended, the onset of muscle fatigue is further accelerated [5]. From a field study on keyboard operators, Ferguson and Duncan [6] concluded that it is the flexion and abduction of the upper arm as well as the ulnar abduction and stretched position of the hands that may be the actual causes of physical troubles of keyboard operators.

It is widely agreed by researchers that the most desirable operating posture is one where the wrists are kept straight. However this straight and unsupported posture cannot be maintained since as the arm muscles tire, the forearms drop, and due to the positive slope of keyboards, wrist extension when typing increases. Therefore keeping the hands moving in a neutral posture zone is desirable. A zone of neutral posture for the wrist when typing is obtained when the hand is not excessively extended (<15°), flexed (<20°) or ulnarly or radially deviated [7]. It is clear therefore that the keyboard should be redesigned to allow more natural postures of the hands.

When the keyboard is split, the two halves must have an opening angle to minimise ulnar deviation of the hands, and must also have lateral slopes to decrease the degree of pronation of the wrist [8]. It has been said that the objective of an ergonomic keyboard is to create a human-orientated tool, with the main criteria for success being the reduction of stress and the improvement of operator acceptance [9]. One of the 'ergonomic' keyboards involved in the study utilises a split design, and was developed to match hand movements and reduce the postural stress imposed by the conventional computer keyboard, and hence minimize fatigue and any resulting pain and disability. The second 'ergonomic' keyboard claims to incorporate three ergonomic considerations which combine to make it easier and more comfortable to use. The design is not split and is highly conventional.

The two objectives of the research reported here were to investigate the extent to which postural advantages are offered to an operator by 'ergonomic' keyboards, when compared to a 'standard' computer keyboard, and to determine the acceptance of such keyboards by the operators.

Method.

Three techniques were applied to the investigation. A brief description and their application to the study are given in Table 1. (overleaf)

Results.

Table 2 (overleaf) provides a summary of the results from the stereophotogrammetry. Table 3 (overleaf) provides the results from the wrist scores from the RULA assessments. There was little different in the scores produced through the operation of the different keyboards, both overall, as indicated by the grand score, and for the individual body parts, except for the wrist scores. Table 4 provides the overall ease of use ratings and general overall ratings, as indicated in the questionnaire.

Table 1: A Summary of the Methods Applied.

Method	Definition	Description	Application
Stereophoto-grammetry [11]	Uses two cameras simultaneously to record three-dimensional information. Trigonometry can then be applied to mathematically model the subject	X,Y and Z co-ordinates are obtained for each of the body markers, which are placed at the shoulder, elbow, wrist and knuckle on the left hand side of the subject.. By obtaining these co-ordinates the position of each point in space can be determined and hence the relative angles between them, using trigonometry.	Used as the primary objective measuring tool. Evaluated the extent to which postural advantages are offered to an operator by 'Ergonomic' computer keyboards.
RULA [12]	Rapid Upper Limb Assessment survey method	A grand score is produced from assessments of the postures of the neck, trunk and upper limbs, along with muscle function and the external loads experienced by the body. This score is then used to determine the level of action needed to reduce the risks of injury.	Included because it is a simple and quick measuring tool and would give some indication of the postures involved in operation of the keyboards, particularly if the primary technique failed or proved not be viable.
Usability questionnaire [13]	-	Based on the work of Çakir [13], the questionnaire contained usability assessments and self-assessed postural comfort.	Aims to determine the acceptance of the keyboards in question by the operators.

Table 2: A Summary Of The Results From The Stereophotogrammetry.

	Standard Keyboard	**Non-split Design 'Ergonomic' Keyboard**	**Split-Design 'Ergonomic' Keyboard**
Abduction (angle in degrees)			
Mean	20.42	18.87	10.56
Standard Deviation	11.08	6.5	9.79
Extension (angle in degrees)			
Mean	14.10	14.15	10.04
Standard Deviation	10.69	10.46	6.58

Table 3: The Wrist Posture Scores From The RULA Assessments.

Subject Number	Standard Keyboard	Non-split Design 'Ergonomic' Keyboard	Split-Design 'Ergonomic' Keyboard
1 LHS=	3	3	2
RHS=	3	3	3
2 LHS=	3	3	1
RHS=	3	3	1
3 LHS=	4	4	2
RHS=	4	4	2
4 LHS=	2	2	2
RHS=	2	3	2
5 LHS=	3	4	2
RHS=	3	4	2

Key:
RHS = Right hand side LHS = Left hand side
The scores and their corresponding wrist postures:

1. = neutral; the wrist is straight
2. = 15° flexion/extension
3. = >15° flexion/extension
   + 1 if the wrist is in either radial or ulnar deviation.

Table 4: The Ease Of Use and General Overall Ratings Of The Keyboards, As Indicated On The Questionnaire.

Subject Number	Standard Keyboard	Non-split Design 'Ergonomic' Keyboard	Split-Design 'Ergonomic' Keyboard
1 - Ease of use	2	1	5
- General overall rating	1	1	-
2 - Ease of use	1	1	2
- General overall rating	2	3	1
3 - Ease of use	2	2	3
- General overall rating	3	2	2
4 - Ease of use	1	1	6
- General overall rating	2	2	6
5 - Ease of use	3	2	6
- General overall rating	3	2	-

Key:
Ease of use: Easy(1) - Difficult(6)
General overall rating: Good(1) - Bad(6)

Discussion.

Statistical analysis of the data collected stereophotogrammetrically, revealed a significant difference between the angles of abduction and extension produced from the operation of the split-design 'ergonomic' keyboard, when compared with the operation of the standard and non-split design 'ergonomic' keyboard. The split -design keyboard decreases the angle of ulnar abduction from around 20° to 10°. This decrease is due to the opening angle between the two halves of the keyboard. The angles of extension produced from operation of the split-design keyboard was approximately 29% lower than the extension angles produced from the operation of the other two participating keyboards. The mere adoption of the posture of ulnar deviation will give rise to sensations of tension in the muscles, tendons and ligaments concerned (6), i.e. static loading. Hence when sustained, such a posture is a significant potential contributor to muscle fatigue, disseminated overuse syndrome (14) and eventually WRULD's. By alleviating or reducing ulnar deviation, and extension to such an extent, the split-design 'ergonomic' keyboard will reduce the static muscle work of the upper extremities, hence lowering the risk of complications in the forearms and hands.

The rows of keys on a standard keyboard are spaced evenly over a distance of approximately 21cms. for both hands. However the separation of the elbows (with the arms comfortably by the sides) is so much greater than the width of the keyboard that the forearms must turn inwards across the front of the body when operating. This position will further aggravate ulnar deviation. Anthropometric data collected from the subjects, and the results from the stereophotogrammetry show that where the biacromial shoulder widths of the subjects is largest, the opening angle of the split-design keyboard is not sufficient to alter the angle of ulnar deviation produced from the operation of the keyboard. The shoulder widths of 'larger' operators will always exceed the width of a fixed angle split keyboard, forcing the forearms to continue to turn inwards and further aggravating ulnar deviation, despite the opening angle of the split-design keyboard. To accommodate the inward turning of the forearms without compensating by ulnar deviation would require a keyboard that is split in design, yet where the two halves could be separated to suit the shoulder widths of the individual operators.

From the results of the RULA applications it appears that for wrist postures when operating a computer keyboard, the introduction of the split-design keyboard can be seen as a successful modification to the workstation. It yields lower scores than the non-split designs, resulting in working postures where the risk factors for the wrist are now minimal. Rose (5) notes that it is not possible to operate a conventional keyboard with the hands in a neutral position, hence the absence of wrist scores of one for both of the non-split designs. Further-more, since the shoulder span of operators will often exceed the width of the keyboard, it is necessary to abduct the hands in order to place the unequal length fingers on the home row. This is illustrated in the RULA results for the wrist since the scores for the non-split designs are most frequently three and four. A additional score of one has often been added to the wrist score for these keyboards when the wrist is in either radial or ulnar deviation.

Conclusion.

This research suggests that the application of RULA alone to the study of keyboard operating posture is not suitable. The results produced did not reveal any differences in the postures adopted at the keyboards in question, except for the wrist postures. The unsuitability of RULA to this application is due to the level of detail it provides. For example it omits assess-ments of the fingers and thumbs, which is particularly pertinent to this study since risk factors for these digits is high. Furthermore it is thought that the range of motions produced by typing, are too manipulative for RULA to detect a difference in the postures adopted, when operating different designs of computer keyboard. The range of movement covered by each score for the body parts is considered too large to highlight such subtle differences in posture.

From the analysis of the questionnaire it appears that the subjects clearly preferred and easily accepted the design of the non-split design 'ergonomic' keyboard. For each of the assessments this keyboard was rated the most positively, while the split design was usually rated the most negative. A positive assessment on the dimensions included generally indicates a high acceptance of the design. The poor performance of the split-design keyboard on the questionnaire is possibly due to experimental design. Since negative transfer effects from prior use of a (standard) keyboard can last months, an extensive period of training and acclimitisation on the new design would be needed to ensure that the keyboard is more accurately evaluated. This was not possible within the timescale available in this study. Similarly for the self-assessed postural comfort component of the questionnaire, the split-design keyboard was often rated the least comfortable for the body parts included, while the non-split design 'ergonomic' keyboard was rated most comfortable. The poor performance of the split-design keyboard may be due to the unfamiliar postures forced by its design, which have been perceived as 'uncomfortable' by the subjects. The success of the non-split design 'ergonomic' keyboard on the questionnaire can attributed to its conventional design, switch lever mechanism and soft landing feature, which help to provide more comfort when operating. Since the subjects were not given prolonged training on the split-design keyboard, the findings of the questionnaire can only be tentative. The use of stereophotogrammetry to establish upper limb postures in three-dimensions was established and has been discussed more fully elsewhere [11].

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