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September 29, 1995

Mr. John Choate
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Dear Mr. Choate:

Dr. Robertson ask that I fax and send a copy of this paper.

Therefore, enclosed that is what you will find.

Sincerely,

Debbie

Debora R. Sampson, Secretary to
Rick N. Robertson, Ph.D.

DRS:
Enclosure

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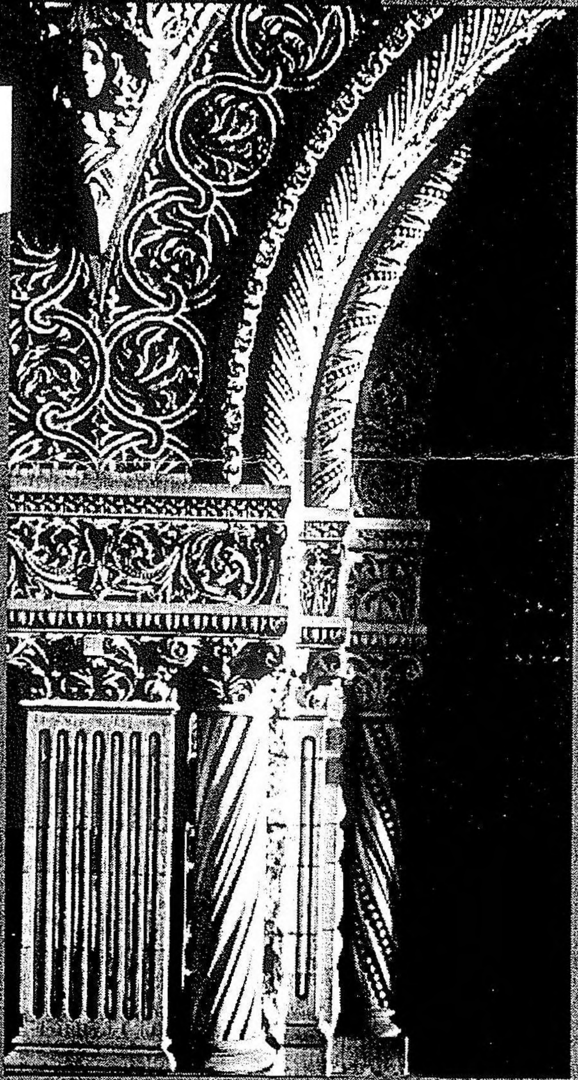

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QUANTIFICATION OF TENDON EXCURSION THROUGH KINEMATIC ANALYSIS OF TYPING MOVEMENTS ON ALTERNATIVE KEYBOARD LAYOUTS

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INTRODUCTION

Cumulative trauma disorders (CTD) account for over 60% of reported occupational illnesses and a large number of these cases are among office workers and keyboard operators (BLS, 1992). CTD's continue to be a problem despite growing attention to workstation ergonomics and other preventative strategies. One might conclude that the standard keyboard layout needs to be analyzed in terms of injury potential. Typing on the standard or 'QWERTY' keyboard layout demands large, awkward movements since the keyboard layout was originally designed to slow typing and prevent jamming of the keys of early typewriters. These large angular excursions of the fingers can translate internally to large excursions of the finger flexor tendons through the confined area of the carpal canal. Evidence suggests that excessive excursion can induce trauma to the connective tissue structures resulting in tendinitis and edema. This becomes particularly serious when swelling of the tissues compress the median nerve causing symptoms typically ascribed to Carpal Tunnel Syndrome. By minimizing range during repetitive motion one may reduce tendon excursion and the reduce probability of cumulative trauma. Minimization of range can be translated in a practical sense to alternative keyboard layouts which map the most frequent keys to the home row. This paper presents preliminary results in quantifying tendon excursion for typing on the QWERTY layout and two alternative keyboard layouts. Data was collected for three subjects through video motion analysis and tendon excursions were calculated through a predictive model. Two subjects showed consistent results with the alternative layouts requiring less total excursion than the standard layout.

REVIEW AND THEORY

Carpal Tunnel Syndrome (CTS) is thought to be caused by compression of the median nerve within the carpal canal. The main structures in close proximity to the median nerve are the finger flexor tendons - Flexor Digitorum Profundus and Superficialis. Thickening of the flexor tendon sheaths, secondary to repetitive motion, has been implicated as a cause for compression of the median nerve (Werner et al., 1983). Cyclic loading tests on the profundus tendons have shown that stress transmitted to the sheath during excursion is significant and a cause of cumulative strain (Goldstein et al., 1987). These findings may indicate that the highly repetitive sliding motion of the tendons through the canal might not only produce tendinitis or tenosynovitis but focal damage to the nerve as well. A number of ergonomic studies also support the findings in correlating repetitive typing motion with a high incidence of CTD. Pascarelli et al. (1993) evaluated 53 disabled keyboard operators and found symptoms of pain and paresthesia in addition to over a third diagnosed with CTS.

Previous biomechanical studies of keyboards include a study by Gerard et al. (1994) which found that the subjects exhibited less muscle activity to maintain a resting posture for typing on a split contoured keyboard with standard layout. Nakaseko et al. (1985) tested the split keyboard with adjustments of opening angle, lateral inclination and forearm support. About 70% of the subjects preferred the split keyboard with a large forearm wrist support. Other studies have focused on the development of a biomechanical model of typing including characterization of impact loading and fingertip kinematics (Dennerlein et al., 1993).

The QWERTY layout is the standard alphanumeric input device for computer entry. Inherent in using the QWERTY layout is the relatively large excursions of the fingers. Ober (1993) calculated that the fingers of a typist on a QWERTY layout would travel 2.6 miles a day during a typical 8 hour day. For the DVORAK layout, the fingers would travel only 1.7 miles. The DVORAK layout is an alternative layout in which the 70-80% of typing is performed on the home row. Another layout is the ASINREDHOT (Finger Relief Co., Stamford, CT) which minimizes the remapping of the keys yet retains the majority of the typing on the home row.

The present study investigated changes in kinematics and flexor tendon excursion for the standard and alternative keyboard layouts. The goal of the study was to characterize total tendon motion for typing a matched sample on the QWERTY, DVORAK and ASINREDHOT layouts and provide a preliminary survey of the results.

PROCEDURES

Fourteen 6 mm reflective markers were adhered to the dorsal surface of each hand at the centerline of the MP, PIP, DIP joints. Markers were also placed at the wrist joint between the styloid processes and at a location 4 cm proximal to the wrist marker. A Peak5 motion analysis system was utilized to calculate the 3-dimensional coordinates and joint angles of the fingers and wrist. Two cameras were positioned at oblique angles on the right and left sides of the keyboard and a third camera was positioned above the monitor for the frontal view of the hands. A custom calibration frame (36 cm x 25 cm x 16 cm) encompassing the volume of the motion was used to accurately calculate the coordinates of the markers within the volume space. A hardware circuit and software program were implemented to synchronize the keystroke data with the 1/60 second video data. Typing speed in wpm was also measured in software during typing trials. An LED was used to synchronize the three cameras at the start of each trial.

Three dimensional coordinates were obtained by digitizing the markers in each camera view. Flexion and extension angle data were calculated at the wrist, MP, and PIP joints. The angle data was incorporated into the predictive model developed by Armstrong and Chaffin (1978). The model relates the finger and two extrinsic finger flexors, profundus and superficialis, as a pulley system dependent on the joint angle and tendon moment arm. Joint thickness measurements were taken of each subject as described in the Collation of Anthropometry (Garrett et al., 1961).

The text sample consisted of nonsense "words" reflecting the frequencies of letters and word lengths of "standard" written English. Statistical representation of letter frequency was critical since the alternative layouts are designed to map the most frequent keys on the home row. The alternative keyboard layouts were "simulated" by replacing the letter location on the alternative layout with the QWERTY equivalent. For example, the first nonsense word in the text sample is "rvw". The letters "r", "v" and "w" correspond to key locations "o", "." and "," respectively on the DVORAK layout. Simulation of layouts does not require keyboard retraining and allows each subject to act as their own control. This is especially important since typing kinematics are unique to the individual.

Data was collected for three subjects with average touch typing speeds of 40 wpm. Each subject typed the 100 character text sample for the three simulated layouts. Valid trials were those with one or no errors to preserve integrity of letter frequencies.

RESULTS

The first 5 seconds of the left index PIP angle and keystroke data for Subject 1 for both QWERTY and DVORAK layouts are plotted in Figure 2. Note the angular deflections in typing of letters "r", "v" and "f" as these keys are assigned to the left index finger on the QWERTY layout. Conversely on the DVORAK layout only slight variations were recorded as only one key on the home row ("f") was typed by this finger in the portion of data shown.

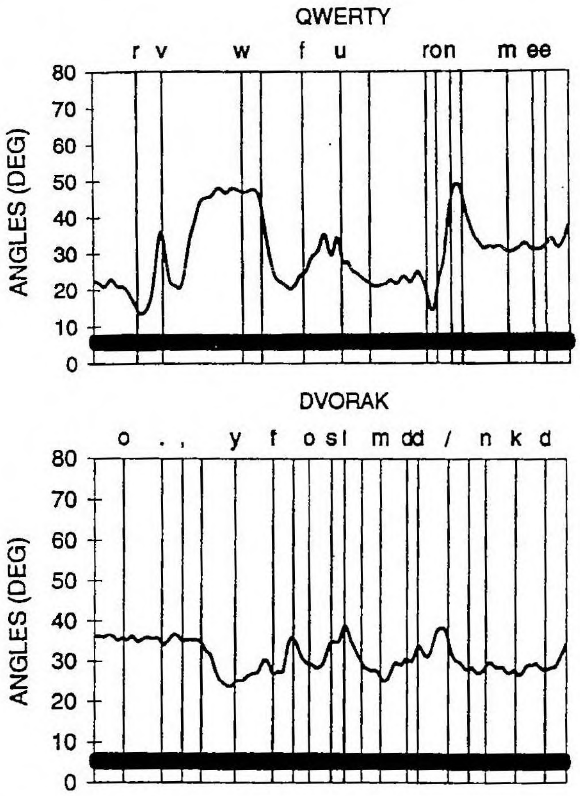

Figure 1. Sample plots of left index PIP angle data and keystroke timing in QWERTY and DVORAK typing trials of subject 1.

The tendon excursion per digit for the profundus tendons of Subject 1 (left hand) is provided in Figure 2. A comparison of total tendon excursion (summation of profundus and superficialis displacement in both hands) of all subjects is provided in Table 1. Calculations for the excursions of the superficialis tendons were relatively similar to those of the profundus.

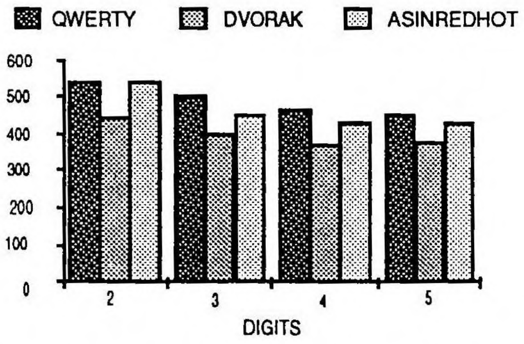

Figure 2. Excursion of the flexor digitorum profundus in digits 2-5 (left hand) of subject 1

Table 1. Total excursion (in mm) and % difference for profundus flexor tendon for each keyboard layout

	QWERTY	DVORAK	ASINREDHOT
Subj. 1	3638	3476	3371
% Diff		4.5 %	7.3 %
Subj. 2	3300	3085	3208
% Diff		6.5 %	2.8 %
Subj. 3	3412	3619	4000
% Diff		- 6.1 %	- 17.2 %

DISCUSSION

Subjects 1 and 2 showed consistent results with the DVORAK and ASINREDHOT layouts requiring less total tendon excursion than typing on the QWERTY layout. Angular displacement plots also correlated with these findings. The third subject, however, showed opposite results, indicating variability of kinematics and/or performance. One of the variables which was not controlled was typing speed. It was noted that subject 3, unlike subjects 1 and 2, typed with significant speed variation between the QWERTY (51 wpm) and alternative layouts (about 38 wpm). Future studies may need to account for digraph effects, or common letter pairs, in the text samples to ensure consistent, natural kinematics for all three layouts. The basic methodology, however, proved to be acceptable in measuring tendon excursion. According to Moore et al. (1991), the best method of studying ergonomic impact is in quantifying the effects on internal structures. Long range goals for these studies may be the establishment of guidelines in keyboard modification and typing techniques for the purpose of reducing the incidence of CTD among keyboard operators.

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