EFFECTS OF ELECTRONIC DEVICE OVERUSE BY UNIVERSITY STUDENTS IN RELATION TO CLINICAL STATUS AND ANATOMICAL VARIATIONS OF THE MEDIAN NERVE AND TRANSVERSE CARPAL LIGAMENT

EUGENIA HOI CHI WOO, PhD, PETER WHITE, PhD, and CHRISTOPHER WAI KEUNG LAI, PhD

Department of Health Technology and Informatics, The Hong Kong Polytechnic University, Room Y934, 9/F, Lee Shau Kee Building, Hung Hom, Kowloon, Hong Kong Special Administrative Region, China

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ABSTRACT: *Introduction*: This study investigates the results of a questionnaire, provocative tests, and ultrasonographic measurements of carpal tunnel morphological parameters in intensive and nonintensive electronic device users. *Methods*: Forty-eight university students (equal numbers of intensive and nonintensive users, ≥5 h/day and <5 h/day of electronic device usage, respectively) were randomly selected after questionnaire responses were received and evaluated clinically and by ultrasonography. All participants were right-handed. *Results*: Intensive users had significantly more positive results in Phalen's and Durkan's tests and reported more wrist/hand pain compared with nonintensive users ($P < 0.05$). Intensive users also had significantly larger median nerve cross-sectional areas, flattening ratios, and perimeters as well as greater bowing of the transverse carpal ligament compared with nonintensive users ($P < 0.05$). *Discussion*: Overuse of electronic devices may adversely affect the median nerve within the carpal tunnel and the transverse carpal ligament, resulting in numbness, tingling, and pain in the hand. Caution may be warranted when using handheld electronic devices.

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Because of advances in information technology, use of electronic devices has become a part of everyday life. Frequent use of these devices without taking regular breaks may cause repetitive strain injury that affects not only the neck and shoulders but also the hands and wrists.[1] Smartphones and tablet computers involve thumb or finger interactions with the screen. Although these activities are generally not physically rigorous, prolonged periods of repetitive motion could lead to excessive force being exerted on the median nerve, thereby compressing it.[2] A recent study found that, on average, students use electronic devices over 3 h per day[3] and report musculoskeletal complaints. In addition, use of electronic devices compels users to engage in extension/flexion and radial/ulnar deviation of the wrist. These repetitive and awkward hand motions are involved in the etiopathogenesis of carpal tunnel syndrome (CTS),[4] possibly due to an increase in the volume of the carpal tunnel contents or a decrease in the size of the carpal tunnel,[5] which results in increased pressure within the carpal tunnel.[6]

Although CTS is a growing public concern for young computer/smartphone users, relatively little research has been carried out in this field.[7–9] These studies have attempted to evaluate the effects of smartphone overuse in relation to clinical and functional status of the hand.[7,8] However, individual studies have focused on 1 type of electronic device and have not examined in detail hand-use habits, which may lead to over/underestimation of the findings. Therefore, this study investigates the results of questionnaire, physical, and ultrasound evaluations of the hand in intensive and nonintensive electronic device users. We tested the hypothesis that overuse of electronic devices is likely to affect adversely the median nerve within the carpal tunnel and the transverse carpal ligament (TCL), resulting in numbness, tingling, and pain in the hand. These problems must be addressed at an early stage of CTS to prevent permanent nerve damage and functional sequelae.[10]

MATERIALS AND METHODS

Participants. This study was approved by The Hong Kong Polytechnic University Human Subjects Ethics Subcommittee. Forty-eight university students between 18 and 25 years of age were invited to participate in this study; all participants provided written informed consent. Participants were selected according to criteria used in our previous study,[3] in which students who used various electronic devices frequently (i.e., ≥5 h/day) were classified as intensive electronic device users, whereas others who used electronic devices less frequently (i.e., <5 h/day) were classified as nonintensive users. Five hours was applied as a cutoff point for intensive and nonintensive users because there were no previous studies to act as a reference, so the classification was based on the Regulation of the Code of Practice for Working with Display Screen Equipment of the Hong Kong Occupational Safety and Health Branch, Labour Department.[11] Students were excluded if they had (1) a history of wrist surgery or fracture; (2) a history of CTS or other peripheral nerve disease; (3) a history of underlying disorders associated with CTS, such as

Abbreviations: CSA, cross-sectional area; CTS, carpal tunnel syndrome; FR, flattening ratio; ICC, intraclass correlation coefficient; TCL, transverse carpal ligament

Key words: carpal tunnel syndrome; electronic device overuse; intensive users; median nerve; nonintensive users; transverse carpal ligament; ultrasonography

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Correspondence to: P. White; e-mail: peter.white@polyu.edu.hk

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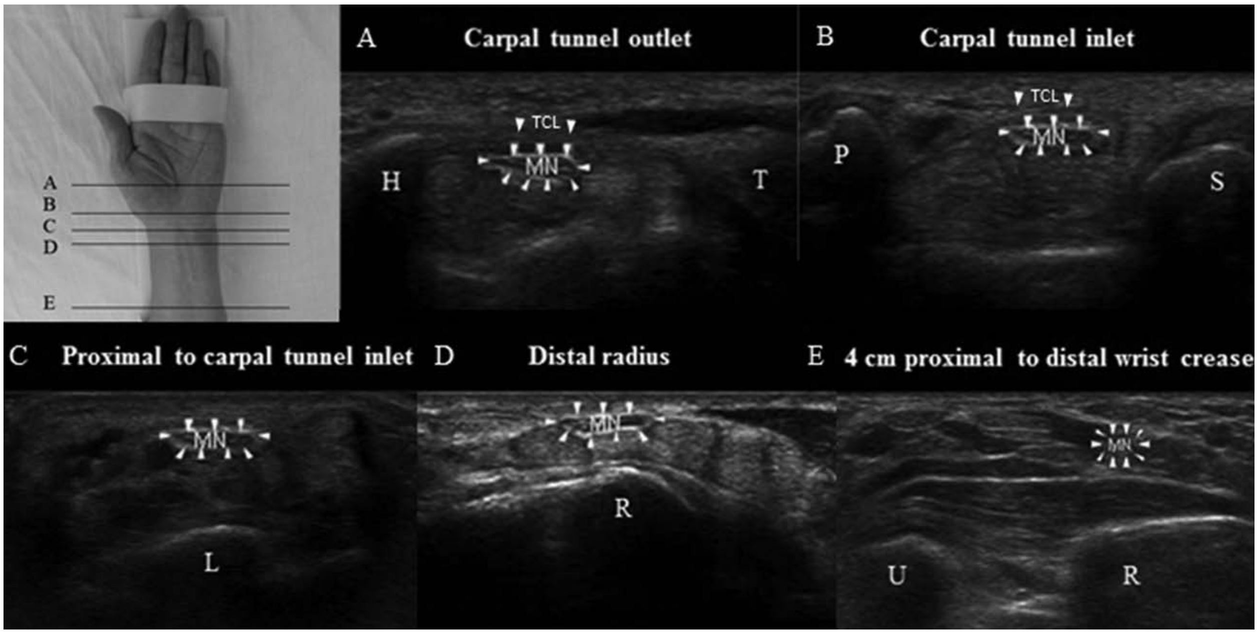

FIGURE 1. Locations for measurements of the 5 levels of the wrist. The ultrasound transducer was placed transversely at the 5 levels of the wrist: carpal tunnel outlet **(A)**, carpal tunnel inlet **(B)**, proximal to carpal tunnel inlet **(C)**, distal radius **(D)**, and 4 cm proximal to distal wrist crease **(E)**. MN, median nerve; TCL, transverse carpal ligament. Bony landmarks are H, hamate; L, lunate; P, pisiform; R, radius; S, scaphoid; T, trapezium; U, ulnar.

diabetes mellitus, rheumatoid arthritis, hypothyroidism, pregnancy, or obesity; (4) an abnormality of the median nerve, such as bifid median nerve or persistent median artery, as identified during the ultrasound examination; or (5) involvement in regular sports activities or a part-time job that involved repetitive wrist motions, sustained wrist deviation, and/or prolonged pinch grip.

Self-Reported Questionnaire. A self-reported questionnaire was administered to collect participants' information about the frequency and duration of electronic device use, including computers, mobile phones, and game consoles, and self-report of any musculoskeletal pain or discomfort in several body regions—neck, shoulder, back, elbow, and wrist/hand—that might relate to electronic devices usage in the immediate 12 months prior to the survey date. The same questionnaire had been used and validated in our previous study.[3] The demographic data, such as age, sex, height, weight, and determination of dominant hand as well as medical history were also collected.

Physical Examinations. Phalen's and Durkan's tests were performed to confirm the participants' current wrist status. During Phalen's test, the appearance of numbness or paresthesia in the median nerve distribution of the hand within 60 s after pushing the dorsal surfaces of both hands together and flexing the wrists to increase pressure on the median nerve was considered a positive result.[12] In Durkan's test, tingling or abnormal sensation in the median nerve distribution of the hand within 30 s after initiating pressure by the examiner's thumb over the median nerve at the carpal tunnel to increase its pressure was considered a positive result.[13] Positive results may be considered as indicative of CTS.[14]

Ultrasound Imaging. After completion of physical examinations, the ultrasound examinations were carried out with a Philips ultrasound unit (HD11 XE; Philips Medical Systems, Bothell, WA) with an L12–5 linear array transducer of frequency 5–12 MHZ. Participants sat on a chair facing the examiner with the elbow flexed at approximately 90°, forearm resting flat on a table, hand supinated, and fingers fully extended. During the scan, the wrist was held in a neutral position, and the ultrasound transducer was placed transversely at 5 levels of the wrist, including (1) carpal tunnel outlet, (2) carpal tunnel inlet, (3) proximal to carpal tunnel inlet, (4) distal radius, and (5) 4 cm proximal to distal wrist crease (Fig. 1). These regions were chosen to delineate the corresponding morphological changes of the median nerve before and after passing through the carpal tunnel at different levels. Both hands of each participant were imaged, and wrist circumferences were measured.

The transverse images of the median nerve with measurements of the cross-sectional area (CSA), flattening ratio (FR), perimeter, circularity, and palmar bowing and thickness of the TCL (Fig. 2) were obtained 3 times, and an

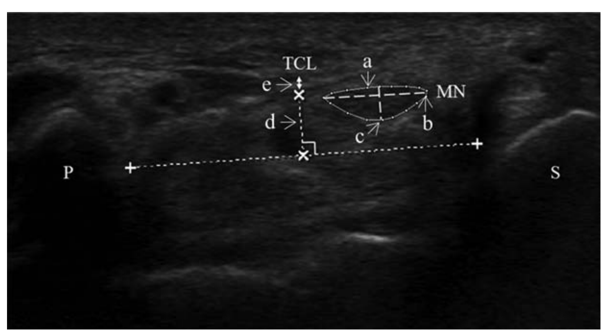

FIGURE 2. Measurements of the ultrasound parameters. Cross-sectional area of the median nerve **(a)**, major axis length **(b)** and minor axis length **(c)** of the median nerve, palmar bowing of the transverse carpal ligament **(d)**, and thickness of the transverse carpal ligament **(e)**. MN, median nerve; TCL, transverse carpal ligament. Bony landmarks are P, pisiform; S, scaphoid.

average of the 3 measurements was used for analysis to reduce random error. Definitions and measurements were the following:

1. CSA was defined as the area within the hyperechogenic boundary of the median nerve by a direct tracing method[15]
2. FR was defined as the ratio of the medial-lateral diameter (major axis length) to the anterior-posterior diameter (minor axis length) of the median nerve
3. Perimeter was defined as the length of the outline of the median nerve
4. Circularity was defined as 4π times the nerve area divided by the square of nerve perimeter, which ranged between 0 and 1; a circularity equal to 1 indicated a perfect circle, whereas a circularity <1 indicated deviation from a circle, such as a more ellipsoid or irregular shape
5. Palmar bowing of the TCL was defined as the distance from a line drawn between its attachments to the pisiform/hamate and the scaphoid/trapezium and taking the measurement at 90° from this line to the palmar apex of the ligament[16]
6. Thickness of the TCL was measured as closely to the midline as possible in the midportion of the carpal tunnel

Statistical Analysis. The images were processed in ImageJ (version 1.47; NIH, Bethesda, MD). All data were analyzed in SPSS (version 18.0; SPSS, Chicago, IL). $P < 0.05$ was considered statistically significant. For the physical examinations, test-retest reliability was analyzed with Cohen's κ for the dichotomous data (i.e., positive or negative findings). A κ value greater than 0.75 was considered as good agreement.[17,18] For the ultrasound examinations, both interrater and intrarater reliability were estimated by intraclass correlation coefficient (ICC) model 3. An ICC value greater than 0.75 was considered as good reliability.[19,20] Student's t test was used to compare the mean of variables between intensive and nonintensive electronic device users. Paired t test was used to analyze the mean differences between the dominant and nondominant hands. One-way repeated-measures ANOVA with post hoc Bonferroni adjustment was used to determine the effects of morphological changes at different levels of the wrist from the baseline measurements. χ^2 Test, Spearman's rank correlation test (r_s), and Pearson's correlation test (r) were used to assess univariate associations between variables and clinical findings, intensity and duration on wrist/hand symptoms, and ultrasonographic parameters, respectively.

RESULTS

Reliability of Measurements. The κ values for test-retest reliability of Phalen's and Durkan's tests were 0.650 and 0.750, respectively. For the ultrasound examinations, the ICC interrater and intrarater reliability values of the measurements of CSA were 0.911 and 0.990, respectively; FR were 0.911 and 0.988, respectively; TCL bulge were 0.987 and 0.995, respectively; and TCL thickness were 0.911 and 0.912, respectively.

Questionnaire Survey Results. The values obtained from the 48 participants (24 intensive and 24 nonintensive electronic device users) were analyzed. There were equal numbers of men and women. Mean age was 20 years, mean body mass index was 21.4 ± 2.8 kg/m^2, and all participants were right-handed. There were no significant differences in terms of age, sex, body mass index, height, or weight between intensive and nonintensive users, but there was a statistically significant difference in the usage patterns of various electronic devices between them. On an average day, intensive users spent 9.1 ± 2.3 h using electronic devices, whereas nonintensive users spent 2.8 ± 1.0 h using electronic devices. Intensive users spent more time using tablet computers and playing electronic games than nonintensive users, whereas none of the nonintensive users had any game devices. In addition, they used their smartphones with a single hand. Details are summarized in Table 1.

Intensive users reported more musculoskeletal pain than nonintensive users, and this occurred in 1 or more sites. They also had significantly more wrist/hand discomfort and had a higher severity score than nonintensive users. Their discomfort was related to electronic device usage. Details are shown in Table 2.

Physical Examinations Findings. Intensive users demonstrated positive Durkan's test results more frequently compared with nonintensive users ($P < 0.01$). They also had significantly larger wrist circumferences in right hand compared with nonintensive users ($P < 0.05$).

Baseline Ultrasound Examination Findings. Median nerve CSAs were significantly larger in intensive users than in nonintensive users at all levels of the wrist except at 4 cm proximal to distal wrist crease, whereas the FR, perimeter, and TCL bulge were significantly larger in intensive users than in nonintensive users at carpal tunnel inlet. In addition, the median nerve in the dominant right hand was significantly larger in CSA at the carpal tunnel outlet and demonstrated a larger FR proximal to the carpal tunnel inlet than the left hand. Similarly, the palmar bowing of the TCL at carpal tunnel outlet and inlet were found to be significantly greater in the right hand than in the left hand. Only 1 of the 24 intensive users exceeded the normal value of 10 mm^2 for CSA, but all of them exceeded the cutoff value of 3 for FR, and half exceeded the cutoff value of 4 mm for TCL bulge.[16] Details are summarized in Table 3.

Association of Electronic Device Exposures With Wrist/Hand Pain Intensity and Duration of Symptoms, Clinical Test Findings, and Ultrasonographic Parameters. With regard to exposure, total time spent using electronic devices on a typical day showed a strong significant association with levels of pain intensity ($r_s = 0.428$, $P = 0.002$) and

Table 1. Frequency and duration of electronic device use

	Intensive users $n = 24$ (%)	Nonintensive users $n = 24$ (%)	*P*-value
Desktop computer			
No	3 (12.5)	6 (25)	0.277
Yes	21 (87.5)	18 (75)	
Frequency			
<5 days	6 (28.6)	10 (55.6)	0.084
≥5 days	15 (71.4)	8 (44.4)	
Duration			
<5 h	11 (52.4)	18 (100)	0.005†
≥5 h	10 (47.6)	0 (0)	
Years of experience			
<5	2 (9.5)	0 (0)	0.830
≥5	19 (90.5)	18 (100)	
Laptop computer			
No	5 (20.8)	11 (45.8)	0.137
Yes	19 (79.2)	13 (54.2)	
Frequency			
<5 days	7 (36.8)	6 (46.2)	0.199
≥5 days	12 (63.2)	7 (53.8)	
Duration			
<5 h	10 (52.6)	13 (100)	0.027*
≥5 h	9 (47.4)	0 (0)	
Years of experience			
<5	14 (73.7)	9 (69.2)	0.317
≥5	5 (26.3)	4 (30.8)	
Tablet computer			
No	9 (37.5)	19 (79.2)	0.003†
Yes	15 (62.5)	5 (20.8)	
Frequency			
<5 days	9 (60)	3 (60)	0.013*
≥5 days	6 (40)	2 (40)	
Duration			
<5 h	12 (80)	5 (100)	0.003†
≥5 h	3 (20)	0 (0)	
Years of experience			
<5	13 (86.7)	5 (100)	0.002†
≥5	2 (13.3)	0 (0)	
Mobile phone			
No	0 (0)	0 (0)	1.000
Yes	24 (100)	24 (100)	
Frequency			
<5 days	1 (4.2)	1 (4.2)	1.000
≥5 days	23 (95.8)	23 (95.8)	
Duration			
<5 h	11 (45.8)	24 (100)	0.074
≥5 h	13 (54.2)	0 (0)	
Years of experience			
<5	16 (66.7)	18 (75)	0.226
≥5	8 (33.3)	6 (25)	
Home video game console			
No	20 (83.3)	24 (100)	0.043*
Yes	4 (16.7)	0 (0)	
Frequency			
<5 days	4 (100)	0 (0)	0.070
≥5 days	0 (0)	0 (0)	
Duration			
<5 h	4 (100)	0 (0)	0.057
≥5 h	0 (0)	0 (0)	
Years of experience			
<5	2 (50)	0 (0)	0.004†
≥5	2 (50)	0 (0)	
Handheld game console			
No	13 (54.2)	24 (100)	<0.001†
Yes	11 (45.8)	0 (0)	
Frequency			
<5 days	9 (81.8)	0 (0)	0.006†
≥5 days	2 (18.2)	0 (0)	
Duration			
<5 h	11 (100)	0 (0)	0.001†
≥5 h	0 (0)	0 (0)	
Years of experience			
<5	4 (36.4)	0 (0)	<0.001†
≥5	7 (63.6)	0 (0)	

*Significance at $P < 0.05$, Student's t test on the intensive and nonintensive users.

†Significance at $P < 0.01$, Student's t test on the intensive and nonintensive users.

duration of symptoms ($r_s = 0.401$, $P = 0.005$) for wrist/hand discomfort as well as values of ultrasonographic parameters: CSA (at tunnel outlet: in left hand $r = 0.519$, $P < 0.001$ and in right hand $r = 0.505$, $P < 0.001$; at tunnel inlet: in left hand $r = 0.485$, $P < 0.001$ and in right hand $r = 0.455$, $P = 0.001$), FR (at tunnel outlet: in left hand $r = 0.424$, $P = 0.003$ and in right hand $r = 0.171$, $P = 0.245$; at tunnel inlet: in left hand $r = 0.452$, $P = 0.001$ and in right hand $r = 0.348$, $P = 0.015$), and TCL bulge (at tunnel inlet: in left hand $r = 0.351$, $P = 0.014$ and in right hand $r = 0.586$, $P < 0.001$). Total number of electronic devices used also had a significant association with positive Durkan's test results of right hand ($\chi^2 = 14.232$, $P = 0.007$) as well as values of ultrasonographic parameters: CSA (at tunnel outlet: in left hand $r = 0.302$, $P = 0.037$ and in right hand $r = 0.424$, $P = 0.003$; at tunnel inlet: in left hand $r = 0.373$, $P = 0.009$ and in right hand $r = 0.394$, $P = 0.006$), and TCL bulge (at tunnel inlet: in left hand $r = 0.356$, $P = 0.013$ and in right hand $r = 0.592$, $P < 0.001$).

DISCUSSION

In this study, Phalen's and Durkan's test results demonstrated moderate agreement, and the measurements of size and shape of the median nerve and TCL demonstrated good reliability. Based on the reliability analyses, the measures used in the study were acceptable for further analyses.

Prevalence of Wrist/Hand Pain. The present study found a significantly higher prevalence of wrist/hand pain in intensive electronic device users than in nonintensive users. This observation was consistent with previous studies indicating that longer

Table 2. Prevalence of musculoskeletal symptoms in different body parts during the past 12 months

	Intensive users n = 24 (%)	Nonintensive users n = 24 (%)	*P*-value
Musculoskeletal pain			
No	2 (8.3)	18 (75)	<0.001†
Yes	22 (91.7)	6 (25)	
Discomfort regions			
Neck	15 (68.2)	3 (50)	0.548
Shoulder	17 (77.3)	3 (50)	0.107
Upper back	9 (40.9)	1 (16.7)	0.250
Low back	6 (27.3)	2 (33.3)	0.781
Elbow	5 (22.7)	0 (0)	0.024*
Wrist/Hand	10 (45.5)	0 (0)	0.001†
Pain severity level			
Elbow			
Level 1 or less	1 (20)	0 (0)	0.040*
Level 2–4	0 (0)	0 (0)	
Level 5–7	3 (60)	0 (0)	
Level 8–10	1 (20)	0 (0)	
Wrist/hand			
Level 1 or less	1 (10)	0 (0)	0.002†
Level 2–4	2 (20)	0 (0)	
Level 5–7	3 (30)	0 (0)	
Level 8–10	4 (40)	0 (0)	
Condition(s) causing discomfort			
Computer use	16 (72.7)	6 (100)	0.212
Mobile phone use	14 (63.6)	6 (100)	0.180
Playing electronic games	7 (31.8)	0 (0)	0.030*
Doing exercise	5 (22.7)	0 (0)	0.045*

*Significance at $P < 0.05$, Student's t test on the intensive and nonintensive users.

†Significance at $P < 0.01$, Student's t test on the intensive and nonintensive users.

duration of computer use related to more prevalent wrist/hand discomfort.[21–25] A large national survey found that daily use of a keyboard for more than 4 h was associated with shoulder and wrist/hand pain.[26] Additionally, there was a significant association between time spent on gaming and internet browsing with a mobile phone and pain in the right thumb.[27] Apart from duration, posture is another important risk factor.[28] One explanation is that the design of input devices requiring repetitive finger movements, including clicking, scrolling, swiping, tapping, and pressing buttons, may affect fingertip forces, tendon excursion, and muscular effort.[29] The position of input devices has the greatest effect on the position of the shoulder, elbow, and wrist.[30] Several studies showed that mobile device use was linked to more nonneutral wrist postures.[31–33] Such postures can increase pressure in the carpal tunnel which may relate to CTS.[34]

We also observed that, compared with nonintensive users, intensive users had more positive test results. This finding was comparable to a previous study by Aydeniz and Gürsoy[35] showing that, compared with nonusers, extensive computer users had more positive clinical test results for musculoskeletal diagnoses in the elbow and wrist regions. They found that all disorders were more common in the right hand than in the left hand, which is in agreement with the current study. This suggests that intensive users may be more prone to pain in their wrists and more susceptible to CTS.

Baseline Values of Ultrasonographic Parameters Among Intensive Electronic Device Users. The most important result of the current study is that intensive users had significantly enlarged and flattened median nerves and greater TCL bulge within the carpal tunnel compared with nonintensive users. This may be due to frequent use of hands and fingers to operate the devices. This observation is consistent with previous studies indicating that excessive use of smartphones may adversely affect the median nerve and increase the probability of occurrence of CTS.[7–9] Other studies found evidence for wrist abnormalities in computer users, such as restricted wrist range of motion[36] and reduced sensory nerve function.[37] This suggests that intensive users may have a higher risk of developing CTS, and, thus, precautions are required when using electronic devices.

Baseline Values of Ultrasonographic Parameters in the Dominant Hand. We found significant differences between both hands in CSA and FR of the median nerve as well as in the palmar bowing and thickness of the TCL. These differences may be explained by greater activity of the dominant hand. Because the participants in this study were right-handed, their mean baseline values of the right hand were higher. This observation was consistent with previous studies showing that the CSA and the FR are significantly higher in the dominant hand.[38,39] Meanwhile, larger wrist circumference of the dominant hand in intensive users was found in this study. This may be due to the habit preference of single-hand use. Recent studies showed that smartphone operation with 1 hand caused greater upper trapezius pain and induced increased upper extremity muscle activity than operation with both hands.[40,41] A study by İnal and colleagues[7] also showed enlargement of the median nerve in highly active smartphone users who have a habit of single-handheld smartphone use. They further demonstrated that not only the median nerve but also tendons were significantly larger in the dominant hand of smartphone users than in the dominant hand of nonusers. Although ergonomic standards and guidelines for computer workstations are readily available today, they usually are not compatible with the current setups

Table 3. Mean values of baseline ultrasound measurements at 5 levels of the wrist

	Intensive users (mean ± SD)	Nonintensive users (mean ± SD)	*P*-value
At carpal tunnel outlet*			
CSA (mm^2)			
Left hand	7.6 ± 0.6	7.1 ± 0.7	0.006§
Right hand	7.9 ± 0.6	7.3 ± 0.6	0.002§
P-value (dominant and nondominant hands)	0.002§	0.010‡	
FR			
Left hand	3.9 ± 0.4	3.8 ± 0.5	0.232
Right hand	3.9 ± 0.5	3.8 ± 0.5	0.646
Perimeter (mm)			
Left hand	14.5 ± 1.1	14.0 ± 1.2	0.145
Right hand	14.7 ± 1.1	14.4 ± 1.1	0.240
Circularity			
Left hand	0.5 ± 0.1	0.5 ± 0.1	0.904
Right hand	0.5 ± 0.1	0.5 ± 0.1	0.677
TCL bulge (mm)			
Left hand	2.0 ± 0.2	2.0 ± 0.2	0.791
Right hand	2.2 ± 0.2	2.2 ± 0.4	0.930
P-value (dominant and nondominant hands)	<0.001§	0.007§	
TCL thickness (mm)			
Left hand	1.2 ± 0.1	1.2 ± 0.1	0.956
Right hand	1.2 ± 0.1	1.3 ± 0.1	0.775
At carpal tunnel inlet†			
CSA (mm^2)			
Left hand	7.9 ± 0.9	7.2 ± 0.6	0.002§
Right hand	7.9 ± 0.9	7.3 ± 0.7	0.004§
FR			
Left hand	3.4 ± 0.4	3.0 ± 0.5	0.002§
Right hand	3.4 ± 0.4	3.0 ± 0.5	0.014‡
Perimeter (mm)			
Left hand	13.1 ± 1.1	12.4 ± 1.2	0.047‡
Right hand	13.2 ± 1.0	12.5 ± 1.2	0.037‡
Circularity			
Left hand	0.6 ± 0.1	0.6 ± 0.1	0.677
Right hand	0.6 ± 0.1	0.6 ± 0.1	0.426
TCL bulge (mm)			
Left hand	3.6 ± 0.5	3.3 ± 0.5	0.042‡
Right hand	3.8 ± 0.4	3.4 ± 0.3	<0.001§
P-value (dominant and nondominant hands)	0.025‡	0.032‡	
TCL thickness (mm)			
Left hand	1.2 ± 0.1	1.2 ± 0.1	0.129
Right hand	1.2 ± 0.1	1.2 ± 0.1	0.979
At proximal to carpal tunnel inlet			
CSA (mm^2)			
Left hand	7.1 ± 0.8	6.7 ± 0.7	0.048‡
Right hand	7.2 ± 0.7	6.8 ± 0.7	0.049‡
FR			
Left hand	3.1 ± 0.5	2.9 ± 0.6	0.410
Right hand	3.3 ± 0.5	3.1 ± 0.8	0.231
P-value (dominant and nondominant hands)	0.023‡	0.028‡	
Perimeter (mm)			
Left hand	12.3 ± 0.9	11.9 ± 1.4	0.171
Right hand	12.7 ± 1.0	12.0 ± 1.4	0.073
Circularity			
Left hand	0.6 ± 0.1	0.6 ± 0.1	0.512
Right hand	0.6 ± 0.1	0.6 ± 0.1	0.104

TABLE 3. *Continued*

	Intensive users (mean ± SD)	Nonintensive users (mean ± SD)	*P*-value
At distal radius			
CSA (mm^2)			
Left hand	6.8 ± 0.7	6.4 ± 0.8	0.041‡
Right hand	6.9 ± 0.7	6.5 ± 0.7	0.044‡
FR			
Left hand	2.4 ± 0.5	2.3 ± 0.5	0.642
Right hand	2.4 ± 0.5	2.3 ± 0.5	0.274
Perimeter (mm)			
Left hand	11.1 ± 0.9	10.6 ± 0.9	0.121
Right hand	11.0 ± 0.7	10.7 ± 0.9	0.356
Circularity			
Left hand	0.7 ± 0.1	0.7 ± 0.1	0.797
Right hand	0.7 ± 0.1	0.7 ± 0.1	0.614
At 4 cm proximal to distal wrist crease			
CSA (mm^2)			
Left hand	5.9 ± 0.5	5.9 ± 0.5	0.750
Right hand	6.0 ± 0.5	6.1 ± 0.6	0.822
FR			
Left hand	2.0 ± 0.3	1.9 ± 0.3	0.754
Right hand	2.0 ± 0.2	1.9 ± 0.2	0.685
Perimeter (mm)			
Left hand	9.5 ± 0.5	9.6 ± 0.6	0.614
Right hand	9.7 ± 0.7	9.8 ± 0.6	0.526
Circularity			
Left hand	0.8 ± 0.1	0.8 ± 0.1	0.344
Right hand	0.8 ± 0.1	0.8 ± 0.1	0.393

CSA, cross-sectional area; FR, flattening ratio; TCL, transverse carpal ligament.

**Distal, hamate-trapezium level.*

†Proximal, pisiform-scaphoid level.

‡Significance at $P < 0.05$, Student's t test on the intensive and nonintensive users, paired t test on the dominant and nondominant hands.

§Significance at $P < 0.01$, Student's t test on the intensive and nonintensive users, paired t test on the dominant and nondominant hands.

required by mobile technologies.[42] Future studies investigating ergonomic designs for handheld electronic devices, such as single hand use, are warranted.

Association of Electronic Device Exposures With Wrist/Hand Pain Intensity and Duration of Symptoms, Clinical Test Findings, and Ultrasonographic Parameters. In this study we found no correlation between wrist/hand symptoms, clinical findings, and demographic factors. However, the amount of time spent on electronic devices was strongly associated with pain intensity and duration for wrist/hand discomfort. The level of wrist/hand pain intensity was more severe and tended to last longer in intensive users than in nonintensive users. This observation is consistent with previous studies showing a dose-response relationship between pain intensity and duration of computer use.[43,44] These studies also concluded that moderate to severe pain intensity and inconvenience to everyday life were common among computer users.

Similarly, the total number of electronic devices used was strongly associated with a positive Durkan's sign in the right hand. This observation was consistent with a previous study showing a positive correlation between cumulative hours of computer use and positive Tinel's and Phalen's signs in the right hand.[35] Another study focusing on smartphone use also reported that positive Phalen's and reverse Phalen's test signs were associated with the degree of addiction to smartphones, periods of use, duration of use per day, and duration of continuous usage time.[8] These clinical tests have been used to aid in the diagnosis of CTS, but it should be noted that the reported sensitivity and specificity of Tinel's and Phalen's tests vary from 30% to 100%.[45]

Furthermore, the amount of time spent on electronic devices and total number of electronic devices used were positively associated with CSA and FR of the median nerve as well as palmar bowing of the TCL. This observation was consistent with previous studies showing that frequency, duration, and years of experience using electronic devices may cause the enlargement of the median nerve and other soft tissues, such as tendons, within the carpal tunnel.[7,46] These studies also concluded that intensity of electronic device use was positively correlated with pain duration and severity. Another study found that a reduction in the size of the space within the carpal tunnel was due to thickened muscles and ligaments after the use of smartphones, and, thus, these soft tissues pressed on the median nerve.[9] This also explains why the median nerve exhibits acute changes in response to a keyboarding task.[38,47] In these 2 cited studies, the authors further suggested that CSA increased after 30–60 min of keyboarding, returning to baseline after 30 min of rest; they also observed greater changes of the median nerve in those who typed with greater angles of ulnar deviation.[48] This suggests that exercise and rest breaks should be used for reducing the risk of CTS associated with computer-related tasks.

Limitations of the Study. This study has several limitations. The small sample and relatively homogeneous study population limit generalizability. The cross-sectional design may lead to false-positive or false-negative outcomes. The self-reported nature of the data may raise questions regarding accuracy. The diagnosis of CTS relied on clinical symptoms (Phalen's and Durkan's tests) rather than electrodiagnostic testing (nerve conduction studies and electromyography). Therefore, additional exploration may be required for verification of these results.

In conclusion, intensive electronic device users had an enlarged and flattened median nerve and greater TCL bulge within the carpal tunnel; also, they more frequently (1) had positive clinical tests indicative of CTS and (2) reported wrist/hand pain compared with nonintensive users. Caution may be warranted when using handheld electronic devices to minimize the chance of developing CTS.

Ethical Publication Statement: We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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