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A Study on the Effect of Design Factors of Slim Keyboard's Tactile Feedback

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***Abstract*—**With the rapid development of computer technology, the design of computers and keyboards moves towards a trend of slimness. The change of mobile input devices directly influences users' behavior. Although multi-touch applications allow entering texts through a virtual keyboard, the performance, feedback, and comfortableness of the technology is inferior to traditional keyboard, and while manufacturers launch mobile touch keyboards and projection keyboards, the performance has not been satisfying. Therefore, this study discussed the design factors of slim pressure-sensitive keyboards. The factors were evaluated with an objective (accuracy and speed) and a subjective evaluation (operability, recognition, feedback, and difficulty) depending on the shape (circle, rectangle, and L-shaped), thickness (flat, 3mm, and 6mm), and force (35±10g, 60±10g, and 85±10g) of the keyboard. Moreover, MANOVA and Taguchi methods (regarding signal-to-noise ratios) were conducted to find the optimal level of each design factor. The research participants, by their typing speed (30 words/ minute), were divided in two groups. Considering the multitude of variables and levels, the experiments were implemented using the fractional factorial design. A representative model of the research samples were established for input task testing. The findings of this study showed that participants with low typing speed primarily relied on vision to recognize the keys, and those with high typing speed relied on tactile feedback that was affected by the thickness and force of the keys. In the objective and subjective evaluation, a combination of keyboard design factors that might result in higher performance and satisfaction was identified (L-shaped, 3mm, and 60±10g) as the optimal combination. The learning curve was analyzed to make a comparison with a traditional standard keyboard to investigate the influence of user experience on keyboard operation. The research results indicated the optimal combination provided input performance to inferior to a standard keyboard. The results could serve as a reference for the development of related products in industry and for applying comprehensively to touch devices and input interfaces which are interacted with people.

***Keywords*—**Input performance, mobile device, slim keyboard, tactile feedback.

I. INTRODUCTION

As touch technology matures, an increasing number of mobile devices begin to adopt the technology, resulting in an influential trend. In the research for American-based users conducted by comScore [1], tablet computers are now defined as a "fourth screen" that is in the line of consumer products including television, computer, and smartphone. Tablet computers such as Apple iPad, hTC Flyer, and HP TouchSmart provide an instinctive touch interface [2] for browsing the Internet, sending files, and receiving information [3]. However, for general tasks such as entering texts, virtual touch keyboards often have a reduced size or layout due to the size of screen and could not provide the same functionality of a physical keyboard. Moreover, most devices do not support virtual keyboards [4], making them the devices for specific tasks [5]. According to Google's survey [6] on 1,400 tablet users in the United States, 78% of the users sent and received e-mail using their tablet computers, and the same result was confirmed in the study of Mülle et al. [7] on the usability and frequency of use of tablet computers. These results indicate that the use of tablet computers is not limited to gaming and receiving information; users frequently perform text entering related tasks, such as sending and receiving messages or e-mail, information inquiry, and note taking. An increasing number of users begin to complete tasks of productivity using tablet computers, and this implies the change of definition of tablet computer. Nonetheless, the operability of a physical keyboard cannot be totally replaced by a touch keyboard. Even an expert would need constant visual feedback [8]. In response to this problem, ASUS produced the Eee Pad Transformer. The unique base design allows the connection of a tablet computer with a mobile keyboard as a specific design for meeting office demands. While developers work hard to improve the inconvenient input method of tablet computers, the weight is increased as a disadvantage. In 2012, Microsoft launched its first tablet computer, Microsoft Surface, which includes a mobile keyboard in the form of a protection cover that provides rapid and comfortable input performance as compared to touch screen. The operability research on a membrane keyboard and a standard keyboard shows that the standard keyboard could provide the best operating performance. However, the input performance of the membrane keyboard shows an increasing trend [9].

The demands for entering texts increase as users more frequently use tablet computers. However, user may encounter problems such as mistyping, change of habit, less comfortable, key feedback, and input performance when using the virtual touch keyboard. The portable membrane keyboards launched by manufacturers never take motional and tactile feedback into consideration when designing the keys, neglecting the fact that constant visual feedback is required even by an expert user [8]. The result is poor operating experience and effects below expectations. Seeing the potential market demands for portable keyboards, this study looked into the possibility of increasing input performance by enhancing the tactile feedback and

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comfortableness of slim keyboards.

II. RESEARCH METHODS AND PROCEDURES

A. Experimental Task

The experiment of this study carried out an evaluation of the input performance and user satisfaction for slim keyboards. The evaluation criteria included accuracy and speed [8], [10]–[13], and the experimental design involved English typing tests, the results of which could be influenced by the participants' familiarity with the keyboard [9]. The familiarity was determined by the participants' words per minute. Each task consisted of six and seven English short sentences of about 170–200 characters. The contents of the typing tasks were chosen from MacKenzie and Soukoreff's [14] 500-sentence database for English typing tests, which ensured that when engaging in the tasks the participants would not be affected by the difficulty of the tasks. The purpose of this study was to investigate factors that influenced tactile feedback and input efficiency. The task design did not include case sensitivity, combinations, and punctuations.

B. Participants

To prevent typing speed from influencing the test results, the participants were required to take an online typing speed test for preliminary screening. According to the standard of the TQC typing speed credential (30 words/ minute), the participants were divided into two groups: one that was familiar with English typing and could type more than 30 words per minute; and one that was unfamiliar with English typing and could only type no more than 30 words per minute (Table I).

TABLE I
PARTICIPANT INFORMATION

	Male	Female	Left-Handed	Right-Handed	Mean Age	Typing Speed (words/min.)
Familiar with English Typing	6	12	3	15	20	55
Unfamiliar with English Typing	9	9	3	15	24	21

C. Design of the Experimental Keyboard Sample

Based on literature review and a user experience survey, this study attempted to improve the design factors of slim keyboards and enhance input performance and user satisfaction. Fingers, in a static status, require different response time and feedback when touching objects of different shapes and thickness. Thus, influences of shapes and thickness on key design can be defined. Circle, rectangle, and textured strips can be easily detected and recognized by fingers and provide a higher accuracy of recognition [15]. The shapes can be categorized as circle, rectangle, and L-shaped by their different levels, allowing users to discern the key locations with their touch. The levels of thickness were defined as 3mm and 6mm. Flat keyboards were used as the control group to evaluate the influence of thickness on slim keyboards. In addition, as compared to a standard keyboard, slim keyboards do not provide travel feedback; therefore, the experiment adjusted the key force to change the sensitivity of keys. The levels of force were set according to Deininger's experiment. His finding shows that a force between 100 to 400g does not result in any difference in input performance [16]. Other research also shows that a force between 25.5 and 150.3g results in the optimal performance [17]. According to measurements, the force of a standard keyboard is approximately 85g±10g, while a force of 20g can easily cause mistyping. Three levels of force were incorporated in the experiment: 35±10g that reduced mistyping, 85±10g that was similar to the force of a standard keyboard, and 60±10g that served as the medium value. With these three values, the influence of force on input performance was observed and analyzed to find the force value that is suitable for slim keyboards.

Three design factors were extracted from the samples of the experiments: shape, thickness, and force. Each factor comprised three levels: shape (circle, L-shaped, and rectangle), thickness (flat, 3mm, and 6mm), and force (35±10g, 60±10g, and 85±10g). The size and layout of the keyboard is shown in the Table II below:

TABLE II
KEYBOARD DESIGN FACTORS

Design factor	Level		
Shape	Circle	Rectangle	L-shaped (textured strips)
Thickness	Flat	3mm	6mm
Force	35g±10g	60g±10g	85g±10g

Regarding the definition of size, previous research showed that the operating time is shorter when the keyboard has a closer proportion to the original keyboard size. Moreover, performance and satisfaction can be influenced if the key size is only 92% or below of the original size [18]. According to their finding, the size of our experimental keyboard sample was 240mm in length, 148mm in width, and 0.5mm in thickness.

The production of the slim keyboard adopted membrane switches that are sandwich-structured. The top and bottom layers of the three layers of membranes are silver-printed circuits, and the middle layer is an insulating, porous layer. When fingers press the keys, the top membrane would contact with the bottom membrane, and current flows through the circuits of the two membranes as the switch is turned on, as indicated in Fig. 1. The keys travel approximately 0.1–0.5mm with a force of 60–300g [19]. In addition to membrane switches, a membrane keyboard also consists of appearance design, a nameplate, wireless communication module, and lithium battery.

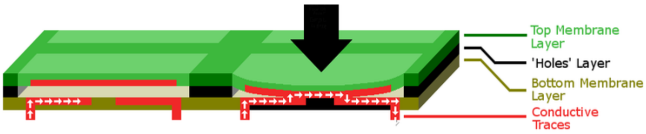

Fig. 1 Design principle of membrane keys

D. Fractional Factorial Design

In a study that involved a large number of variables, participants would have to complete all 27 tasks if a factorial

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design was implemented. This will lead to excessively long testing time. Moreover, increased mental workload might compromise the reliability of the experiments. Therefore, fractional factorial design was adopted in this study to simplify the experimental procedures and save time. The design was also able to reduce the production cost of the keyboard. The response surface methodology proposed by Box and Wilson [20] suggests the application of partial experiments to obtain the optimal response and information concerning whether product quality is affected. Fractional factorial design has been comprehensively applied in the manufacturing process improvement of different kinds of products [21].

E. Experiment Procedures

Control variables involved in this study included the shape, thickness, and force of keys. Three English typing tasks were administered on each participant using three respective representative keyboard samples. To avoid increased learning efficacy, which might impact the test results, the tasks were administered in various sequences for the participants. The task procedures were as follows: 1) The participants were first divided into two groups according to their typing speed (30 words/minute). 2) Details of the experiment were provided, including the typing tasks, questionnaire, software input interface, and introduction to related hardware. 3) Before the experiment was initiated, the participants were asked to take a pretest, which involved using a slim pressure-sensitive keyboard different from the experiment sample. 4) The participants were required to fill in a demographic questionnaire. 5) The participants were asked to engage in the tasks using the nine keyboard samples, the design of which was based on an orthogonal array derived from the three levels of the three design factors. To avoid the influence of increased learning efficacy on the research results, the keyboards were distributed in different sequences. Moreover, considering the mental workload of the participants, the test time was limited within 30 minutes. 6) The subjective evaluation questionnaire was administered. 7) Procedure 5 – experiment tasks – and Procedure 6 – subjective questionnaire filling – were repeated until the nine tasks using the nine keyboard samples were all completed. 8) Finally, qualitative interviews were conducted to obtain the most direct opinions and feedback of the participants.

F. Data Collection

The hardware of the experiment equipment included a computer monitor modeled CMV CT726GD, a video recording device modeled SAMSUNG EX1 that recorded hand posture during typing from the lateral perspective, a SONY NEX5 camera that shot pictures of how fingers slid across the keyboard and finger positions from an overhead perspective, the representative keyboard sample, and a PCB connected to the computer. The experiment was operated solely on the Windows operating system. The software of the experiment equipment was Adobe Flash Action Script 3.0 programming monitoring interface. The typing monitoring method was revised by referencing Wobbrock's [22] method. When a participant enters an incorrect string, instead of calculating the total word count of incorrect words and the difference in the number of keystrokes, the error-monitoring program immediately forbids inputting more information, reminding the participant to correct the mistake. Therefore, the program calculates the number of incorrect words, details of these words, and the speed on a single task.

G. Data Analysis

The two evaluation items were objective and subjective evaluations. The objective evaluation consisted of performance evaluation of accuracy and speed, and the subjective evaluation consisted of keyboard operability, key recognition and finger positioning, feedback, and difficulty. The questionnaire was composed of Likert 7-point scales. Multivariate analysis of variance (MANOVA) was used to examine the design factors that influenced input performance. Moreover, signal-to-noise (S/ N) ratios were observed with Taguchi methods. In the objective evaluation (accuracy and speed), the Smaller-the-Better characteristic in Taguchi methods was adopted, meaning fewer incorrect words and faster speed the better. In addition, for the participants, the lower amount of mental workload built up the better. The subjective evaluation (operability, recognition, feedback, and difficulty) was based on the Larger-the-Better characteristic, meaning that larger operability, recognition, and feedback was favored, whereas smaller difficulty was better. The scores of these variables were examined during the statistical analysis stage to ensure the accuracy of the results and to find the optimal levels of the design factors. Finally, qualitative interviews were carried out to collect the participants' most direct feedback, including their perceptions of the difference between the optimized keyboard and a generic keyboard. Furthermore, improvements were suggested.

III. RESEARCH RESULTS AND DISCUSSION

This study examined various keyboard design factors and levels through experiments and found the optimal combination of keyboard design. In this chapter, the typing speed and results of the participants were discussed to analyze the determining factors and causes. In addition, learning curves were created and interviews were conducted on the optimal keyboard design, as compared to a standard keyboard for design verification.

A. Participants with Fast Typing Speed

The objective evaluation consisted on the performance evaluation of accuracy and speed. According to the MANOVA results, for fast typists, significant influence of thickness was found on accuracy ($F=3.44$, $p<0.05$) and speed ($F=8.57$, $p<0.05$). This indicated that change in thickness caused impact on the participants' performance of accuracy and speed. However, no significant difference was found on shape and force.

For fast typists, the accuracy S/N ratio showed the following factor/level evaluation: 1) Shape: L-shaped > rectangular > circle; 2) Thickness: 3mm > 6mm > flat; and 3) Force: 60g±10g > 85g±10g > 35g±10g. The speed S/N ratio showed the following factor/level evaluation: 1) Shape: L-shaped > rectangular > circle; 2) Thickness: 3mm > 6mm > flat; and 3) Force: 60g±10g > 35g±10g > 85g±10g. Evaluating the two objective performance objects, accuracy and speed, showed three identical evaluation results and order of the three levels of shape and thickness. The optimal level of force was 35g±10g, a value identical in all keyboard samples. However, the evaluation result order differed. The cause of this resulted from accuracy. Level 1 (35g±10g) had the lightest force, resulting in the highest number of incorrect words. When the participants entered texts, light key force might cause them to mistype when sense typing, hence the lowest evaluation score. Regarding speed, a force of Level 3(85g±10g) was slowest because the participants had to press the keys harder. This, despite its effect on reducing mistyping, the increased strength in fact enhanced the time needed, hence the lowest evaluation score. The abovementioned S/N ratio could be used to obtain the combination of making an optimal-level keyboard with the appropriate design factors: shape: L-shaped; thickness: 3mm; and force: 60g±10g.

The subjective evaluation questionnaire consisted of 1) keyboard operability; 2) key recognition and finger positioning; 3) feedback; and 4) difficulty. According to the MANOVA results, for fast typists, significant influence of thickness was found on operability ($F=9.08$, $p<0.05$), key recognition and finger positioning ($F=17.87$, $p<0.05$), feedback ($F=7.03$, $p<0.05$), and difficulty ($F=4.97$, $p<0.05$). Force possessed significant influence on operability ($F=9.08$, $p<0.05$), feedback ($F=10.35$, $p<0.05$), and difficulty ($F=4.94$, $p<0.05$), yet not on key recognition and finger positioning. The results indicated that change of thickness influenced the participants' performance of keyboard operability, key recognition and finger positioning, feedback, and difficulty. Change of force influenced key recognition and finger positioning, in addition to three other operating items. Shape did not have any significant influence on the performance.

According to the MANOVA results, for fast typists, significance was found for thickness and force, indicating that these two factors had influences on the input performance of the participants. In the subjective evaluation, the S/N ratios in the three design factors (shape, thickness, and force) were almost the same value. The optimal levels were L-shaped, 3mm, and Level 1. Regarding difficulty, rectangle was the optimal level of shape and demonstrated significant difference from other evaluation items. Moreover, L-shaped, which gained the optimal evaluation in other evaluation items, showed the lowest level in difficulty, as indicated by Fig. 2.

Looking at the initial mean evaluation values, it was found that scores concerning difficulty were generally lower than other evaluation items, as shown in Fig. 3. In addition, in the qualitative interviews, the interviewees pointed out that compared to using a traditional keyboard, difficulty was felt when engaging in the typing tasks using the micro-travel membrane keyboard, hence the cause of generally low scores. Although MANOVA results indicated that the shape of keys was not factors that influenced subjective evaluation, L-shaped keys were chosen to achieve optimal levels for this subjective evaluation.

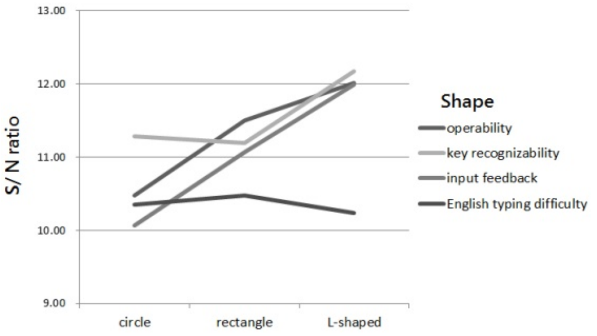

Fig. 2 Shape S/ N ratio of subjective evaluation

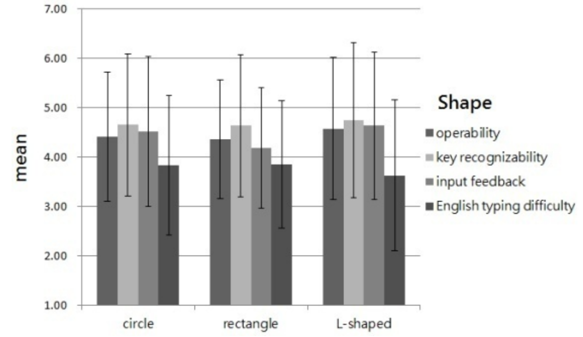

Fig. 3 Shape mean of subjective evaluation

B. Participants with Slow Typing Speed

The objective evaluation consisted on the performance evaluation of accuracy and speed. For slow typists, the MANOVA was based on "Wilk's Lambda distribution" to investigate levels of significance. However, the thickness factor only showed significance in "Roy's greatest root" in the speed. Therefore, according to the MANOVA results, for slow typists, significant influence of thickness was found on speed ($F=4.37$, $p<0.05$). This indicated that change in thickness caused impact on the participants' performance of speed. However, no significant difference was found on shape and force.

Compared with the high consistency demonstrated in the results of fast typists, slow typists showed divers results. L-shaped obtained the optimal level in the shape factor, and flat gained the highest evaluation in the thickness factor because it was evaluated based on accuracy. This was considerably different from what was expected by this study and by general understanding. In previous research, it is argued that a keyboard design lacking operational feedback could lead to low performance [23], [24]. Therefore, we recorded experiment videos and observed results for discussion. Due to the fact that the participants with low typing speed had lower familiarity with English typing and keyboard in general, they were not required to use touch typing. On the contrary, the feedback provided by the keyboard was primarily evaluated through visual observation. When the thickness was flat, the participants hit the keys with more caution, thereby reducing the number of incorrect words. Nonetheless, the level of "flat" obtained a lowest evaluation score in terms of speed, proving the general understanding that reduced typing speed not only increased the time spent but also the accuracy [25]. Moreover, it could be induced that when the participants who did not lay their hands flat on the keyboard when executing the tasks, they could be more focused on recognizing the position of keys. This led to increased accuracy as well as overall increased time spent on the tasks. Regarding the force factor, accuracy received the optimal level when the force was set at the heaviest Level 3 (85g±10g). The reason was that the participants might have to apply more intense pressure, and therefore be more cautious when entering the texts. The result was a reduced amount of incorrect words, but the time spent was lengthened because the error detection system required the participants to correct the incorrect input. A Level 1 (35g±10g) force needed less pressure and it was more likely to mistype, and the speed was consequently reduced.

According to the MANOVA results of the subjective evaluation, for slow typists, significant influence of thickness was only found on operability (F=3.49, $p<0.05$), not on other evaluation items. This indicated that change of thickness influenced the keyboard's operability, whereas changes in shape and force had no impact on performance.

The S/ N ratios of the shape factor showed consistency: L-shaped > rectangle > circle. The results of input feedback were also different, showing significantly smaller values than other evaluation items: rectangle > L-shaped > circle. The design factor/level of the thickness did not show consistency as the input feedback and key recognition were ranked as follows: 6mm > 3mm > flat; operability: 3mm > flat > 6mm; English typing difficulty: flat > 3mm > 6mm. The evaluation of "flat" regarding operability and English difficulty might be greatly different from the anticipated and worse evaluation. Since the evaluation results did not show consistency, the mean S/N ratio was adopted as a reference standard for determining the optimal level, and the result was the finding that 3mm being the optimal level. The force showed significant difference in the S/N ratio. The input feedback and English typing difficulty were ranked as followed: Level 1 > Level 2 > Level 3; key recognition: Level 3 > Level 1 > Level 2; and operability Level 1 > Level 3 > Level 2. These results did not show a significant trend. The optimal level was given to Level 1 if the mean S/N ratio was used for determining the optimal level.

This study identified the optimal levels of each factors through examining the above results. However, due to the lack of consistency of thickness and force in the evaluation results, we could only use the S/N ratio as an auxiliary tool for the determination of optimal levels. Significant differences were found in the optimal levels that could be gained from the evaluation items of thickness and force. The optimal level of shape might be L-shaped, the optimal levels for thickness and force could yet be defined. Moreover, the force factor showed considerably discrepant evaluation, and the significance of force was not revealed in the MANOVA. Thus, we inferred that force was not a factor that influenced the subject evaluation for the participants with slow typing speed.

C. The Combination of Optimal Design Factors/ Levels

According to the research findings, the two groups (fast and slow typists) were significantly different in their optimal design factors/levels. The results of the participants with fast typing speed contributed to two keyboards that provided the optimal levels from the results of the objective and subjective results. The two keyboards both had L-shaped keys and 3mm thickness, differing only in force. The objective evaluation resulted in a force of 60g±10g (Level 2), whereas the force in the subjective evaluation was 35g±10g (Level 1). Force refers to the strength needed by the user to press the keyboard. The results indicated that the participants subjectively anticipated lighter force; however, the objective results indicated that, despite the convenience provided by low-force keyboards, mistyping might occur and result in reduced input performance. That explained why in the objective evaluation a force of 60g±10g (Level 2) was found to be the optimal level. In addition, the results supported the findings of Loricchio, who also examined the key force, that 58g is the optimal key force, according to both results of objective evaluation (typing speed) or subjective evaluation (preference) [26]. In addition, Akagi suggested that a force that is too light (35.5g and 42.5g) might reduce accuracy [27]. Their findings lead to the same conclusion: 55–60g is the optimal force for keyboards [28].

Based on the interview results of interviewees with fast typing speed, we reached the following conclusion: If the participants had existing impressions and understanding of key shapes, they might not get used to the circular keys. Moreover, circular keys had edges that might result in misjudgment about finger positioning. Although the L-shaped key acquired the optimal level, still several interviewees showed their concerns, during the interview stage, that the design might be difficult for the participants to find the correct keys. The cause of these concerns was related to the participants' habit. Originally, we thought thicker keys would provide better feedback for the fingers, but the results showed a better level for 3mm keys. The reason might be that keys that were too thick interfered with the movements of fingers, especially when the keys were L-shaped. When the force was set at 85g±10g (Level 3), the participants could felt the need to apply more pressure, and could feel pain in their little and ring fingers. Sometimes they even did not have enough strength to press the keys.

TABLE III
COMBINATION OF OPTIMAL DESIGN FACTORS AND LEVELS

		Fast Typer	Slow Typer			
Objective evaluation	Shape	L-shaped	Accuracy	L-shaped	Speed	L-shaped
	Thickness	3mm		Flat		3mm
	Force	60g±10g		85g±10g		60g±10g
Significance		Thickness	None		Thickness	
Subjective evaluation	Shape	L-shaped	L-shaped			
	Thickness	3mm	(3mm)			
	Force	35g±10g	(35g±10g)			
Significance		Thickness & force	Thickness			

The results of optimal design factors/levels for the participants with slow typing speed were still inconclusive, and showed significant discrepancies between the objective and subjective evaluation. Moreover, consistency did not exist between the evaluation items. The participants who were not familiar with English typing were unable performing touch typing during the tasks. Most of them relied on visual feedback and did not comply with the standard finger positioning. Additionally, they relied heavily on their index and middle fingers. Through the interviews and video recording, slow typists did perceive significant difference in force, as compared to fast typists who altered their postures with the change of force. We found that slow typists relied on their vision to recognize the key positions and did not require as much tactile feedback. Their tactile perception of shape and thickness was also insensitive.

IV. LEARNING CURVE

In the previous stage of the experiment, we found that fast typists showed more significant differences in their familiarity with the keyboard layout and finger positioning when using various samples for testing. Moreover, consistency was found in their input performance and preference. The optimal combination of keyboard design was less obvious. We could only find the preference from the interview results. Therefore, the learning curves were drawn only to define the target group that was familiar with English typing. The optimal design factors/levels were acquired from the S/N ratios: shape: L-shaped; thickness: 3mm; force: 60g±10g (Level 2). Learning curves were drawn as a comparison between the keyboard sample and the standard keyboard.

The participants were men who were familiar with English typing, used English finger positioning, and had typing speed more than 80 words per minute. To prevent fatigue from affecting the task results, the experiment was controlled within 30 minutes. To keyboard samples were used each day for five typing tasks. Consequently, we obtained results that allowed us to investigate whether a slim keyboard had the same input performance as a standard keyboard. The evaluation standards were accuracy and speed. The tasks were stopped once the performance value within a single day caught up with that of a standard keyboard.

Based on the results, both the participants, after practicing, demonstrated a trend, in terms of accuracy and speed that was almost identical with the standard keyboard. According to the result of the first participant, low accuracy resulted in low speed. Although the adoption of the slim keyboard enhanced accuracy, the time spent was still far from using the standard keyboard. After practicing, the speed was improved to the level of using the standard keyboard. From observation and the interviews we came to know that first-time users of the slim keyboard could not effectively control the pressure they applied. For the second participant, in his fifth task of the day, the accuracy became similar to that using the standard keyboard, yet the time spent was much longer. Thus we arranged for a second day testing. As the participants gained familiarity with the keyboard, the accuracy and speed was significantly enhanced in direct proportion.

V. CONCLUSION AND SUGGESTIONS

By changing the keyboard design factors, this study successfully enhanced the input performance and comfortableness of a micro-travel membrane keyboard. Moreover, we provided suggestions for better design principles.

According to the results, in English typing tasks, the participants with slow typing speed did not provided a representative sample. This was because that their unfamiliarity with English typing prevented them from using all fingers to complete the typing tasks. They relied on vision to search for keys instead of on the feedback provided by touch. Therefore, we suggest prospective research examine possible improvement for these people to enhance their input performance and comfortableness.

The results of the objective evaluation, subjective evaluation, and mental workload evaluation of the participants with fast typing speed led to two combinations of keyboard design factors: objective evaluation: L-shaped/3mm/60g±10g (Level 2); subjective evaluation: L-shaped/3mm/35g±10g (Level 1). The results showed difference in force. In the objective evaluation, a force of Level 2 resulted in significantly higher accuracy as compared to Level, as well as influenced the speed. This indicated that the participants subjectively infused a higher level of easiness and comfortableness into the keyboard with lighter force, which, nonetheless, might reduce accuracy and further made an impact on input performance. In addition, circular keys were not well accepted and received lower evaluation scores because the shape was substantially different from any general key, whereas the L-shaped key received higher evaluation because of its streamlined design and easy-to-recognize edges. In both the objective and subjective evaluation, a key with a thickness of 3mm was universally favored as compared to that of 6mm, contradicting the general understanding that greater thickness might provide better finger feedback. An excessively thick key might affect finger movements and comfortableness as the participants engaged in typing tasks. This was especially the case when the L-shaped keys (textured strips) were adopted.

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