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ORIGINAL RESEARCH

Going Short: The Effects of Short-Travel Key Switches on Typing Performance, Typing Force, Forearm Muscle Activity, and User Experience

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This study examined the effects of 4 micro-travel keyboards on forearm muscle activity, typing force, typing performance, and self-reported discomfort and difficulty. A total of 20 participants completed typing tasks on 4 commercially available devices with different key switch characteristics (dome, scissors, and butterfly) and key travels (0.55, 1.3, and 1.6 mm). The device with short-travel (0.55 mm) and a dome-type key switch mechanism was associated with higher muscle activities (6%–8%, $P < .01$), higher typing force (12%, $P < .01$), slower typing speeds (8%, $P < .01$), and twice as much discomfort ($P < .05$), compared with the other 3 devices: short-travel (0.55 mm) and butterfly switch design and long travel (1.3 and 1.6 mm) with scissor key switches. Participants rated the devices with larger travels (1.3 and 1.6 mm) with least discomfort ($P = .02$) and difficulty ($P < .01$). When stratified by sex/gender, these observed associations were larger and more significant in the female participants compared with male participants. The devices with similar travel but different key switch designs had difference in outcomes and devices with different travel were sometimes not different. The results suggest that key travel alone does not predict typing force or muscle activity.

Keywords*:* mobile computing, biomechanics, tablet, notebook, keyboard

Today's lightweight notebook and tablet computers employ thinner keyboards than earlier models. These designs must sacrifice key travel distance as evidenced by new devices with key travel distances lying outside the current 1.5- to 6.0-mm standards.[1] For example, the Microsoft Surface Pro 4's keyboard has 1.3-mm travel. Standards such as ISO-9241 (*Ergonomics of Human-Computer Interaction*) and ANSI/HFES 100 (*Human Factors Engineering of Computer Workstations*) provide guidelines for the design and development of desktop and laptop computers but may not be relevant for modern devices. Studies comparing external tablet keyboard attachments with the no-travel, on-screen keyboards have demonstrated better performance with attached keyboard use.[2,3] However, the effects of these new short-travel key designs on upper-extremity muscle activity and typing force are unknown.

Keyboard design characteristics including key travel distance,[4] key size,[5] activation force,[6–10] feedback,[11] key switch mechanism,[12] and key location[13] can affect muscle activity, typing force, and typing performance. However, most of these previous studies were conducted using regular desktop keyboards with travel distances within the recommended range of 1.5 to 6.0 mm and with dome or linear spring switches.

Key switch force–displacement is an important consideration for musculoskeletal symptoms. Ripat et al[14] randomly assigned symptomatic typists to use the same commercially available split keyboard[15] in either its normal (0.36-N activation force and 2.8-mm travel) or modified (0.36-N activation force and 0.2-mm travel) design over 24 weeks and found similar improvements from baseline in clinical symptoms and satisfaction in both groups. In addition, symptomatic typists have been shown to type with higher typing forces than those without pain, though typing forces were measured after symptom onset, which limits the ability to assign causality.[16–18] Higher activation force keyboards are generally associated with higher typing force[8,19] and higher muscle activity.[6,7]

The key switch mechanism has also been shown to affect upper-extremity biomechanics, user experience, and forearm musculoskeletal symptoms.[8,11,20,21] Gerard et al[7] found that a buckle spring keyboard with 0.72-N activation force resulted in less typing force and muscle activity than 0.56- and 0.83-N activation force elastomer dome keyboards, and similar typing force and muscle activity when compared with a 0.28-N activation force elastomer dome keyboard. Participants also preferred the buckle spring keyboard, though this was confounded because it was the keyboard they typically used. By contrast, Bufton et al[19] found that higher typing forces were associated with a 0.86-N buckle spring keyboard compared with a 0.68-N elastomer dome keyboard. To achieve thinner designs, many mobile keyboards have abandoned spring and dome keyboards for scissor and butterfly switches.[22,23]

A few studies with micro-travel keyboards (here defined as shorter than the recommended minimum 2.0-mm key travel)[24,25] have shown an association between shorter key travel and reduced muscle activity, typing force, performance, and self-reported typing user experience.[11,26–28] Chaparro et al[11] found that participants typed faster and preferred micro-travel mechanical keyboards over a pressure sensing no-travel keyboards, but they did not measure any typing forces or muscle activity. Similarly, Hoyle et al[27] found better performance, and user experience ratings were associated with moderate micro-travel (1.6 and 2.0 mm) keyboards over very short (0.4 mm) and no-travel keyboards. Kim et al[26] measured upper-extremity muscle activity, typing force, and performance for

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no-travel, micro-travel (1.8 mm), and standard-travel (4.0 mm) keyboards, and found higher muscle activity and typing forces were associated with larger key travel. Kia et al[25] recently tested 5 commercially available micro-travel tablet, notebook, and desktop keyboards (0.5–2.0 mm) and found decreased flexor muscle activity, increased typing forces, decreased ulnar deviation, and increased typing performance were associated with increasing travel distance. However, these differences were relatively small and may be related to unmeasured keyboard factors as the devices did not share the same form factors.

Moreover, few of these studies have examined the effects on specific individual characteristics such as sex/gender, anthropometry, and strength. Previous studies have demonstrated higher associations between typing biomechanics[29] and technology-related pain and injury[30] in women as compared with men. As such, the difference in the effects of mobile computing devices and micro-travel keyboards across sex/gender needs further investigation.

More investigation is necessary to understand micro-travel's effects on human health and performance to provide design guidance. The purpose of this study was to investigate the effects of 4 different micro-travel keyboards on forearm muscle activity, typing force, typing performance, and self-reported discomfort and difficulty. In addition, the study sought to investigate if the effects of micro-travel distance keyboards differed between male and female participants. The study tested the null hypotheses that no significant differences will be observed in outcome measures across devices with different key travel and key force–displacement characteristics and that the same trend will be observed in both male and female participants.

Methods

The study was a repeated-measures laboratory experiment comparing 4 different commercially available keyboards with small key travel distance with equal number of male and female participants to examine the effect on forearm muscle activity, typing force, typing performance, and self-reported discomfort and difficulty across all participants and within each sex/gender.

Study Population

A total of 20 participants, balanced for sex/gender, were recruited from the local community. Inclusion criteria for participants were greater than 21 years of age, perfect or corrected vision, ability to touch type 30 words per minute, English language proficiency, and no history of upper-extremity musculoskeletal pain or injury. Female participants ranged in age from 21 to 33 years (average [SD]: 27 [3] y), in stature from 153 to 180 cm (168 [3] cm), and in grip strength from 177 to 314 N (245 [39] N). Male participants ranged in age from 21 to 32 years (average [SD]: 27 [4] y), in stature from 169 to 186 cm (179 [5] cm), and in grip strength from 255 to 481 N (373 [69] N). Of the 20 participants, 19 (10 females and 9 males) self-reported to be right-handed. Right-hand grip strength was measured using a hand strength dynamometer (Stoelting Inc, Wood Dale, IL) in supinated position with an extended elbow. Participants were coached to grip as hard as possible 3 times without breaks, and the highest measure was used. All protocols were approved by the Harvard T.H. Chan School of Public Health and the Northeastern Institutional Review Boards for human research, and all participants provided written informed consent before participating.

Experimental Tasks

Participants completed 2 typing tasks for each of the 4 devices. The first typing task was a 1-minute typing test on an online typing test program (Typing Speed Test; TypingMaster Inc, Helsinki, Finland). For the second task, participants typed for 3 minutes to transcribe up to 3 news articles, depending on their typing pace, into a word processor. The chosen articles were on current events and written for an 11- to 14-year-old audience. This was meant to simulate more average typing tasks such as writing an e-mail without inducing fatigue, and participants were asked to type at their normal pace. During the typing tasks, participants sat upright on an armless, backed office task chair with their feet flat on the floor and their thighs parallel to the ground. The monitor was adjusted such that the top of the screen was aligned with the participant's eyes, and the center was aligned with his or her sternum, and the horizontal distance was the same for all participants. All participants used the same monitor, and brightness and light settings were kept constant for all participants. The devices were placed on a force platform on a desk such that they were centered with the monitor, and the gap between the G and H keys was aligned with the participant's sternum. The desk's height was adjusted using visual inspection so that the keyboards were approximately at elbow height with approximately 90° elbow flexion and neutral wrists.

Independent Variable: Device

Each participant typed on 4 commercially available micro-travel devices (Table 1), each with a different combination of key travel, short (S) or long (L), and mechanism (dome, butterfly, or scissor). The devices were Tablet S (0.55 mm): Apple iPad® Pro (Apple Inc, Cupertino, CA); Notebook S (0.55 mm): Apple MacBook® Pro (Apple Inc); Tablet L (1.3 mm): Surface® Pro 4

Table 1 Experimental Devices and Properties

	Tablet S (short)	Notebook S (short)	Tablet L (long)	Notebook L (long)
Brand	Apple Inc	Apple Inc	Microsoft Corporation	Microsoft Corporation
Model	iPad® Pro	Macbook® Pro	Surface® Pro 4	Surface Book®
Year	2016	2016	2015	2016
Travel, mm	0.55	0.55	1.30	1.60
Switch mechanism	Dome	Butterfly	Scissor	Scissor
Force, g	73–83	60–70	60–70	60–70
Key length × width, cm	1.5 × 1.5	1.7 × 1.6	1.6 × 1.5	1.5 × 1.5
Space between keys, cm	0.4	0.2	0.3	0.3

(Microsoft Corporation, Redmond, WA); and Notebook L (1.6 mm): Microsoft SurfaceBook® (Microsoft Corporation). These were chosen for their different key travel distances and mechanisms as well as for their current commercial availability. The order of the devices tested was randomized and counterbalanced within sex/gender across the 20 participants. Participants typed on each keyboard for 5 minutes before the trials to become comfortable and acclimated to the devices.

Dependent Variables: Muscle Activity

Study outcomes included the normalized median amplitude of electromyography (EMG) signals of 6 right forearm muscles: the extensor carpi radialis, extensor carpi ulnaris, extensor digitorum (ED), flexor carpi radialis, flexor carpi ulnaris, and flexor digitorum superficialis. Only the right side was tested because previous research has shown no significant differences in muscle activities between the right and left arm during typing.[31] After cleaning each participant's right forearm with alcohol and abrading with an exfoliating sponge to reduce impedance, bipolar EMG sensors were mounted on the muscle bellies as identified through palpation and asking the participant to do demonstrative movements while the researcher provided resistance.[32,33] Delsys 8 Bagnoli System (Delsys, Natick, MA) measured, filtered, and amplified the EMG signals prior to their recording on a personal computer at 2000 samples per second using a USB A to D backplanes (NI cDAQ-9172; National Instruments, Austin, TX). Postprocessing of the signals in MATLAB (MathWorks Inc, Natick, MA) included rectifying the signal and then second-order low-pass filtering at 3 Hz (single pole).[33–35]

Prior to the typing tasks, protocols and data collection, participants performed maximum voluntary contractions (MVCs) for each muscle resisted by trained experimenters to normalize the amplitude of the EMG signals. For each contraction, participants were instructed to ramp up to their maximum muscle output, and each MVC was collected for 3 seconds, 3 times with at least 2 minutes of rest between trials. The highest 1-second average amplitude of the processed EMG signal during the three 3-second trials provided the MVC value for each muscle. The median value for each muscle's EMG signal was calculated for the middle 30 seconds of the typing test and the middle 2 minutes for the long-form typing task to avoid discrepancies caused at the beginning or end of the task.

Dependent Variable: Typing Force

The median typing force was measured by custom force platform under each keyboard.[29,34] The platform had 3 miniature compression load cells (9.55 mV/N and 44.48-N maximum; ELFF-B4-10L; Measurement Specialties, Hampton, VA) mounted underneath it in a triangular pattern.[34] A USB backplane (NI cDAQ-9172; National Instruments) powered, amplified, and sampled the signal from each of the 3 load cells at 2000 samples per second. Postprocessing of the data included band-pass filtering (1–20 Hz, sixth-order, Butterworth filter) to remove noise and wrist contact using the biomechZoo toolbox in MATLAB (MathWorks Inc)[32] and custom MATLAB code. When unloaded, the root mean square value of sensor noise was .0063 N. Normalized force was calculated as typing force divided by grip strength. The median value for each signal was calculated for the middle 30 seconds of the typing test and the middle 2 minutes for the long-form typing task to capture sustained typing and to avoid discrepancies caused at the beginning or end of the task.

Dependent Variable: Typing Performance

For the timed typing test task, typing performance was measured in words per minute (WPM). The computer software provided a measure of typing performance in WPM. An adjusted typing score was also calculated using the software by subtracting the number of errors from the total words typed.

Dependent Variable: Perceived Experience

Participants self-reported discomfort and difficulty with each keyboard after each trial. After each new device, participants received 2 papers with 10-cm visual analog scales that asked them to mark between 0 and 10, where 0 was "no discomfort" and 10 was "a lot of discomfort," and 0 for "no difficulty" and 10 for "a lot of difficulty."

Statistical Analysis

A repeated-measures analysis of variation for each dependent study outcome tested the null hypothesis followed by Tukey post hoc comparison for each keyboard design. Individual analysis of variation models estimated the 6 muscles' median %MVC, median typing force, median normalized force, typing speed, adjusted typing speed, discomfort, and difficulty. The muscle activity and typing force models included participants as a random effect, and device and typing task as fixed effects, whereas the performance and experience models did not include typing task. In addition to the models for all participants, separate models were stratified across the 2 sex/gender groups to examine the effects of device within sex/gender.[36–38] Significance criteria for the F statistic (alpha value) was set at .05. When a significant effect was found, a post hoc analysis with Tukey HSD provided between group comparisons.

Results

Forearm extensor (extensor carpi radialis, ED, and extensor carpi ulnaris) muscle activity varied significantly across the devices with less median muscle activity ($P < .01$) on Notebook S, Tablet L, and Notebook L compared with Tablet S (Table 2). No significant differences were observed for the forearm flexor muscles (flexor digitorum superficialis, flexor carpi ulnaris, and flexor carpi radialis). The timed typing test was associated with significantly higher muscle activity across all of the muscles tested than the long-form transcription task ($P < .001$). No significant 2-way interaction effects were observed between device and task.

Typing force varied significantly across devices (Table 2) with Tablet S associated with significantly higher median typing force compared with the other devices ($P < .001$). The timed typing test was associated with significantly higher typing force than the long-form transcription task ($P < .001$). No significant 2-way interaction effects were observed between device and task.

Typing speed also varied significantly across devices with slower typing speeds for Tablet S compared with Notebook L and Notebook S ($P = .004$; Table 3). After adjusting for typing errors, the significant difference remained ($P = .004$). Notebook L was also associated with a faster average adjusted typing speed (72 WPM) compared with Tablet S (64 WPM) tablet device ($P = .004$). Adjusted speeds on Tablet L and Notebook S were not significantly different from adjusted speeds on Tablet S and Notebook L.

The self-reported questionnaire revealed significant differences in perceived discomfort and difficulty across the devices (Table 4). Participants rated Notebook L with least discomfort;

Table 2 Across Participant Marginal Means (and SEs) for Forearm EMG (%MVC) and Typing Force. Repeated-Measures Analysis of Variance Keyboard Device and Typing Task

		Keyboard device			
	P value[a,b]	Tablet S	Notebook S	Tablet L	Notebook L
Median EMG %MVC					
ECR	**.001**	4.5[A] (0.49)	4.2[B] (0.49)	4.2[B] (0.49)	4.4[**AB**] (0.5)
ED	**<.001**	8.1[A] (0.77)	7.3[B] (0.77)	7.5[B] (0.77)	7.7[B] (0.8)
ECU	**.01**	7.8[A] (0.84)	7.2[B] (0.84)	7.2[B] (0.84)	7.3[B] (0.8)
FDS	.11	3.0 (0.36)	2.7 (0.36)	3.0 (0.36)	2.8 (0.4)
FCU	.61	2.6 (0.53)	2.6 (0.53)	2.7 (0.53)	2.6 (0.5)
FCR	.12	2.3 (0.32)	2.1 (0.32)	2.3 (0.32)	2.3 (0.3)
Median typing force					
Newtons	**<.001**	0.47[A] (0.02)	0.42[B] (0.02)	0.42[B] (0.02)	0.42[B] (0.02)
Normalized, %	**<.001**	3.5[A] (0.3)	3.2[B] (0.3)	3.1[B] (0.3)	3.2[B] (0.3)

Abbreviations: ECR, extensor carpi radialis; ECU, extensor carpi ulnaris; ED, extensor digitorum; EMG, electromyography; FCR, flexor carpi radialis; FCU, flexor carpi ulnaris; FDS, flexor digitorum superficialis; MVC, maximum voluntary contraction.

[a]Repeated-measures analysis of variation with participant as a random variable, keyboard device (4 levels), and typing task (2 levels). Bold values indicate a significant effect ($P < .05$). [b]For significant main effects, Tukey post hoc groupings are ranked such that A > B > C > D. Values with the same superscript letters indicate no significant difference.

Table 3 Performance: Across Participant Marginal Means (and SEs) During a 1-Minute Typing Test

		Keyboard devices			
	P value[a,b]	Tablet S	Notebook S	Tablet L	Notebook L
Total speed, WPM	**.004**	67[B] (4)	73[A] (4)	72[AB] (4)	75[A] (4)
Adjusted speed,[c] WPM	**.004**	64[B] (4)	70[AB] (4)	69[AB] (4)	72[A] (4)

Abbreviation: WPM, words per minute.

[a]Repeated-measures analysis of variation with participant as a random variable and keyboard device (4 levels). Bold values indicate a significant effect ($P < .05$). [b]For significant main effects, Tukey post hoc groupings are ranked such that A > B > C > D. Values with the same superscript letters indicate no significant difference. [c]Adjusted speed calculated as total speed – errors.

Table 4 Self-Report: Across Participant Marginal Means (and SEs) for Self-Reported Discomfort and Difficulty

		Keyboard devices			
	P value[a,b]	Tablet S	Notebook S	Tablet L	Notebook L
Discomfort, cm	**.02**	3.05[A] (0.45)	1.53[AB] (0.45)	1.44[AB] (0.45)	1.07[B] (0.45)
Difficulty, cm	**<.001**	4.80[A] (0.48)	3.17[AB] (0.48)	2.05[B] (0.48)	1.99[B] (0.48)

[a]Repeated-measures analysis of variance with participant as a random variable and keyboard device (4 levels). Bold values indicate a significant effect ($P < .05$).[b]For significant main effects, Tukey post hoc groupings are ranked such that A > B > C > D. Values with the same superscript letters indicate no significant difference.

however, this was only significantly different ($P = .02$) from Tablet S. For difficulty, participants rated Notebook L least difficult, followed by Tablet L. These difficulty ratings were significantly lower ($P < .001$) than Tablet S.

The effects of device on forearm muscle activity showed similar trends with both sex/gender groups; however, statistical significance was present for almost all of the muscles in the female participants and for only one muscle in the male participants (Table 5). In total, 5 (extensor carpi radialis, ED, extensor carpi ulnaris, flexor digitorum superficialis, and flexor carpi radialis) of the 6 muscles tested showed significant differences ($P < .05$) across the 4 devices in female participants compared with only one (ED) ($P = .01$) in male participants (Table 5). Tablet S induced greater forearm muscle activity than the other 3 devices for both female and male participants.

The device's effect on typing force showed similar trends and significance in both groups (Table 5). Tablet S was associated with more absolute and normalized typing force than the other devices in both female and male participants, though a more significant result was observed for female normalized force than for male normalized force ($P < .001$ vs $P = .02$).

Both groups performed similarly across the 4 devices with slowest performance achieved on Tablet S ($P < .05$; Table 6). Female participants typed fastest on Notebook L in terms of both total speed ($P = .02$) and adjusted speed ($P = .03$), whereas male participants typed fastest on Notebook S for total speed ($P = .02$) and adjusted speed ($P = .01$).

After stratifying by sex/gender, fewer differences across devices were observed for self-reported discomfort and difficulty (Table 7). Only difficulty in male participants showed significant differences ($P = .01$) with Tablet S rated significantly more difficult than Tablet L and Notebook L.

Discussion

In response to the widespread availability and use of thinner keyboards, the goal of this study was to examine the effects of

Table 5 Across Participant Marginal Means (and SEs) for EMG (%MVC) and Typing Force. Repeated-Measures Analysis of Variance Keyboard Device and Typing Task

		Keyboard device			
	P value^{a,b}	Tablet S	Notebook S	Tablet L	Notebook L
Median EMG %MVC					
Females					
ECR	**.003**	4.7^{A} (0.76)	4.3^{B} (0.76)	4.4^{B} (0.76)	4.5$^{\mathbf{AB}}$ (0.76)
ED	**<.001**	7.6^{A} (1.0)	6.7^{B} (1.0)	6.8^{B} (1.0)	6.9^{B} (1.0)
ECU	**.01**	8.4^{A} (1.4)	7.3^{B} (1.4)	7.4^{B} (1.4)	7.5^{AB} (1.4)
FDS	**.03**	3.9 (0.61)	3.2 (0.61)	3.8 (0.61)	3.4 (0.61)
FCU	.39	3.4 (0.90)	3.2 (0.90)	3.6 (0.90)	3.3 (0.90)
FCR	**.01**	2.8^{A} (0.40)	2.4^{B} (0.40)	2.6^{AB} (0.40)	2.6^{AB} (0.40)
Males					
ECR	.18	4.3 (0.66)	4.2 (0.66)	4.1 (0.66)	4.2 (0.66)
ED	**.01**	8.7^{A} (1.14)	7.9^{B} (1.14)	8.1^{AB} (1.14)	8.5^{AB} (1.14)
ECU	.59	7.3 (0.97)	7.1 (0.97)	7.1 (0.97)	7.0 (0.97)
FDS	.85	2.1 (0.27)	2.1 (0.27)	2.1 (0.27)	2.2 (0.27)
FCU	.99	1.9 (0.51)	1.9 (0.51)	1.9 (0.51)	1.9 (0.51)
FCR	.42	1.8 (0.49)	1.9 (0.49)	1.9 (0.49)	1.9 (0.49)
Median typing force					
Females					
Newtons	**<.001**	0.46^{A} (0.03)	0.41^{B} (0.03)	0.39^{B} (0.03)	0.41^{B} (0.03)
Normalized, %	**<.001**	4.2^{A} (0.35)	3.7^{B} (0.35)	3.7^{B} (0.35)	3.5^{B} (0.35)
Males					
Newtons	**.003**	0.48^{A} (0.03)	0.43^{B} (0.03)	0.46^{AB} (0.03)	0.44^{B} (0.03)
Normalized, %	**.02**	2.9^{A} (0.35)	2.7^{B} (0.35)	2.7^{AB} (0.35)	2.8^{AB} (0.35)

Abbreviations: ECR, extensor carpi radialis; ECU, extensor carpi ulnaris; ED, extensor digitorum; EMG, electromyography; FCR, flexor carpi radialis; FCU, flexor carpi ulnaris; FDS, flexor digitorum superficialis; MVC, maximum voluntary contraction.

[a]Repeated-measures analysis of variance with participant as a random variable, Keyboard Device (4 levels), Typing Task (2 levels). Bold values indicate a significant effect ($P < .05$). [b]For significant main effects, Tukey post hoc groupings are ranked such that A > B > C > D. Values with the same superscript letters indicate no significant difference.

Table 6 Performance: Across Participant Marginal Means (and SEs) for Adjusted Speed During a 1-Minute Typing Test

		Keyboard devices			
	P value^{a,b}	Tablet S	Notebook S	Tablet L	Notebook L
Total speed, WPM					
Females	**.02**	68^{B} (6)	70^{AB} (6)	69^{AB} (6)	76^{A} (6)
Males	**.02**	67^{B} (7)	76^{A} (7)	75^{AB} (7)	74^{AB} (7)
Adjusted speed, WPM					
Females	**.03**	66^{A} (6)	67^{A} (6)	66^{A} (6)	73^{A} (6)
Males	**.01**	62^{B} (6)	72^{A} (6)	72^{A} (6)	72^{A} (6)

Abbreviation: WPM, words per minute.

[a]Repeated-measures analysis of variance with participant as a random variable and keyboard device (4 levels). Bold values indicate a significant effect ($p<0.05$). [b]For significant main effects, Tukey post hoc groupings are ranked such that A > B > C > D. Values with the same superscript letters indicate no significant difference.

different key travels and key switch mechanisms currently available in thinner keyboards on forearm muscle activity, typing force, typing performance, and self-reported discomfort and difficulty. Device significantly affected biomechanical outcomes, and the differences across devices were similar for all 4 outcomes: Tablet S with short-travel and a dome-type key switch mechanism was associated with higher muscle activity, higher typing force, slower typing speeds, and worse self-reported discomfort and difficulty.

Overall the results show that given similar activation force, larger key travel distances were associated with better performance and experience. The fastest typing speed and least discomfort and difficulty were observed for the device with the largest travel distance. Participants self-reported more discomfort and difficulty with the devices with the shortest travel distance. These results are consistent with most previous research.[26,27] Kia et al[25] also found that the better typing speed and accuracy was associated with larger key travel.

Table 7 Across Participant Marginal Means (and SEs) for Self-Reported Discomfort and Difficulty

		Keyboard devices			
	P value[a,b]	Tablet S	Notebook S	Tablet L	Notebook L
Female					
Discomfort	.14	2.88 (0.64)	1.09 (0.64)	1.03 (0.64)	1.16 (0.64)
Difficulty	.05	5.08 (0.75)	3.54 (0.75)	2.58 (0.75)	2.24 (0.75)
Male					
Discomfort	.29	3.17 (0.63)	1.82 (0.63)	1.71 (0.63)	1.01 (0.63)
Difficulty	**.01**	4.61[A] (0.65)	2.93[AB] (0.65)	1.70[B] (0.65)	1.82[B] (0.65)

[a]Repeated-measures analysis of variance with participant as a random variable and keyboard device (4 levels). Bold values indicate a significant effect ($P < .05$). [b]For significant main effects, Tukey post hoc groupings are ranked such that A > B > C > D. Values with the same superscript letters indicate no significant difference.

The present results suggest that key travel alone does not predict biomechanical outcomes and that key mechanism and activation force are also important factors in key switch design. Specifically, the 2 devices with the same short travel (0.55 mm) had the largest differences across most muscles, though this difference was relatively small (<1.0% MVC). These 2 devices differed in activation force and mechanism: Tablet S had a dome switch mechanism and a higher activation force than Notebook S, which had a butterfly switch mechanism. Similarly, this study found that key travel distance was not strictly associated with typing force, typing performance, or perceived experience, as Tablet S was associated with the worst results across these measures compared with the other 3 devices. These results align with studies that have tested different activation forces[8,20,26,28] and mechanisms.[7,12,19]

In terms of trends observed within sex/gender stratified groups, the results suggest that the effect of the 4 devices was different in female and male participants similar to what has been observed in general occupational health and safety studies.[36,39,40] More statistically significant differences across devices were observed in female participants compared with male participants. This result suggests that women may be more affected by micro-travel keyboard designs than men, similar to the study of Won et al,[29] which suggested differences in anthropometry increased the awkward postures and higher muscle activity for female participants. Though the differences observed were small, it is possible that over prolonged use, these differences could correspond to increased risk.[41,42] Moreover, the kinematics of the users was not measured as it is suspected that the differences in posture would be small across these devices; however, perhaps reaching some of the nonhome row keys magnified the effects of the different devices. In this study, differences in strength probably played a role as all the metrics were normalized by strength or MVCs, meaning that female participants exerted more of their maximum effort than male participants.

As the demand for thinner keyboards and devices increases, it is important for mobile technology designers to consider both the user's experience and sex/gender when deciding on key force–displacement trade-offs. Others before have made these recommendations for general concepts surrounding occupational ergonomics concerning sex/gender in both practice and research.[36,39] These results support the importance of considering gender in usability testing to ensure that the designs mitigate differences observed within different populations.

This study investigated the effect of 4 commercially available devices, and as such it is not possible to disentangle the various travel, force–displacement, and mechanism characteristics in a full factorial designed study. The comparisons made above were done so within this context; however, they are supported by other studies that have shown similar patterns. The study did not collect wrist posture that could account for the increased muscle activity in Tablet 1, which did not have any wrist supports; however, participants were set up to maintain similar wrist postures across devices, and the other dependent variables corresponded with the EMG results.

Furthermore, the study was conducted in a laboratory setting, and the short duration of typing may not accurately reflect real-world, long-term device use, and it is possible that computing has changed so much that long-form transcription is also not reflective of the modern typing experience. In addition, the self-reported experience measures were collected after only a short experience with each device and may not be valid measures of long-term discomfort and difficulty. However, consumers would likely only type on devices for a short period in the store, and thus, these results may be important to manufacturers. The EMG effect sizes were relatively small (<1.0% MVC) across all devices and may not corresponded to an increased risk clinically; however, these subtle differences could matter over long-term exposure. We were unable to blind the device brands, and participants' prior experiences with them could have affected their self-reported results and behavior. Gender is a proxy for multiple biological and psychosocial characteristics, and stratifying by a male/female binary may not explain the root cause of the differences observed.

Key travel is only one design feature that may not fully account for the differences in typing force, muscle activity, typing performance, and participant experience. Future studies should explore key spacing, over travel, and activation force in addition to key travel. In addition, future studies should account for individual differences, such as anthropometry, strength, and sex/gender.

This study found differences in upper-extremity biomechanics, typing performance, and self-reported experience across 4 micro-travel keyboard devices with 0.5-mm (Tablet S and Notebook S), 1.3-mm (Tablet L), and 1.6-mm (Notebook L) travel distances during short laboratory-based typing tasks. The results further support the importance of other design features, such as activation force and mechanism, as well as keyboard form factors. These considerations will be important as the market continues to demand thinner mobile devices.

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