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Impact of keyboard typing on the morphological changes of the median nerve

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Abstract: Objectives: The primary objective was to investigate the effects of continuous typing on median nerve changes at the carpal tunnel region at two different keyboard slopes (0° and 20°). The secondary objective was to investigate the differences in wrist kinematics and the changes in wrist anthropometric measurements when typing at the two different keyboard slopes. **Methods:** Fifteen healthy right-handed young men were recruited. A randomized sequence of the conditions (control, typing I, and typing II) was assigned to each participant. Wrist anthropometric measurements, wrist kinematics data collection and ultrasound examination to the median nerve was performed at designated time block. **Results:** Typing activity and time block do not cause significant changes to the wrist anthropometric measurements. The wrist measurements remained similar across all the time blocks in the three conditions. Subsequently, the wrist extensions and ulnar deviations were significantly higher in both the typing I and typing II conditions than in the control condition for both wrists ($p<0.05$). Additionally, the median nerve cross-sectional area (MNCSA) significantly increased in both the typing I and typing II conditions after the typing task than before the typing task. The MNCSA significantly decreased in the recovery phase after the typing task. **Conclusions:** This study demonstrated the immediate changes in the median nerve after continuous keyboard typing. Changes in the median nerve were greater during typing using a keyboard tilted at 20° than during typing using a keyboard tilted at 0°. The main findings suggest wrist posture near to neutral position caused lower changes of the median nerve.
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1 Introduction

Recently, computer technology has evolved rapidly, and computers have become one of the essential tools used in daily work in most industries. The literature suggests that computer users are exposed to a high risk of upper musculoskeletal symptoms and work-related musculoskeletal disorders.[1,2] Carpal tunnel syndrome (CTS) is one of the most common peripheral neuropathies among work-related musculoskeletal disorders.[3] CTS occurs when the median nerve is compressed at the carpal tunnel, and it not only affects the quality of life of individuals, but it also has a huge impact on social burden and the economy.[4,5] Notably, CTS could result from work-related activities, non-work-related activities, or both.[6] Over the years, several etiological factors have been found to be associated with CTS, such as age, sex, obesity, and medical conditions, including trauma to the wrist, diabetes mellitus, and arthritic diseases.[7-9]

The contribution of the underlying etiology to computer work-related CTS remains inconclusive. Nevertheless, both positive and negative results on computer work-related CTS have been reported. Several studies have investigated and summarized the biomechanical factors at the workplace, such as forceful gripping, deviated wrist angle from neutral, vibration, and repetition, and their potential risk association with the incidence of CTS.[10-15] On the other hand, systemic reviews have suggested that computer work does not have an important association with CTS,[9] and limitations such as study design, CTS diagnostic methods, biomechanical exposure-quantifying methods, and exposure-outcome measurements could result in potential information bias.[10,16]

Upper extremity posture and the duration of tasks involving the use of computer input devices, such as a keyboard and mouse, contribute to musculoskeletal discomfort among computer users.[1,17] Computer keyboard and mouse use are known to increase carpal tunnel load and cause deformation of the median nerve longitudinal axis.[18] Several studies have reported that changes in wrist posture, finger movement, and contact stress can lead to an increase in carpal tunnel pressure.[19-21] On the other hand, wrist and/or finger movements cause the cross-sectional area of the median nerve to become small at the carpal tunnel region.[22-26]

Previous studies have reported that computer keyboard typing causes acute swelling of the median nerve and that an ulnar deviated wrist during keyboard typing may be a predictor of median nerve changes.[27,28] However, these studies did not examine the effects of keyboard slope during the computer typing task on wrist angle changes and the influences on median nerve changes. Additionally, the design of the keyboard and its position on the workstation could lead to different wrist postures during keyboard typing.[29,30] Therefore, the primary objective of the present study was to investigate the effects of continuous typing on median nerve changes at the carpal tunnel region at two different keyboard slopes (0° and 20°). The secondary objective was to investigate the differences in wrist kinematics and the changes in wrist anthropometric measurements when typing at the two different keyboard slopes.

2 Materials and Methods

2.1 Participants

A convenience sampling method was used to recruit participants in this study. Fifteen right-handed healthy young men (age: 24.8 ± 2.3 years; height: 173.1 ± 4.8 cm; weight: 69.9 ± 9.6 kg; BMI: 23.4 ± 3.3 kg/m^2) without known upper limb musculoskeletal disorders were recruited. The handedness of the participants was determined using the Edinburgh Handedness Inventory.[31] The participants provided written informed consent, and this study was approved by the Ethics Committee of the Faculty of Design, Kyushu University (Approval number 141).

2.2 Experimental Protocol

Participants were required to participate in the following three conditions: control, typing I and typing II. A randomized sequence of the conditions was assigned to each participant. Additionally, the participants were instructed not to perform exercises or weight training involving forceful and repetitive grasping and/or gripping one day prior to participating in the conditions.

Anthropometric measurements for a seated computer workstation were performed prior to participation in the conditions. The participants used a height-adjustable table and chair for all the conditions. First, the chair height was adjusted to allow 90° knee flexion with the feet rested on the floor. Then, the table height was adjusted such that it was aligned to the participant's seated elbow height. Lastly, the height of the computer monitor was set at the participant's seated eye level.

In the control condition, the participants were seated at the workstation with the forearms placed on the table while watching an entertainment show on the computer monitor. The participants were instructed to minimize upper limb movements throughout the control condition. In the typing I and II conditions, the participants were required to perform four 30-min computer typing tasks. A 106-key Japanese keyboard with a thickness of 15 mm was used for computer typing. The keyboard slope was set at 0° for the typing I condition, and a custom-made wedge was used to set the keyboard slope at 20° for the typing II condition. The Typing Trainer™ software (Typing Master Finland, Inc., Helsinki, Finland) was used to monitor typing performance and collect data for each participant.

The control and typing conditions included seven and eight time blocks, respectively, with each time block lasting for 30 min. Wrist ultrasound examination and wrist anthropometric measurements were performed at the end of every 30-min time block. In addition, kinematic data of the wrists were recorded at four time blocks (0, 30, 60, and 90 min) in all three conditions. In order to minimize the rest time between time blocks, the ultrasound examination and wrist anthropometric measurements were completed within 8 min.

2.3 Wrist Anthropometric Characteristics and Wrist Kinematic Measurements

The wrist circumference at the distal border of the ulnar styloid level was measured with an anthropometric tape measure (Cescorf Equipamentos para Esporte Ltda, Porto Alegre, Brazil). The wrist width and wrist depth were measured with a sliding caliper at the same level as the wrist circumference measurement. The wrist anthropometric measurements were repeated at each time block. A single examiner was assigned to ensure consistency and accuracy in wrist anthropometric measurements.

Bilateral wrist joint movements were recorded with a twin-axis goniometer (Model SG 110, Biometrics Ltd, Newport, UK). The distal and proximal end-blocks of the goniometer were attached over the third metacarpal bone and mid-girth of the forearm, respectively. The twin-axis goniometer (SG 110) measured wrist joint movements in two planes (extension/flexion and radial/ulnar deviation). Each goniometer was connected to a wireless goniometer logger and monitored with the Wireless Measurement Application (version 7.11.1) (Sports Sensing Co., Ltd., Fukuoka, Japan) at a 10-Hz sampling rate for both axes.

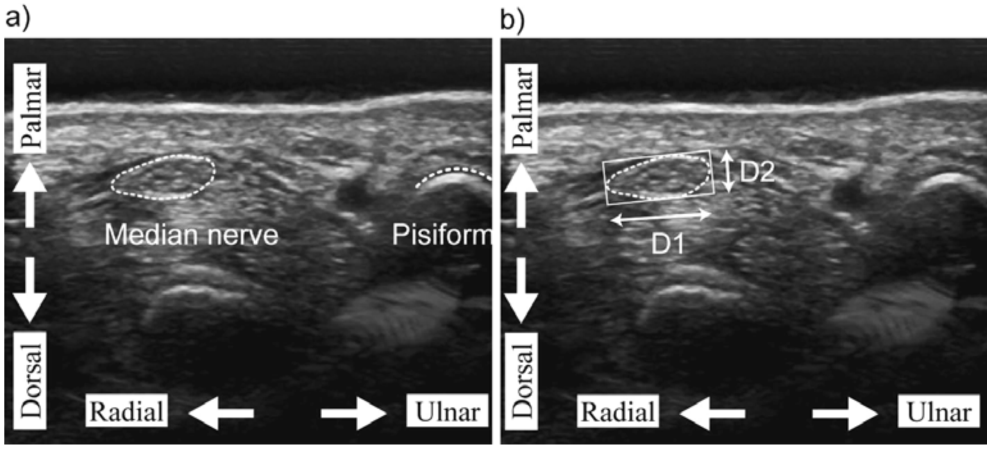

Fig. 1. Quantification of the (a) median nerve cross-sectional area using the tracing method and (b) median nerve diameter using the minimum bounding rectangle method.

Wrist flexion and ulnar deviation were presented with negative angles. Wrist kinematic measurements were continuously performed for four time blocks (0, 30, 60, and 90 min).

2.4 Ultrasound Examination Protocol

Ultrasound images were obtained using the LOGIQ e ultrasound system (GE Healthcare, Milwaukee, WI) with a 12L-RS transducer (imaging frequency bandwidth of 5-13 MHz). A 7.0-mm-thick sonar pad (Nippon BXI Inc., Tokyo, Japan) was used as a coupling agent during the ultrasound examination. The examiner placed the ultrasound transducer gently on the sonar pad to avoid compressive pressure at the wrist during the examination. The forearm was positioned in supination and rested on an arm support on a table, with the elbow at 30° flexion, during the ultrasound examination. The examiner placed the ultrasound transducer parallel to the distal wrist crease to identify the median nerve in the transverse plane, with the proximal border of the pisiform as the anatomical landmark in all conditions. A custom-made L-shaped frame was used to assist the examiner in placing the transducer perpendicular to the wrist. Three images were obtained in a neutral position (0°) for both wrists.

2.5 Image Processing and Analysis

The median nerve cross-sectional area (MNCSA) (Fig. 1a) was quantified using ImageJ software (National Institutes of Health).[32] The median nerve was identified as a hyperechoic structure in the transverse plane, and then, the MNCSA was quantified using the tracing method along the hyperechogenic rim. This quantifying method from a previous study showed good-to-excellent intra- and interrater reliability.[24] Next, the OpenCV library (version 3.1) accessed with a python script was used to quantify the longest diameter in the radial-ulnar direction (D1) and longest diameter in the dorsal-palmar direction (D2) on the traced outline of the median nerve using the minimum bounding rectangle method (Fig. 1b). The mean MNCSA, D1, and D2 of three images were calculated for each time block.

2.6 Statistical Analysis

Two-way repeated analysis of variance (3 × 7 factorial design) was performed with the three conditions (control, typing I, and typing II) and seven time blocks (−30, 0, 30, 60, 90, 120 and 150 min) as factors to examine the differences in wrist anthropometric measurements for both wrists. Subsequently, two-way repeated analysis of variance (3 × 4 factorial design) was performed with the three conditions (control, typing I, and typing II) and four time blocks (30, 60, 90, and 120 min) as factors to examine the differences in wrist kinematics for both wrists.

Next, two-way repeated analysis of variance (3 × 8 factorial design) was performed with the three conditions (control, typing I, and typing II) and eight time blocks (−30, 0, 30, 60, 90, 120, 150, and 180 min) as factors to examine the effects of typing on the MNCSA, D1, and D2. Post-hoc pairwise Bonferroni-corrected comparisons were performed to examine the significant effects between conditions. A post-hoc Dunnett's test was performed to compare the median nerve measurements (MNCSA, D1, and D2) with the time block of 0 min as the control.

A nonparametric Kruskal-Wallis H test was used to examine the differences in typing performance between the typing I and typing II conditions. Subsequently, the Friedman test was performed to examine the repeated measures of typing performances in each condition. All statistical analyses were performed using SPSS version 21.0 software (IBM Corp., Armonk, NY). The significance level was set at α=0.05. All results are presented as mean ± standard deviation.

Table 1. Wrist anthropometric measurements for all conditions (n=15).

Measurement (mm)	Condition		
	Control	Typing I	Typing II
Right wrist			
Wrist circumference	165.3±7.8	165.1±8.0	165.6±8.2
Wrist width	57.9±3.5	57.6±3.2	57.7±3.3
Wrist depth	41.7±3.5	41.6±3.5	42.0±3.2
Left Wrist			
Wrist circumference	163.9±7.4	164.0±7.7	164.5±8.1
Wrist width	57.4±3.3	57.1±3.3	57.2±3.4
Wrist depth	40.9±2.9	40.9±2.7	41.2±3.2

3 Results

The average day span of the randomize conditions (control, typing I and typing II) between conditions I - II, II - III and I - III were 5.3 ± 2.7, 4.1 ± 2.0, and 9.4 ± 4.2 days, respectively.

3.1 Wrist Anthropometric Characteristics

The main effects of condition and time block on the wrist anthropometric measurements were not significant. Wrist circumference, wrist width, and wrist depth remained similar across all the time blocks in the three conditions. The measurements in the control, typing I, and typing II conditions are summarized in Table 1.

3.2 Wrist Kinematic Measurements

The main effect of condition on the changes in wrist flexion-extension was significant ($p<0.01$). The wrist extension was significantly higher in both the typing I and typing II conditions than in the control condition for both wrists ($p<0.05$) (Fig. 2). Furthermore, the wrist extension of only the right wrist was significantly higher in the typing II condition than in the typing I condition ($p<0.05$). The main effect of time block on the angle changes of wrist flexion-extension was not significant.

The main effect of condition on the wrist radial-ulnar deviation was significant in all conditions ($p<0.05$). The wrist ulnar deviation was significantly higher in both the typing I and typing II conditions than in the control condition for both hands ($p<0.05$) (Fig. 2). However, there was no significant difference in the wrist radial-ulnar deviation between the typing I and typing II conditions. Similar to wrist flexion-extension movements, the main effect of time block on the changes in wrist radial-ulnar deviation was not significant.

3.3 Median Nerve Cross-sectional Area Changes in the Control, Typing I, and Typing II Conditions

The main effect of time block on the MNCSA changes was not significant in the control condition. On the other hand, the main effects of condition and time block on the MNCSA changes were significant in both the typing I and typing II conditions ($p<0.01$). However, the effect of the interaction between condition and time block on the MNCSA changes was not significant. No significant differences were noted in the baseline measurements of the MNCSA (time blocks: −30 and 0 min) in all the three conditions. The MNCSA significantly increased in both the typing I and typing II conditions after the typing task (time blocks: 30, 60, 90, and 120 min) than before the typing task (time block: 0 min) (Fig. 3). The MNCSA significantly decreased in the recovery phase (time blocks: 150 and 180 min) after the typing task. Generally, the MNCSA was larger in the typing II condition than in the typing I condition. However, the MNCSA was significantly larger in the typing II condition than in the typing I condition only for the right wrist.

3.4 Median Nerve Diameter Changes in the Control, Typing I, and Typing II Conditions

Similar to the MNCSA, the main effect of time block on the median nerve diameter was significant in both the typing I and typing II conditions ($p<0.05$). However, Dunnett's test indicated that the main effect of condition on only the D2 changes was significant in both the typing I and typing II conditions ($p<0.05$) (Fig. 4). In addition, the effect of the interaction between condition and time block on the D1 and D2 changes was not significant. The D2 values at the time blocks of 60 and 90 min were larger in the typing I and typing II conditions than in the control condition.

3.5 Typing Performances

Table 2 summarizes the typing performances in both the typing I and typing II conditions. The Kruskal-Wallis H test indicated no significant differences in typing performances (words per minute [WPM], gross stroke, and accuracy) between the typing I and typing II conditions. The typing performances between time blocks were not

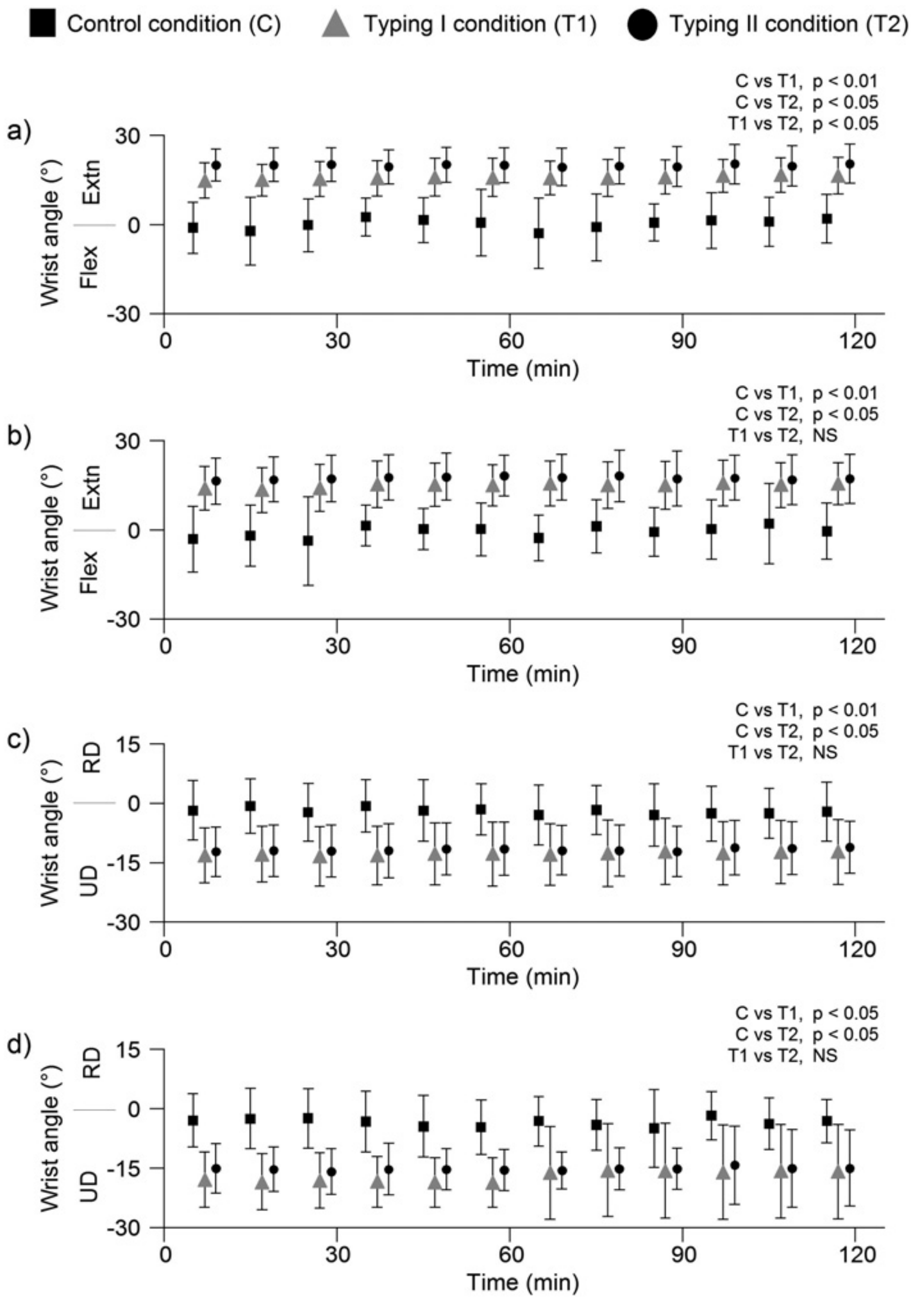

Fig. 2. Wrist kinematic changes in all the conditions.
(a), (c): right wrist; (b), (d): left wrist. Flex: flexion, Extn: extension; RD: radial deviation; UD: ulnar deviation. The mean wrist angle is presented at 10-min intervals.

significant, except for the gross stroke in the typing I condition (p<0.01) (Table 2).

4 Discussion

4.1 Wrist Anthropometric Characteristics

Asymmetrical wrist kinematics and wrist postures are commonly seen among computer users while typing. In the present study, wrist anthropometric characteristics, such as circumference, width, and depth measured in the three conditions remained almost unchanged before and after continuous typing (Table 1). These results suggest that continuous keyboard typing and differences in keyboard slope do not cause acute changes to wrist anthropometric characteristics.

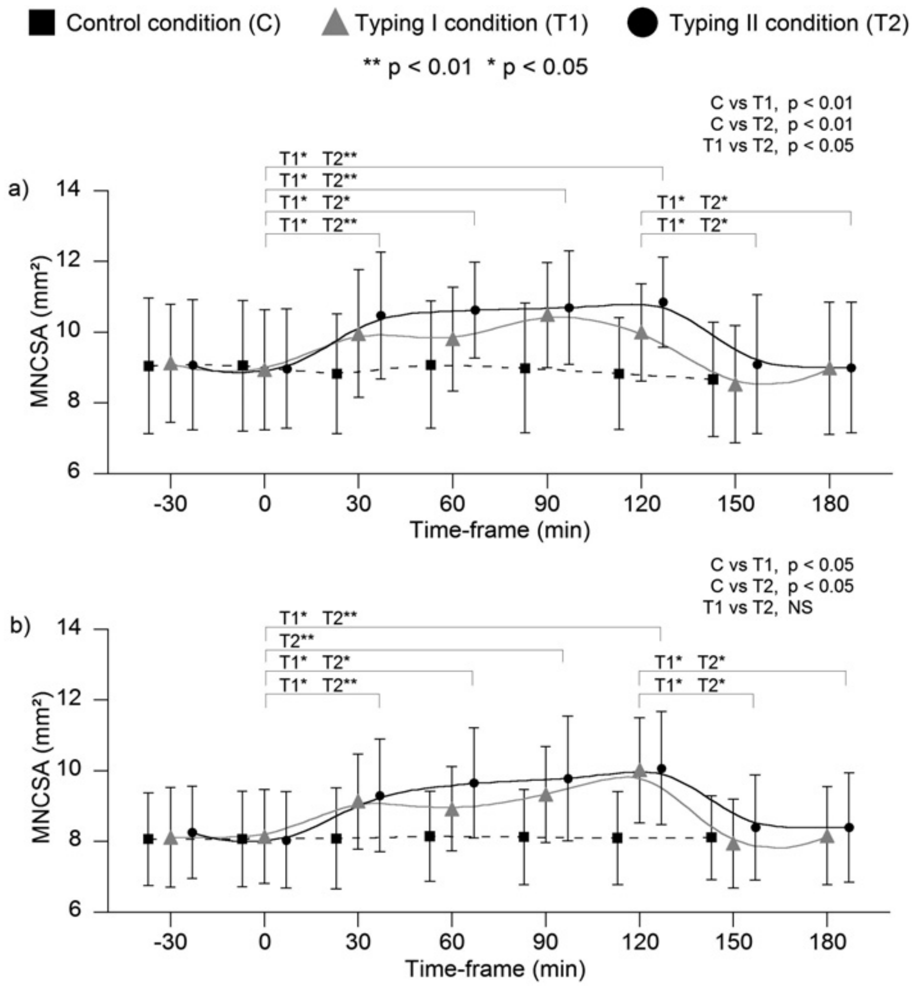

Fig. 3. Median nerve cross-sectional area (MNCSA) changes in all the conditions. *(a) right wrist; (b) left wrist.*

4.2 Impact of Keyboard Typing on the Median Nerve Cross-sectional Area

In the present study, the MNCSAs of both wrists were significantly higher in the typing conditions than in the control condition (Fig. 3). The increases in the MNCSA after typing for 30 min could be due to compression stress at the median nerve secondary to the wrist extension posture, as well as the finger flexor tendons gliding during typing. According to previous studies, single finger and multiple finger flexion movements, and task duration are known to cause a high shear force between tendons.[33,34) Therefore, repetitive finger flexion movements during keyboard typing could lead to an increase in the MNCSA secondary to subsynovial connective tissue swelling from friction between the finger flexor tendons and the median nerve.

The underlying factors that contribute to acute swelling of the peripheral nerve after physical work remain unclear. Generally, physical work has been shown to cause inflammation of the neural tissues and changes in the cross-sectional area of the peripheral nerve.[35,36) Moreover, studies have demonstrated distinguishable mechanical properties and shear movements of the sheath and the core of peripheral nerve during the application of pullout force.[37,38) Therefore, repetitive wrist and finger joint movements could increase the neural dynamic gliding properties and the transverse contraction stress on the median nerve. Therefore, both extra-neural factors, such as shear strain and compressive stress from subsynovial connective tissues and finger flexor tendons, and intra-neutral movements, such as fascicle friction within the epineurium, might contribute to the swelling of the median nerve (Fig. 3) after continuous keyboard typing.

The median nerve measurements between typing with the keyboard at a 0° slope and a 20° slope were compared. The MNCSA was larger when participants typed at a 20° slope than at a 0° slope for both wrists (Fig. 3). Additionally, the wrist extension angle was greater when participants typed at a 20° slope than at a 0° slope (Fig. 2). The carpal tunnel volume reduces as the wrist deviates

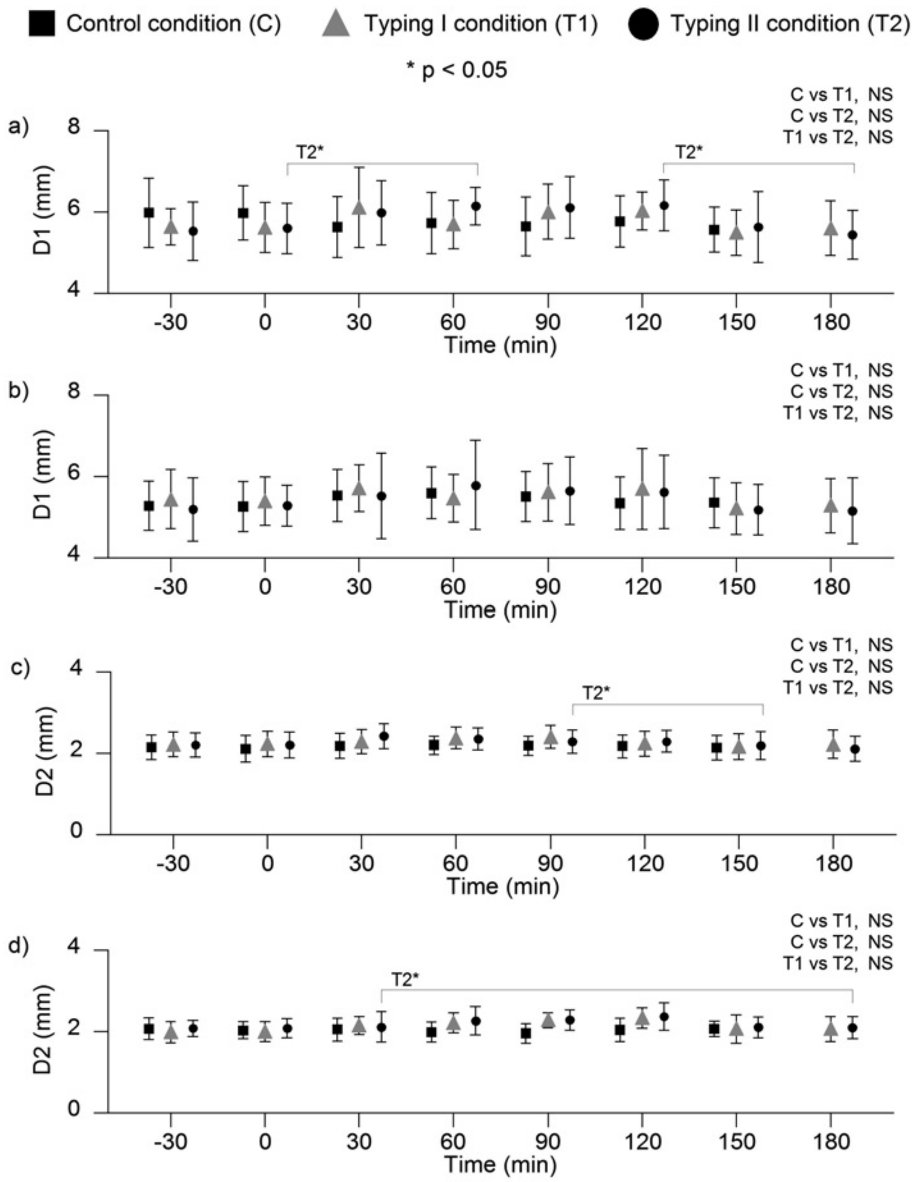

Fig. 4. Median nerve diameter (D1 and D2) changes in all the conditions.
(a), (c) right wrist; (b), (d) left wrist.

into an extension posture.[39] Consequently, the shear strain of the subsynovial connective tissue is known to increase as the wrist deviates from a neutral position to extension and flexion.[40] Therefore, typing with a high wrist extension angle may potentially result in high biomechanical stress at the median nerve owing to a high shear strain at the subsynovial tissues between the finger flexor tendons within the carpal tunnel. A previous study suggested that a high wrist ulnar deviation during typing could lead to a high swelling ratio of the median nerve.[27] However, the ulnar deviation angles in both typing conditions were approximately −12° and −16° for the right and left wrists, respectively. Therefore, high wrist extension during typing at a 20° slope may lead to a greater change in the MNCSA than that observed when typing at a 0° slope.

Notably, the MNCSA was consistently larger at each typing time block until the end of the typing task than at baseline (time block: 0 min). Subsequently, the MNCSA recovered to the baseline level after 30 min of rest (time block: 150 min) and remained the same after 60 min of rest (time block: 180 min) (Fig. 3). Although the typing tasks in this study were 1 hour longer than the tasks in previous laboratory studies,[27,28] the effect of rest on the median nerve after continuous keyboard typing observed in this study is in agreement with the findings of previous studies. Therefore, rest after continuous keyboard typing is important to allow recovery of the swollen median nerve.

Table 2. Summary of typing performances in the typing I and II conditions (n=15).

Condition	Performance	Time (min)			
		30	60	90	120
Typing I	WPM	24.9±12.0	25.3±10.2	26.5±10.2	26.2±11.0
	Gross stroke	3806±1808	3816±1584	4048±1514	4068±1696*
	Accuracy (%)	92.9±4.2	94.7±2.2	94.8±2.5	94.9±1.6
Typing II	WPM	27.3±11.4	27.5±11.1	27.5±11.4	27.5±10.2
	Gross stroke	4174±1704	4177±1672	4201±1721	4186±1549
	Accuracy (%)	94.4±2.3	94.5±2.4	95.2±1.3	94.8±1.9

WPM: words per minute; *$p<0.01$

4.3 Impact of Keyboard Typing on the Median Nerve Diameter

Previous studies explained the morphologic adaptability of the median nerve to extra-neural stress by showing a decrease in the MNCSA and changes in the median nerve diameter at different wrist and finger postures.[22,24-26) Therefore, the irregular shape of the median nerve is influenced by compression stress from surrounding finger flexor tendons within the carpal tunnel. The changes in the MNCSA in the typing I and typing II conditions may suggest an observable proportionate change in the median nerve diameter over typing time. The changes in D1 were inconclusive between the typing I and typing II conditions at different time blocks. In contrast, the D2 values of the left hand were significantly larger at the time blocks of 90 and 120 min than at baseline (time block: 0 min).

Originally, the median nerve diameter was postulated to increase corresponding to the changes in the MNCSA. However, an increase in the MNCSA after keyboard typing did not affect the change in the median nerve diameter (Fig. 4). These findings may suggest a limited capacity for the median nerve to expand in the longitudinal and vertical directions (Fig. 1b) in response to intra-neural edema. Therefore, an increase in the MNCSA with an unchanged median nerve diameter after keyboard typing may indicate an elevation of the intra-neural pressure within the median nerve at the carpal tunnel region. Studies have suggested that the endoneurial fluid pressure increases rapidly and persists after exposure to extra-neural stress.[41-43) Consequently, compressive and shear stresses resulting from repetitive wrist and finger movements may potentially cause edema at the median nerve.

The present study had some limitations. First, the participants in this study had a typing speed of approximately 27 WPM, which is lower than the average typing speed of 36-55 WPM. [28) A slow typing speed may reduce the impact of biomechanical stress on the median nerve and consequently affect the median nerve measurements. Next, the contact force of the palmar wrist on the table was not measured in the control and typing conditions. External contact stress at the wrist may affect the carpal tunnel volume and carpal tunnel pressure. Subsequently, individual differences with regard to the fingertip force applied during keyboard typing may influence the changes in the median nerve. Finally, sex and age are known to be associated with the incidence of CTS.[7,8) This study demonstrates the changes in the median nerve among only young male participants. In comparison, carpal tunnel volume of female individuals is smaller than that of male individuals,[44) which may affect the deformation of the median nerve after keyboard typing. Therefore, further investigations among female individuals are needed to understand the impact of keyboard typing across different age groups among female individuals.

5 Conclusion

This study demonstrated changes in the median nerve after continuous keyboard typing. Changes in the median nerve were greater during typing using a keyboard tilted at 20° than during typing using a keyboard tilted at 0°. The observed results provide a better understanding of the impact of continuous keyboard typing on the median nerve. Additionally, a 30-min rest time is sufficient to enable the median nerve to return to the baseline measurement. Furthermore, placement of the keyboard in a neutral position (0°) could prevent a high wrist extension angle during keyboard typing, and it may reduce acute changes in the median nerve. The findings may benefit and improve ergonomic interventions for the prevention of keyboard-related CTS. Further studies are needed to investigate the effects of various factors, such as wrist posture during daily working hours and duration of computer use, on median nerve changes.

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Conflicts of interest: The authors declare that there are no conflicts of interest.

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