การศึกษาประสิทธิภาพของอุปกรณ์นำเข้าข้อมูลสำหรับการสอบข้อเขียน- การเปรียบเทียบระหว่างอุปกรณ์การเขียนและอุปกรณ์การพิมพ์

Performance study of input devices for generating writing with drawing tasks in written exams-a comparison between handwriting and typing devices

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บทคัดย่อ

การสอบเป็นเครื่องมือในการประเมินผลของมหาวิทยาลัย ซึ่งสามารถทำได้โดยใช้อุปกรณ์ป้อนข้อมูลประเภทต่างๆ ในการสอบข้อเขียน การศึกษานี้เป็นการตรวจสอบการใช้อุปกรณ์ป้อนข้อมูลแบบดิจิทัลว่าจะมีผลต่อการใช้กล้ามเนื้อมากกว่าการใช้เครื่องมือแบบดั้งเดิมหรือไม่ งานวิจัยได้ตรวจสอบคลื่นไฟฟ้ากล้ามเนื้อ ที่ตำแหน่งกล้ามเนื้อ Trapezius (TRAP) กล้ามเนื้อ Biceps brachii (BB) กล้ามเนื้อ Flexor Digitorum Superficialis (FDS) กล้ามเนื้อ Extensor Carpi Radialis Brevis (ECRB) และกล้ามเนื้อ Extensor Digitorum Communis (EDC) ในขณะสอบข้อเขียนโดยใช้อุปกรณ์ป้อนข้อมูลแบบดิจิทัล ได้แก่ Boogie Board, Chromebook, iPad pro, Keyboard Notebook, Ballpoint Pen และ Yoga Book ผลการวิจัยพบว่า นักศึกษามหาวิทยาลัยจำนวน 20 คน ที่ใช้ Boogie Board และ Ballpoint Pen จะมีการใช้กล้ามเนื้อในระดับมากที่สุด ซึ่งเมื่อใช้ Boogie Board และ Ballpoint Pen กลุ่มตัวอย่างมีแนวโน้มใช้กล้ามเนื้อ FDS และ ECRB ในระดับมากที่สุด ตลอดทั้ง Boogie Board ยังส่งผลให้มีการใช้กล้ามเนื้อ BB ในระดับมากที่สุดอย่างต่อเนื่อง นอกจากนี้เมื่อใช้ Yoga Book กลุ่มตัวอย่างมีแนวโน้มใช้กล้ามเนื้อ TRAP, FDS และ EDC เพิ่มขึ้น ในทางตรงกันข้ามเมื่อเป็นการใช้ Chromebook และ iPad pro จะส่งผลให้การใช้กล้ามเนื้อ FDS และ EDC ลดลงอย่างต่อเนื่อง อย่างไรก็ตามเมื่อเป็นการพิมพ์บนคีย์บอร์ดของโน๊ตบุ๊ค กลุ่มตัวอย่างใช้กล้ามเนื้อ BB, FDS และ ECRB น้อยลง ดังนั้นจึงอาจสรุปได้ว่า เมื่อใดที่เป็นการเขียนที่ใช้เวลานาน การใช้คีย์บอร์ดโน๊ตบุ๊คอาจเป็นวิธีที่เหมาะสมมากกว่าการเขียนด้วยลายมือ โดยเฉพาะในด้านการศึกษา ซึ่งการค้นพบนี้ยังชี้ให้เห็นว่าอุปกรณ์นำเข้าข้อมูลที่เป็นการเขียนด้วยลายมือ จะใช้พลังงานมากขึ้นและอาจทำให้เกิดความเสียหายของกล้ามเนื้อในขณะทำงานเขียนด้วยลายมือ

Keywords: การประเมินผล การตรวจคลื่นไฟฟ้ากล้ามเนื้อ การออกแบบด้วยหลักการยศาสตร์ ปฏิสัมพันธ์ระหว่างมนุษย์กับคอมพิวเตอร์

Abstract

Examinations are an assessment and evaluation tool at University. They can be performed using different types of input devices to complete them. This study investigated whether using digital input devices affects muscle activation than a traditional input instrument. We monitored the Electromyography (EMG) activity of Trapezius (TRAP), Biceps Brachii (BB), Flexor Digitorum Superficialis (FDS), Extensor Carpi Radialis Brevis (ECRB) and Extensor Digitorum Communis (EDC) muscle activity during generative writing with drawing tasks in written exams using a Boogie Board, Chromebook, iPad pro, Notebook Keyboard, Ballpoint Pen, and Yoga Book. Twenty university students were included in this study. The results showed Boogie Board, and Ballpoint Pen used the most muscle activity. When using Boogie Board and Ballpoint Pen, participants tended to mostly use FDS and ECRB muscle activity.

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Additionally, Boogie Board consistently had the greatest BB muscle activity. Moreover, when using the indirect input device, Yoga Book, participants had indications of a trend of increasing in TRAP, FDS and EDC muscle activities. In contrast, Chromebook and iPad pro showed consistently lower FDS and EDC muscle activities. However, when typing on the Notebook Keyboard, subjects had the least BB, FDS, and ECRB muscle activity. Therefore, when a long writing scenario is required, a Notebook Keyboard may be a more suitable interface, especially in education. The findings also suggest that handwriting devices have a greater potential energy expenditure in performing handwriting tasks and muscular damage with the maintenance of motor patterns in handwriting tasks.

Keywords: Assessments, Electromyography, Ergonomic design, Human computer interaction

Introduction

Examinations are a very common assessment and evaluation tool in universities. Many Universities are spending more money each year on test administration, such as preparing examination scripts and answer sheets, as well as storing such scripts and sheets. If we analyze all characteristics of examination administration, we see that digital input devices such as keyboards and digital handwriting instruments make possible a more efficient examination process for test administration and review[1-2.]

Previous results have indicated that both computer keyboard characteristics and handwriting instruments can affect users' risks for developing injury and health risks from working conditions, especially during long sessions[3-4]. Moreover, in examination conditions, existing research indicates that assessment can be impacted by the type of device that was used to complete it[5-6]. In addition, psychological effects, such as excitement, fear and anxiety during examination may have an effect on muscle activity[7]. However, digital input devices are increasingly being used especially for test administration, e.g. pen-based testing in drawing, sketching, graphing, and writing text containing a mathematical equation[8-11]. Although digital input devices are increasingly widely used, it is still unclear exactly what type of digital input devices could be more suitable for generating writing with drawing tasks in written exams[12-13].

An important question in this new generation writing scenario is whether using digital input devices affects muscle activation differently than a traditional input instruments. Thus, it is important to understand the use of input devices that may affect physical risk factors and student performance. In this work we intend to empirically answer this research question. We compare generating writing input using six types of device: Notebook Keyboard, Pen and Paper, Yoga Book, Chromebook, iPad pro, and Boogie Board.

Methods

Subjects

Twenty university students at Burapha University and King Mongkut's Institute of Technology Ladkrabang, Thailand, (17 males and 3 females), aged between 20-22 years, participated in this study. Participates were recruited to take part in the study through institutional e-mail, by telephone or by personal contract. In total, 51 e-mail addresses were mailed, 15 completed the online typing test program. 5 students were asked to write down their e-mail address on a list if they were interested to participate in the study. Eighteen subjects were right hand dominant and all subjects met the criteria, based on their experience of touch typing with no history of upper extremity musculoskeletal disorders or pain, discomfort, trauma or sequelae related to the upper limbs. The typing speed for all subjects was 46.15 words per minute (WPM) with an accuracy of 94.21%. The typing speed was collected using an online typing test program (https://10fastfingers.com/typing-test/thai) with the subject's own conventional keyboard during subject recruitment. This experimental protocol was approved by the University's Human Subjects Committee (194/2560) and each subject signed an informed consent prior to their participation in the study.

Table 1 Basic data of the participants

N=20	Classification
Gender	17 males, 3 females
Dominant side	Right hand 18, Left hand 2
Age (years) [mean (SD; range)]	21.27 (0.55; 20-22)
Typing speed (word per minute) [mean (SD; range)]	46.15 (9.50; 33-61.6)
Accuracy (%) [mean (SD; range)]	94.21 (3.39; 91.226-97.176)
Experienced touch typing (years) [mean (SD; range)]	7.72 (1.12; 7-10)

Experimental design

Because the nature of high-stakes assessment limits the amount of experimentation that can be undertaken, it would be suitable to ask students to sit a mock examination. Each of the participants is cited at a different time to participate in the experiment. Except for Keyboard, Notebook and Ballpoint Pen and Paper, the subjects has no experience for using each writing devices. Therefore, before evaluating the various input devices, the subjects were allowed to familiarize themselves with different writing devices including Boogie Board, Chromebook, iPad pro, Notebook Keyboard, Ballpoint Pen, and Yoga Book. Moreover, the seat and work surface were adjusted to match each subject's anthropometry along ANSI/HFES standards[14]. Participants were given different versions of the input devices and one writing exercise that required the participants to complete a paragraph of text containing an alphanumeric and geometrical content. Then students completed a task within 15 minutes (900s) for each different input device. They were also allowed 10 minutes break before starting the next version of the input device, to minimize any residual fatigue effects of the previous condition. Each exercise was followed by completing a questionnaire. Finally, during an interview we asked participants to describe their experience with the writing tool and asked them to compare their experience with all writing devices and their preferences. During the writing sessions, writing accuracy and speed were recorded by screen recorder software. The order of the input devices was randomized and counterbalanced to minimize any potential confusion due to the input device testing order[15-17].

Equipment and Material

Electromyography

The Surface Telemetry EMG version BTS Free EMG300 wireless (BTS Bioengineering Corp.), which is a 16-channel system, with a mode rejection of 126 dB was used to collect the surface EMG (sEMG) signals, conditioned with a digital band-pass filter between 10Hz-350Hz. EMG signals were recorded using digital data at a sample rate of 1000 Hz. Disposable Ag/AgCl surface electrodes with an 8 mm diameter pick up area (Ambu Blue Sensor P, REF: P-00-S/50) were placed with a 20-mm inter-electrode spacing over the five muscles.

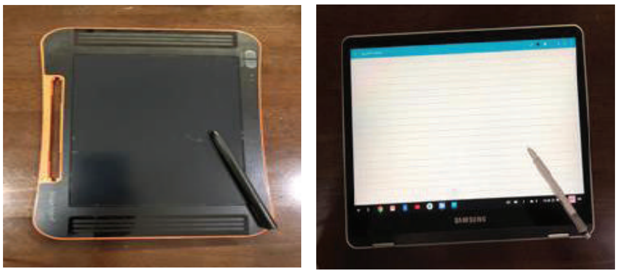
Writing material

In the repeated–measures laboratory experiment, participants performed writing for fifteen minute sessions on each of six input device conditions including Boogie Board, Chromebook, iPad pro, Keyboard, Ballpoint Pen and paper and Yoga Book (Figure. 1).

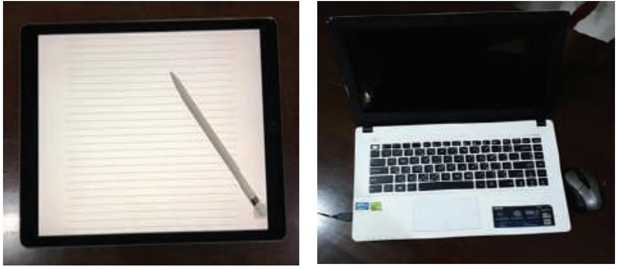
The subject wrote on foolscap folio, with line spacing of 8 mm and paper gramature of 56g/m 2(g), using a pen with blue ink ballpoint, with medium point of 0.7 mm and line width of 0.4 mm, with hexagonal barrel. This object was conceived and developed as to be clean and reliable, and it is now the world's most-used writing instrument[18] and offers more precision with handwriting task[19-20].

The digital pen technology characteristics included Boogie Board, Chromebook, iPad pro and Yoga Book. Each of the digital pen technologies used in the study were chosen to cover a regular characteristic of digital pen technologies that are on offer. We considered the characteristics based on the accuracy, weight, grips, length, shape, tip size, and other functionality such as touch sensitivity, and electronic erasers.

The Notebook Keyboard had palm rests and tactile feedback. The key spacing (center-to-center distance) was approximately 19 mm on all the keyboard and all conformed to ANSI[14, 21].



Boogie Board Chromebook



Ipad Pro Notebook Keyboard

Ballpoint Pen and Paper Yoga Book

Boogie board stylus
Chromebook stylus
iPad pro stylus
Ballpoint pen
Yoga book stylus

Figure 1 Input devices used in study

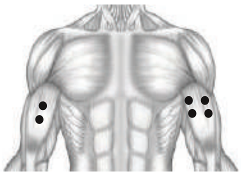
Muscle activity

Muscle activity was recorded from the Trapezius (TRAP), Biceps Brachii (BB), Flexor Digitorum Superficialis (FDS), Extensor Carpi Radialis Brevis (ECRB)[4, 22-24], and the Extensor Digitorum Communis (EDC) muscle. The TRAP, BB, FDS and ECRB muscle were selected for their main functions to stabilize and move the upper arm during fine dexterity activities such as handwriting[22]. The EDC muscle were selected for their major role in extending the phalanges, then the wrist, and the elbow. The EDC tends to separate the fingers as it extends them[4].

Electrode placement

The location of muscles was identified through palpation during voluntary contraction[25-26]. The active electrodes for the TRAP muscle were placed 2 cm lateral to the halfway point between C7 and the right acromium process[27] (Figure 2 A). The BB was identified by asking the subject to flex their forearm in the supinated position and then the palpate muscle mass in the anterior aspect of the arm emerges[28] (Figure 2 B). The EDC was identified by palpating the muscle on the dorsal side of the forearm one third of the way up the forearm and having the subject wiggle their fingers. The electrodes were located where the muscle contractions could be felt[25-26] (Figure 2 C). Similarly, the FDS was located by touching the muscle on the palmar side one third of the way up the forearm and locating the electrodes where the muscle contractions could be felt[25-26] (Figure 2 D). The ECRB was identified by asking the subject to extend the wrist and palpate the muscle mass approximately 5 cm distal from the lateral epicondyle of the elbow[28] (Figure 2 E).

A. Electrode placement for the upper Trapezius (TRAP) site, post aspect.



Electrode placement for the Biceps-Brachium (BB) site, ant aspect.

C. Electrode placement for Extensor Digitorum Communis (EDC) site, post aspect.

D. Electrode placement for the Flexor Digitorum Superficialis (FDS) site, ant aspect.

E. Electrode placement for Extensor Carpi Radialis Brevis (ECRB) site, post aspect.

Figure 2 Electrode placement

Prior to applying the EMG electrodes to the skin, the electrode contact area was prepared by shaving where necessary and then the skin surface was cleaned with Alcohol 70° GL prior to electrode fixation in order to reduce contact impedance[28]. Then, the electrodes were connected to wireless surface sensors and the system communicated with a PC through a WiFi router, which managed 5 electrode channels simultaneously.

EMG data acquisition and analysis system

The electrodes were connected wirelessly to the BTS Free EMG300 (BTS Bioengineering Corp.) with a common mode rejection of 126 dB and then they were converted from analog-to-digital (A/D). The raw EMG data was fed into a specific analysis system programed with EMG-Analyzer software for further analysis. The analysis system used Root Mean Square (RMS) to eliminate the interference of ambient electromagnetic fields[30], and the Butterworth high pass filter at 20 Hz was used to apply additional digital filters to minimize the phase shift phenomenon in the RMS algorithms[30]. Moreover, the analysis system was equipped with a band pass in the range of 10-350 Hz filter that were needed to avoid anti-aliasing effects within sampling[30].

The filtered EMG data from the TRAP, BB, FDS, ECRB and EDC muscles was normalized relative to Maximum Voluntary Contractions (%MVC) for each muscle (Figure. 3), the 10th (static), 50th (median) and 90th (peak) muscle activities were calculated[31]. To obtain the two MVCs, an isometric contraction held at outer-range position, the subjects were instructed to extend their wrists and fingers up against isometric resistance (EDC) and to flex their fingers down against isometric resistance (FDS) with verbal encouragement. To obtain BB MVCs, the subjects were instructed to exert a force with the elbow flexor muscles and to minimize the involvement of other muscles[32]. To obtain TRAP MVCs, the isometric resistance was applied as subjects performed a continuous single shoulder shrug with their arms at their sides and without bending or twisting at the hips/waist[33-34]. Each contraction time lasted for three to five seconds[35]. Five MVCs were collected from which the maximum RMS signal over a 1s period was identified and used to normalize the EMG data.

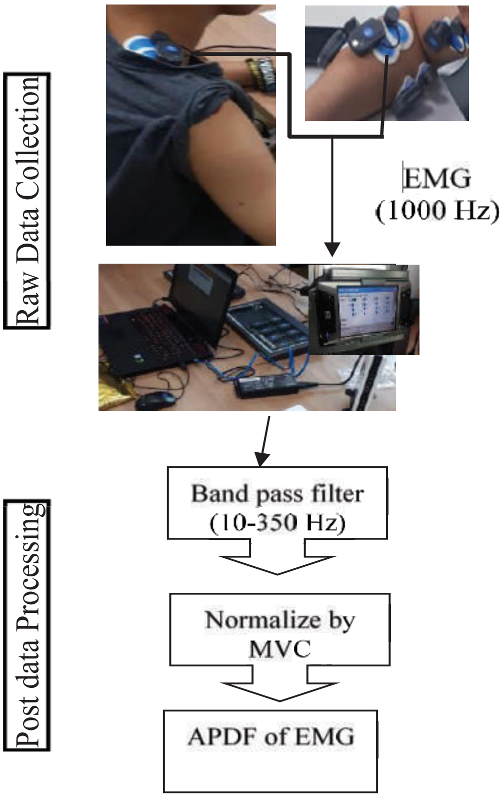


Figure 3 Experimental setup

Data analysis

In order to reduce variation and condense the colossal amount of data, the section corresponding to the task execution was divided into 6 time periods of electrical activity (EA). The first collection started at the second of 30-s epoch (time window) and the next collection was done every 150 seconds. An analysis system calculated EMGs values for every 30-s epoch[36]. Filtered EMGs was normalized by the maximum voluntary contractions (MVC). The data was analyzed with statistical software SPSS for Windows (version 21.0) (SPSS Inc., Chicago, IL, USA). We employed the method of means contrast based on analysis of variance (ANOVA) for the following reasons: (I) the sample followed a normal distribution, (II) the number of groups to be analyzed was greater than two, (Yoga Book, Chromebook, iPad pro, Boogie Board, note book key board and Ballpoint Pen) (III) all the samples were the same size (this is a small number: 20 subjects). ANOVA is an inferential statistic for analyzing the mean difference between muscle activities. This statistic can control Type I errors. In those cases, having a difference between the means, an additional exploration of the difference among means multiple comparisons test, is needed. Any statistical significance was followed-up with a post-hoc Tukey HSD to determine whether there were significant differences between handwriting and typing devices.

Results

The results of the EMG analysis indicated variations in muscular behavior during the execution of the writing with drawing tasks in written exams as follows.

Trapezius

The results indicated that there were differences in TRAP muscle activity between input devices (Figure. 4). The Yoga Book had a significantly higher static (10^{th} percentile) muscle activity compared to the Chromebook and Notebook Keyboard ($p<0.05$) and a higher median (50^{th} percentile) muscle activity compared to the Chromebook and iPad pro respectively ($p<0.05$) whereas boogie with a Ballpoint Pen had a significantly higher peak (90^{th} percentile) muscle activity compared to Notebook Keyboard ($p<0.05$).

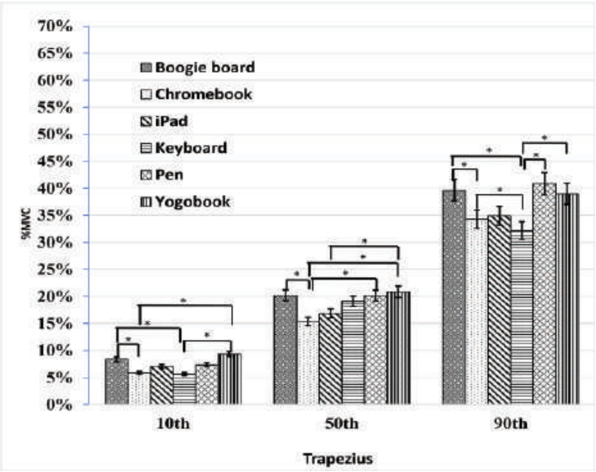


Figure 4 Comparison of 10^{th} 50^{th} and 90^{th} %tile muscle activity of TRAP. *statistical significance at α=0.05.

Biceps brachii

There were significant differences in the static median and peak BB muscle activities across the input devices (Figure. 5). The Boogie Board showed a consistently higher BB activity for the 10th 50th and 90th percentile muscle activity whereas the Notebook Keyboard had a lower static, median and peak ($p<0.05$) muscle activity.

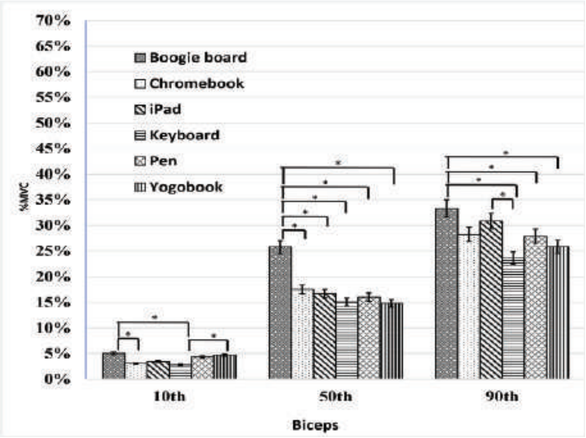


Figure 5 Comparison of 10th 50th and 90th %tile muscle activity of BB. *statistical significance at α=0.05.

Flexor digitorum superficialis

There were significant differences in static median and peak FDS muscle activities across input devices (Figure 6). The Ballpoint Pen showed a higher FDS activity for the 50th and 90th percentile muscle activity.

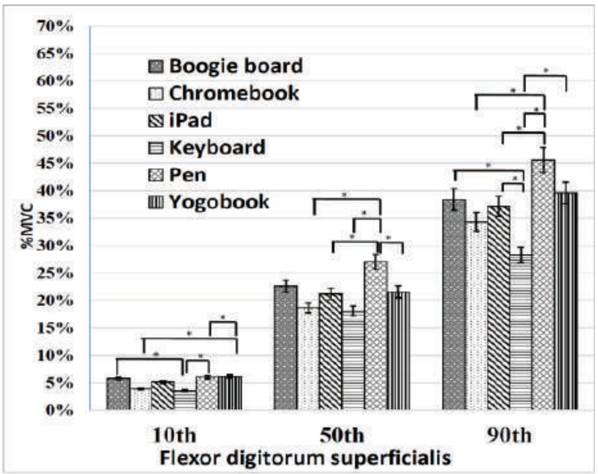


Figure 6 Comparison of 10th 50th and 90th %tile muscle activity of FDS. *statistical significance at α=0.05.

Extensor carpi radialis brevis

There were significant differences in static median and peak ECRB muscle activities across input devices (Figure 7). The Ballpoint Pen showed higher ECRB activities for the 50th and 90th percentile muscle activity with the Notebook Keyboard having a consistently lower static (p<0.05), median (p<0.05) peak (p<0.05) muscle activity.

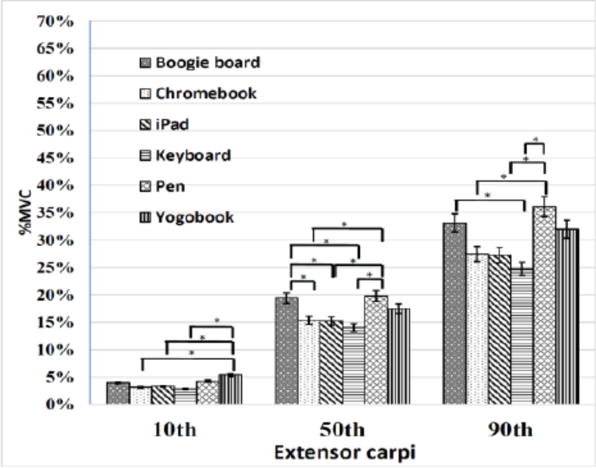


Figure 7 Comparison of 10th 50th and 90th %tile muscle activity of ECRB. *statistical significance at α=0.05.

Extensor digitorum communis

There were significant differences in the static median and peak EDC muscle activities across the input devices (Figure. 8). The Yoga Book had the highest peak (p<0.05) muscle activity (90th percentile) when compared to Chromebook and Notebook Keyboard respectively, whereas Chromebook showed lower EDC activities for the 50th and 90th percentile muscle activity compared to the Boogie Board and Ballpoint Pen (50th percentile) (p<0.05), and Boogie Board, Ballpoint Pen and Yoga Book (90th percentile) (p<0.05) respectively. Moreover, the Boogie Board had a higher static muscle activity (10th percentile) when compared to the Chromebook and the Notebook Keyboard (p<0.05) respectively.

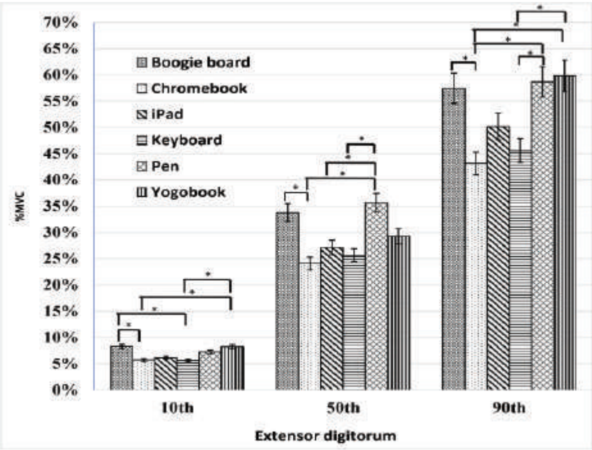


Figure 8 Comparison of 10th 50th and 90th %tile muscle activity of EDC. *statistical significance at α=0.05.

Discussion

The present study evaluated whether using digital input devices affects muscle activation, physical risk factors and student's performance, differently than a traditional input instrument. This study intends to help demonstrate the best practices for a University wanting to implement innovation for their examinations. This research result allows an efficient examination process for all parties involved, reflected in decreased correction times and lower copying and printing costs. The EMG results indicated that when using a Boogie Board and Ballpoint Pen, participants had a trend of higher FDS and ECRB muscle activities. Although, this study showed that writing with a Ballpoint Pen required the higher muscle activity for FDS and ECRB muscles compared to Boogie Board, there was no muscle activity difference between the Boogie Board and Ballpoint Pen. This is likely because the Boogie Board tip felt almost like a real pen and friction between the stylus and the slate was similar to Pen and paper[37]. Moreover, during interview, some participants expressed their opinion about enjoying writing with a Boogie Board. "Because the friction between the nib and surface is smooth and resembles regular pen and paper"

When expressing feelings about the Ballpoint Pen, the subjects often commented that "I had to press harder on the tip of the Ballpoint Pen nib to write with it, as the Ballpoint Pen nib is not fluid and smooth". "the feed's ink is not flowing smoothly, so I have to press hard on the Ballpoint Pen nib". This finding in the FDS and ECRB muscle activities corresponds with previous studies. Almeida, et al.,[22] which found that muscle activity associated with use of a pen involved a higher FDS muscle activity compared to ECRB muscle activity while perform handwriting tasks. Due to the difference of grasp patterns, there is an expenditure of different muscle activities (Figure 9 and Figure 10)[22, 38]. Thus, beyond the grasp pattern, the nib and ink feed are the most important component that may affect muscle activity.

Additionally, when using a Boogie Board, participants had consistently higher BB activities for the 10th 50th 90th percentile muscle activities, compared to other devices (Figure. 5). However, to our knowledge, there have only been a few previous studies using EMG to Boogies Board. This is likely because the adoption of proximal joint movements, such as shoulder elevation and elbow flexion, during the handwriting[22].

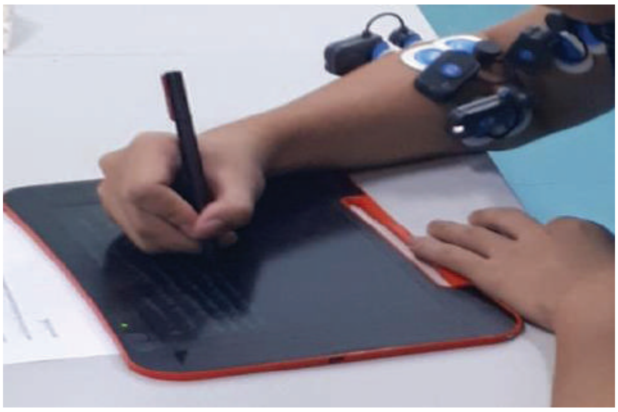


Figure 9 Participant's handwriting samples from Boogie Board

Figure 10 Participant's handwriting samples from Ballpoint pen

Moreover, if we analyzed the Boogie Board, the results showed the EDC muscle was higher for the 10th 50th 90th percentile muscle activities compared to other muscle activities (Figure. 11). This is likely because of the major role of the EDC muscle in extending the phalanges, then the wrist, and the elbow. The EDC tends to separate the fingers as it extends them, and it extends the medial four digits of the hand[4].

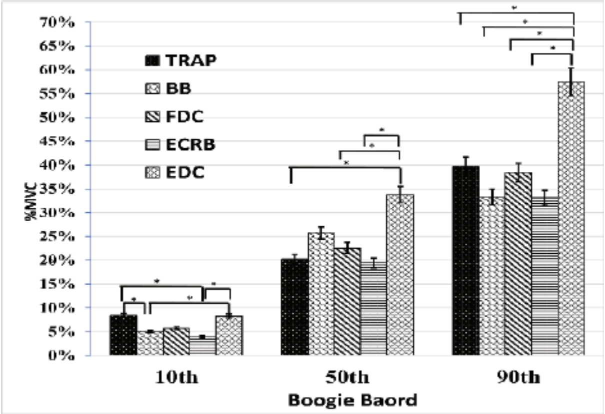
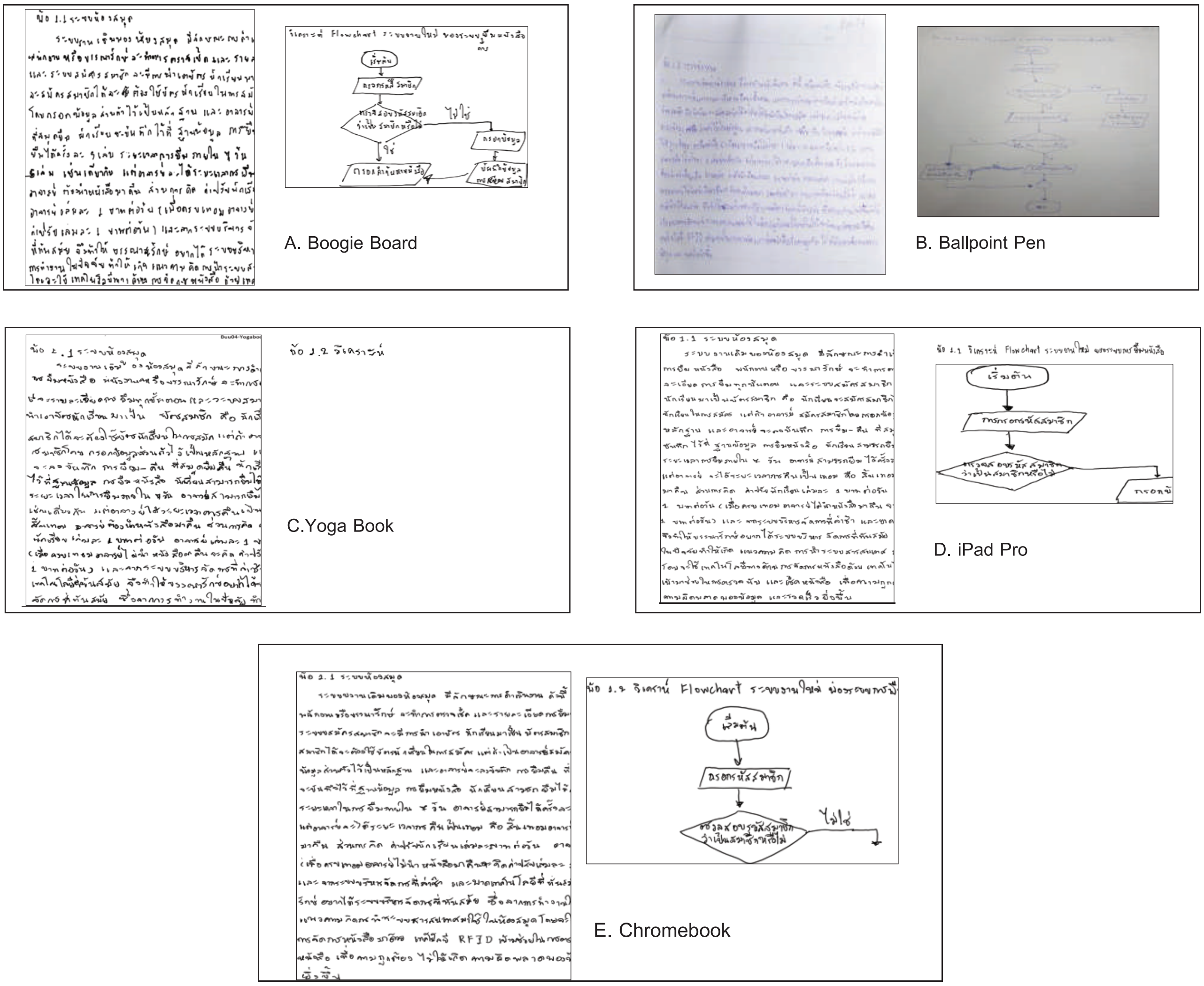


Figure 11 Comparison of the TRAP, BB, FDC, ECRB and EDC muscle activities of the Boogie Board

Besides, when expressing feelings about the Boogies Board, the subjects commented that “because of the similarity between a black screen of slate and line color of stylus, it created the difficulty of seeing the appearance of stokes, so I had to alter my writing size”. “Sometimes, I had to press harder on the tip of stylus nib to write with it, because of the color of stokes and black screen is not contrast” (Figure 12). Thus, our analysis of all the descriptive data indicate that beyond stylus accuracy and precision of strokes, the contrast between background and text color invoked a stronger connection to one’s writing because it forced them to alter their writing size and variety of pressures, and these may ultimately affect muscle activity[11].


A. Boogie Board

B. Ballpoint Pen

C.Yoga Book

D. iPad Pro

E. Chromebook

Figure 12 The images were cropped to show details of the character’ size and the variety of stroke pressure created using Boogie Board compared to handwriting sample from other devices. (Participants No.4)

Interestingly, when using the indirect input device, Yoga Book, participants had consistently higher TRAP, FDS, and EDC activities especially for the 10th percentile muscle activities, compared to Chromebook ($p<0.05$). However, to our knowledge, there have been few previous studies using EMGs on Yoga Book. Also, we analyzed the screen recorder and video data regarding the subject's writing. We found that participants wrote with a variety of pressure in handwriting. Some participants had more difficultly forming and terminating writing with the Yoga book (Figure 12 C). When participants begin to write, they had to look at the screen to monitor their stroke as well as seeing what they had already written on the screen whilst the subject wrote down on the touch slate (halo keyboard) (Figure 13). These were thought to be a result of mismatch of the interaction between the nib on the touch slate and the appearance of digital ink on the screen. Many participants commented on the appearance of their stroke beautification and their aesthetics. Moreover, they expressed opinions about a mismatch of the movement between the nib and digital ink on screen, if it forced them to alter their writing size, needed them to write slower and required more attention. Participants most often expressed the opinion "difficult to control". "The writing on the line is not easier to master than other devices". These may lead to a higher energy expenditure with the maintenance of a motor pattern in handwriting tasks[11, 22]. Therefore, inking on screen with altered writing size would likely involve higher muscle activities.

However, if we analyzed TRAP, FDS, and EDC activities for the 50th 90th percentile muscle activity, then we see that the Yoga Book indicated variations in muscle activities. The possible reason would be the difference in adapting movement patterns for individuals. When handwriting events were improperly handled, many more modified their behavior than participants were comfortable with, so they would have a different movement style[11] and eventually it may lead to the difference of muscle activities.

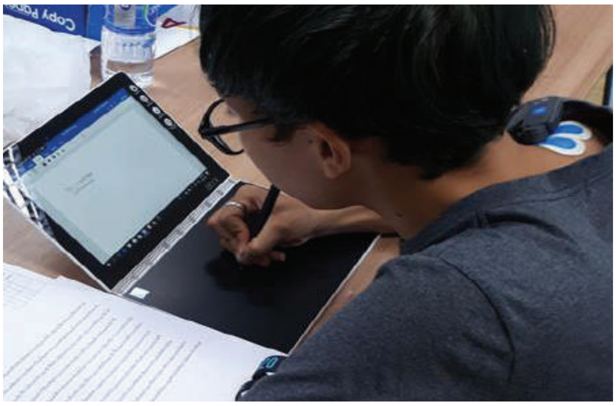


Figure 13 The usage of Yoga Book with stylus

When using Chromebook and iPad Pro, participants had consistently lower FDS (Figure 6) and EDC (Figure 8) activities for the 10th 50th 90th percentile muscle activities. Although, the iPad pro had a higher FDS and EDC muscle activity than Chromebook, there were no muscle activity differences between the Chromebook and iPad Pro. This is likely because both of the styli had pressure sensitivity and low latency thereby enabling smooth inking on the screen[39]. Moreover, when participants expressed opinions about Chromebook and iPad Pro, they were frequently described as "different and easy to control" by participants. Participants had positive writing experiences with them and felt that their display surface felt "smooth" which is a prominent feature identified as an ideal characteristic. In addition, with unintended touch, participants could write in a comfortable position and could rest their palm on the display (Figure14 and Figure15). Many participants felt that the stylus tip felt almost like a real pen and there was enough friction between the stylus and screen to feel natural. Interestingly, stroke beautification and productivity were similar between them (Figure 12 D and E). Thus, our analysis of all the descriptive and letter formation data shows that lower FDS and EDC muscle activities among Chromebook and iPad Pro may be caused by the mature grasp pattern which is the handwriting activity itself, modifying the muscular performance when controlling the stylus on the surface[40].

Figure 14 The usage of Chromebook

Figure 15 The usage of iPad Pro

When typing on the Notebook Keyboard, subjects had consistently the lowest BB (Figure 5), FDS (Figure. 6) and ECRB (Figure 7) muscle activity for the 10th 50th and 90th %tile muscle activities. The possible reason might be due to subjects being able to rest either their fingers or hands during typing[4, 22] as well as an adjustment of the chair and work surface to match each user's anthropometry in accordance with ANSI/HFES standards[14]. Thereby the preferred working position for most Notebook Keyboard participants is the forearms being parallel to the floor and elbows at the sides; this allows the hands to move easily over the keyboard[41-42] (Figure16). If not, then Notebook Keyboard for long period of time may affect muscle strain and risk of carpal tunnel syndrome or other kinds of repetitive strain injury[43-46]. Moreover, previous studies, Callegari, et al.,[47] and Nag, et al.,[48] found that when using the Notebook Keyboard, the hand and wrist rest would support the user's wrists as they type, and the BB and EDC muscle activity showed a reduced percentage of fatigue. This may lead to a muscle-selective reduction in the occurrence of fatigue and thus provide direct evidence that they may prevent work-related musculoskeletal disorders.

Figure 16 The usage of Notebook Keyboard

In addition, when we analyzed the Notebook Keyboard's muscle activity especially for the 50th percentile muscle activity: TRAP (19.118 %MVC), BB (15.0680 %MVC), FDS (18.0930 %MVC), ECRB (14.0560 %MVC) and EDC (25.6406 %MVC), we found that the EDC muscle was the highest muscle activity. This may play a major role in extending the phalanges, then the wrist, and finally the elbow. It also tends to separate the fingers as it extends them, and it extends the medial for digits of the hand. Similarly, the TRAP muscle is a higher muscle activity. This may be a function of the TRAP muscle to support the arm[4,49]. This finding corresponds with previous studies, Kim et. al.,[4] and found that the Notebook Keyboard's muscle activity showed a tendency to be an intermediate TRAP muscle activity. The reason is the difference in muscle activities by typing force[4,50], higher typing forces applied to a Notebook Keyboard are more likely to be affected by key activation force than the typing speed[4]. As this present study allowed subjects to type at their preferred speed, this may have affected the difference in muscle activity by typing force[4,50]. As a result, muscle activity may be problematic due to the typing forces reduce with lower key activation forces and that the lower typing forces resulted in reduced muscle activity[4], and the study condition where subjects may use different typing forces, further clarification should be made in future studies to draw conclusive information.

Conclusion

Universities allocate more budget each year on test administration, and digital input devices are increasingly being used, especially for test administration. However, computer keyboard characteristics and handwriting instruments can affect user's risks for developing injury and health risks from working conditions. Therefore, it is important to understand whether using digital input devices affects muscle activation, physical risk factors and student's performance. In conclusion, the study demonstrated that there were differences between handwriting and typing devices for generating writing with drawing task in written exams. This work provided insight evidence of the difference between input devices in muscle activity. According to the result obtained in the EMG activities, using a Boogie Board, and Ballpoint Pen may be detrimental and cause muscle damage after trying to generate writing tasks for long sessions, especially in written exams that require the students to express their knowledge with alphanumeric and geometrical content. Moreover, when using and indirect input device like the Yoga Book, participants had an indication of a trend of increasing in TRAP, FDS and EDC muscle activities. This was thought to be a result of the pressure on the nib of the Ballpoint Pen and alteration of writing size when using the Boogie board and Yoga Book. These could be crucial when the accumulate over time. Besides, participants had positive experiences with Chromebook and iPad Pro and felt that these were ideal characteristics for generating writing. When typing on the Notebook Keyboard, subjects had the lowest BB, FDS, and ECRB muscle activity, this may imply that using a Notebook Keyboard may be an efficient tool for generating writing with drawing task, especially geometrical content in written exams. Moreover, using this tool may allow teachers to spend less time checking and correcting the answers once students have finished. Thus, when a task involves alphanumeric and geometrical content, it is more likely that the technological advances could be most advantageous[51].

Limitations and Future direction.

Even though conducted over a short experimental period, the results of this experiment indicated the tendency of user's risk for developing health problems from long-term use of IT instruments for writing. There are a number of limitations to this study. Fist, we eliminated specific factors: the thinking time, short and long answer for writing, and the revision level by participants that may impact or influence the real writing examination. Second, this study focused only on muscle activity and did not include typing forces and quality of writing. Since Notebook Keyboard had consistently the lowest muscle activities, it is uncertain if participants used substantially different typing forces that reduce with lower key activation forces and that the lower typing forces resulted in reduced muscle activity[4], futures researches should take into account the limitation of this study by including using a force platform and investigating the individual keystroke force profiles as well as the other muscle activity such as Neck muscle, back muscle and abdominal muscle.

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