International Journal of Information Technology and Business Management
29th Dec 2014. Vol.32 No.1

ISSN 2304-0777 www.jitbm.com

INFLUENCE OF STYLUS TIP MATERIAL ON HANDWRITING INPUT PERFORMANCE OF HANDHELD DEVICES

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ABSTRACT

This study used an experimental method to investigate the effects of various stylus tip materials on the handwriting input performance of handheld devices. The stylus tip materials used in this study were stainless steel, plastic, wood, and rubber. Performance assessment indicators were Chinese character handwriting input speed, accuracy, and ease of writing. The results showed that plastic stylus tips yielded the highest degree of ease of handwriting input, and rubber stylus tips yielded the slowest handwriting input speed and the lowest level of ease of handwriting input. An extremely high or low friction coefficient between stylus tip material and touch screen decreased the ease of handwriting input. A high friction coefficient also decreased its speed. When the size of a handwriting input box was of sufficient size, all types of stylus tip materials yielded extremely high handwriting input accuracies.

Keywords: Stylus, Material, Handheld Device, Handwriting Input

1. INTRODCUTION

Powerful and portable personal digital assistants (PDAs) have allowed daily life to become extremely convenient; therefore, handheld devices have become increasingly popular. Because they are small, the size of the user interface for character input is a crucial research topic.

Two character input methods exist: stylus-based text (i.e., an artificial alphabet) and handwriting character text (i.e., a natural alphabet) entry methods. The stylus-based text entry method (e.g., standard keyboard and predictive keyboard) is suitable for alphanumeric languages, whereas the handwriting character text entry method (e.g., perfect handwriting recognition) is suitable for nonalphabetic languages (Ren & Zhou, 2009). Lewis (1999) investigated character input methods for small-sized screens (i.e., standard keyboard, predictive keyboard, and perfect handwriting recognition) and found that the handwriting entry method performed with the fastest speed. Related studies indicated that handwriting input resembles writing Chinese characters on paper, and thus is suitable for Chinese character input into a handheld device (Chen et al., 2014).

The handwriting entry method consists of two main parts: a handwriting recognizer and a handwriting input interface (Bouteruche et al., 2005). Numerous studies have focused on developing technologies for character and pattern recognition performed by a handwriting recognizer (Ren & Zhou, 2009). Several studies have investigated the performance of a handwriting input interface, which comprises a stylus and a touch screen. Several studies have indicated that the definition and size of the handwriting area of a touch screen influenced the effectiveness of handwriting input. Ren and Zhou (2009) investigated the handwriting character input boxes of PDAs and found that the optimal size of an input box was a 12 mm × 14 mm rectangle for letters and numbers; for Chinese characters, the optimal size of an input box was a 14 mm × 14 mm square. From the perspective of character recognition technology, handwriting input in a defined area yields high recognition accuracy and few error corrections. However, from a user perspective, writing characters

ISSN 2304-0777 www.jitbm.com

in an unframed area feels more comfortable (Ren & Zhou, 2009).

Related studies on touch screen handwriting character input boxes have diverse views about styluses. Chen et al. (2014) believed that finger-based handwriting input methods interested mobile phone designers and system developers more than stylus-based handwriting input methods. However, the traits of fingers (i.e., finger type, length, and width) can be analyzed, but cannot be improved. Therefore, limited improvements on finger-based handwriting input can be produced. Zou et al. (2011) believed that the screen size of a handheld device limited the use of a finger for writing; in particular, participants typically could not use their fingers to continually write more than three simplified Chinese characters at a time. Therefore, stylus-based handwriting input has been considered a natural and effective Chinese character input method for touch screen devices.

Previous studies on styluses have emphasized the importance of the optimal size of a stylus. For example, Wu and Luo (2006) explored the effects of various stylus diameters and lengths when clicking, writing, and drawing on a screen, and suggested that a stylus with a diameter of 8 mm and a length of 100 mm or longer was most suitable for use as a pen-based input device. Kao (1976) investigated writing tools used by adults and found that ballpoint pens were most preferred when writing on paper, followed by pencils, and then by fountain pens. These results suggested that the type of pen tip influenced writing performance on paper. However, no studies have explored the effect of stylus tip materials on handwriting input interfaces. Therefore, this study investigated the effects of stylus tip materials on handwriting performance when using handheld devices.

2. RESEARCH FRAMEWORK

To examine the influence of stylus tip material on handwriting performance for handheld devices, this study proposed a research framework (Fig. 1) consisting of one independent variable (i.e., stylus tip material) and three dependent variables (i.e., three indicators for handwriting input performance). Four stylus tip materials were used in this study: stainless steel, plastic, wood, and rubber. The three indicators for handwriting input performance were handwriting input speed, accuracy, and ease of handwriting.

Input speed was most frequently used to measure handwriting input performance (Chen et al., 2014; Wu & Luo, 2006). Previous studies on pen-and-paper-based writing indicated that various writing tools influenced writing speed. Kao (1979) investigated the writing speeds of ballpoint pens, pencils, fountain pens, and felt pens and found that ballpoint pens yielded the fastest writing speed and fountain pens yielded the slowest writing speed. Therefore, this study regarded stylus tip material as influencing handwriting input speed on handheld device, and proposed the first hypothesis (H1).

H1: Stylus tip material influences handwriting input speed.

Another commonly used indicator for handwriting input performance is handwriting input accuracy. Handwriting input accuracy is represented by the number of handwriting characters recognized by a handwriting input system (Chen et al., 2014; Wu & Luo, 2006). Bailey (1988) indicated that the pressure on the contact point between a writing tool and a writing surface directly influenced handwriting stability. Various friction coefficients between various types of stylus tip materials and touch screens influenced the pressure on the contact point between stylus tip and touch screen. Therefore, this study regarded stylus tip materials as influencing handwriting input accuracy and proposed the second hypothesis (H2).

H2: Stylus tip material influences handwriting input accuracy.

Kao (1979) investigated whether various types of pen tips (i.e., ballpoint pens, pencils, fountain pens, and felt pens) influenced ease of writing on paper, and found that the characteristics of pen tips were substantial influences. Felt pens exhibited the highest degree of writing ease and ballpoint pens exhibited the lowest degree of writing ease. Therefore, this study regarded the pen-based input interface of handheld devices as yielding similar results; it regarded stylus tip material as influencing ease of handwriting, and proposed the third hypothesis (H3).

H3: Stylus tip material influences ease of handwriting.

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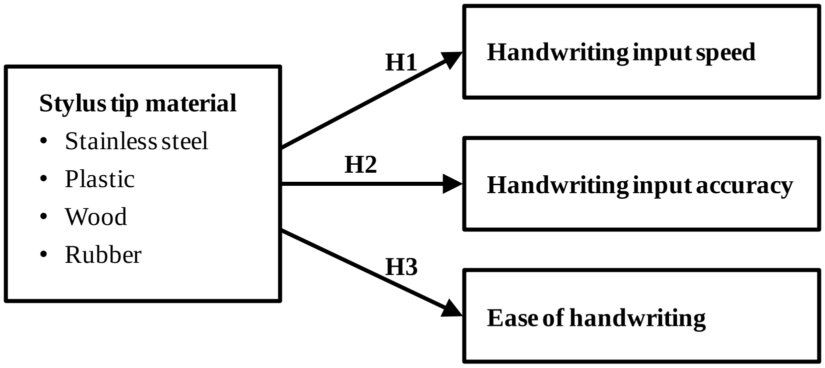

Figure 1: Research framework

3. METHODS

This study explored the influence of stylus tip material on handwriting input for handheld devices. Seventeen students (eight men and nine women) at Ming Chi University of Technology served as participants. The average age of the participants was 25.24 ± 2.46 years. All participants were right-handed with normal or corrected vision. All participants had no hand or eye disorders or related diseases.

The independent variable was stylus tip material, and the dependent variables were input speed, accuracy, and ease of handwriting (Table 1). In this study, the static friction coefficient between stylus tip material and touch screen (μ_s) was defined as the friction coefficient of stylus tip material. Based on the friction coefficient, stylus tip material consisted of four levels: stainless steel (μ_s = 0.222), plastic (μ_s = 0.290), wood (μ_s = 0.377), and rubber (μ_s = 0.445) (Table 2). Input speed was represented by the amount of time required to input 10 Chinese characters. Input accuracy was represented by the ratio of the number of input characters recognized to 10 input characters. Ease of input was represented by a score for ease of handwriting input (the lowest score = 1, the highest score = 5). A high score indicated a high degree of ease of handwriting.

Table 1: Experimental variables

Type	*Variable*	*Level or Unit*
Independent variable	Stylus tip material	Stainless steel Plastic Wood Rubber
Dependent variable	Input speed Accuracy Ease of handwriting	Sec % Score

Table 2: Friction coefficients of various stylus tip materials

Stylus Tip Material	*Static Friction Coefficients (μ_s)*
Stainless steel	0.222
Plastic	0.290
Wood	0.377
Rubber	0.445

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Experimental devices were a PDA (iPAQ Pocket PC H3850), a stylus with a length of 12.6 cm and a diameter of 0.9 cm, four alternative stylus tips (i.e., stainless steel, plastic, wood, and rubber stylus tips), and a digital camera. The system setting for the PDA was as follows: Microsoft MingLiU font, a character size of 12 pt, medium stroke thickness, black font color, and a system response time of 1 s. A handwriting box was configured as follows: full screen (6 cm × 5.5 cm), single lattice (2 cm × 2 cm), and double lattice (2 cm × 2 cm × 2 cm) (Table 3). Experimental tools were Chinese-character-input samples and a subjective assessment questionnaire. The Chinese-character-input samples were divided into five groups: 5-, 10-, 15-, 20-, and 25-stroke characters. Each group contained 10 characters (Table 4). The subjective assessment questionnaire was a 5-point Likert scale (1 = very uneasy; 2 = uneasy; 3 = not uneasy or easy; 4 = easy; and 5 = very easy).

Table 3: Handwriting box size

Handwriting Box	*Size*
Full screen	6.0 cm×5.5 cm
Single lattice	2.0 cm×2.0 cm
Double lattice	2.0 cm×2.0 cm×2

Table 4: Input characters

Number Of Character Strokes	*Input Characters*
5-stroke	丙 以 他 代 冬　世 主 付 令 兄
10-stroke	倍 倦 借 們 個　乘 唐 倒 剛 候
15-stroke	億 儉 劉 嘻 嘘　價 劇 厲 嘿 噗
20-stroke	勸 寶 攔 獻 癢　競 籃 繼 飄 蘇

This study adopted a within-subjects experimental design. The combination of stylus tip material type, handwriting box size, and the number of character strokes established 48 experimental conditions for this experiment (4 × 3 × 4), and each participant received all experimental conditions. Figure 2 shows the experimental setting where a participant sits on a chair in front of a desk with a height of 72.4 cm. According to the experimental setting, a participant whose right hand was placed against the desk surface and whose left hand held a PDA performed a Chinese-character handwriting input task. Prior to the experiment, the researcher explained the experimental procedure to the participant. The participant then received 48 practice trials to become familiar with the experimental procedure. For each experimental trial, the participant followed instructions and used a handwriting input method to input 10 characters (chosen from the list of Chinese-character-input samples) into the PDA. After the experimental trials, the input speed and correctness were recorded. Each participant received the 48 experimental conditions in a random order, and had 3-min breaks between trials. After completing the experiment, participants rated their impressions about the ease of input. The data collected from this experiment were analyzed using the Statistical Product and Service Solutions software package.

International Journal of Information Technology and Business Management
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ISSN 2304-0777 www.jitbm.com

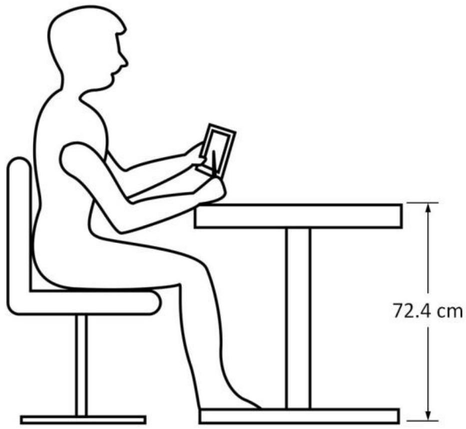

Figure 2: Experimental setting

4.1 Handwriting input speed

A one-way analysis of variance (ANOVA) was performed by using stylus tip material as the independent variable and handwriting input speed as the dependent variable. The results showed that stylus tip material ($F(3, 812) = 6.31$, $p < .001$) significantly influenced handwriting input speed at $\alpha = .05$ (Table 5). Therefore, the first hypothesis (H1) in this study was verified.

As shown in Table 6, the Duncan post hoc test indicated that the average handwriting input speeds for stainless steel, plastic, and wood stylus tips (3.98 s, 4.09 s, and 4.09 s, respectively) were substantially lower than that for rubber stylus tips (4.54 s). When the friction coefficient of stylus tip material (μ_s) was 0.445, the average handwriting input speed substantially decreased.

4. RESULTS

Table 5: The ANOVA analysis for stylus tip material and various dependent variables

Dependent Variable	*Between Groups*			*Within Groups*			*F*	*p-Value*
	SS	*df*	*MS*	*SS*	*df*	*MS*		
Input speed (sec)	38.77	3	12.92	1662.04	812	2.05	6.31	.000***
Accuracy (%)	165.07	3	55.02	297634.80	812	366.55	.15	.930
Ease of handwriting (score)	45.10	3	15.03	38.59	64	.60	24.93	.000***

*Notes: ***p < .001.*

Table 6: The average scores on various dependent variables for various types of stylus tip materials and their 95% confidence intervals

Dependent Variable	*Stylus Tip Material*	*M*	*SD*	*SE*	*95% CI*		*Group*
					Lower	*Upper*	
Input speed (sec)	Stainless steel	3.98	1.39	.10	3.78	4.17	A
	Plastic	4.09	1.48	.10	3.88	4.29	A
	Wood	4.09	1.37	.10	3.90	4.28	A
	Rubber	4.54	1.48	.10	4.34	4.75	B
Accuracy (%)	Stainless steel	79.51	18.13	1.27	77.01	82.01	C
	Plastic	78.58	19.74	1.38	75.85	81.30	C
	Wood	78.43	19.29	1.35	75.77	81.09	C
	Rubber	78.43	19.39	1.36	75.76	81.11	C
Ease of handwriting (Score)	Stainless steel	3.71	.69	.17	3.35	4.06	D
	Plastic	3.06	.75	.18	2.67	3.44	E
	Wood	2.65	.93	.23	2.17	3.13	E
	Rubber	1.47	.72	.17	1.10	1.84	F

Notes: Factors with the same letter across groups indicate that their averages are not significantly different。

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4.2 Handwriting input accuracy

A one-way ANOVA analysis was performed by using stylus tip material as the independent variable and handwriting input accuracy as the dependent variable. The results showed that stylus tip material ($F(3, 812) = 0.15$, $p < .930$) did not significantly influence handwriting input accuracy at $\alpha = .05$ (Table 5). Therefore, the second hypothesis (H2) in this study was not supported.

As shown in Table 6, the Duncan post hoc test indicated that the average handwriting input accuracy scores for plastic, rubber, wood, and stainless steel stylus tips (79.51, 78.58, 78.43, and 78.43, respectively) did not substantially vary from one another.

4.3 Ease of handwriting input

A one-way ANOVA analysis was performed by using stylus tip material as the independent variable and ease of handwriting input as the dependent variable. The results showed that stylus tip material ($F(3, 64) = 24.93$, $p < .001$) significantly influenced ease of handwriting input at $\alpha = .05$ (Table 5). Therefore, the third hypothesis (H3) was verified.

As shown in Table 6, the Duncan post hoc test indicated that plastic stylus tips yielded the highest degree of ease when writing (3.71), followed by stainless steel (3.06), wood (2.65), and rubber (1.47) stylus tips.

The average ease of handwriting input score and the friction coefficient of stylus tip material formed an inverted U-shaped relationship (Fig. 3). A regression analysis was performed by using the friction coefficient of stylus tip material as the predictive variable (x) and the ease of handwriting input as the dependent variable (y). The regression equation was as follows: $y = -3.71 + 50.11x - 86.81x^2$ ($r^2 = 0.968$). When the friction coefficient of the stylus tip material (x) equaled 0.289, a maximum score for ease of handwriting input (y) was reached.

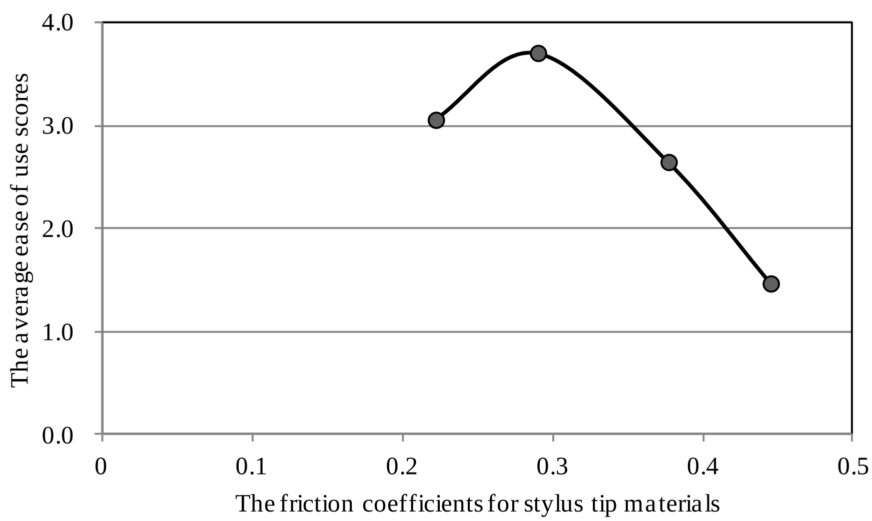

Figure 3: The distribution of average ease of use scores across the friction coefficients for various stylus tip materials

5. DISCUSSION

5.1 The influence of stylus tip material on handwriting input speed

The results showed that stylus tip material influenced handwriting input speed; the handwriting speed for rubber stylus tips was slower than for other types of stylus tips (i.e., stainless steel, plastic, and wood). The friction coefficients of stylus tips were

0.222 for stainless steel, 0.290 for plastic, 0.377 for wood, and 0.445 for rubber. Therefore, this study concluded that when the friction coefficient of a certain stylus tip material reached a specific value, handwriting input speed abruptly slowed down. The threshold should be between 0.377 and 0.445. Similar to the study by Kao (1979) regarding pen-and-paper-based writing, ballpoint pens with a low friction coefficient yielded the fastest handwriting speed, and fountain pens with a high friction coefficient yielded the slowest handwriting speed, reflecting the effect of the friction coefficient.

5.2 The influence of stylus tip material on handwriting input accuracy

Numerous related studies commonly used input accuracy as an indicator for handwriting input performance (Chen et al., 2014; Wu & Luo, 2006). For example, Ren and Zhou (2009) used input accuracy as an indicator for measuring kana and kanji handwriting input performance, and found that the area of an input box substantially influenced handwriting input accuracy. However, this study found that stylus tip material did not substantially influence handwriting input accuracy, and all types of stylus tips yielded high handwriting input accuracy. As indicated by Ren and Zhou (2009), the reason for this may be that an input box of 1.4 cm × 1.4 cm or 1.9 cm × 1.9 cm yielded few error corrections and protruding strokes. In this study, the smallest and largest input boxes used were 2 cm × 2 cm and 6 cm × 5.5 cm, respectively. Both input boxes were larger than the optimal size of the input box used by Ren and Zhou (2009), and because the handwriting input boxes used in this study were sufficiently large, all types of stylus tip materials yielded extremely high handwriting input accuracies.

5.4 The influence of stylus tip material on ease of handwriting input

Kao's (1970) study on pen-and-paper-based writing indicated that various writing tools yielded various degrees of ease when writing. The current study showed that various types of stylus tip materials yielded various degrees of ease of handwriting input, and that the participants were most satisfied with plastic stylus tips. Kao (1979) indicated that ballpoint pens with the lowest friction coefficient yielded the lowest degree of ease of writing. The study showed that stylus tips with an extremely high or low friction coefficient decreased the ease of handwriting input. Therefore, it inferred that an optimal friction coefficient that yields a maximal degree of ease of handwriting input should be identified. The current study used a regression analysis method to construct a regression equation and to predict that optimal ease of handwriting input resulted as the friction coefficient of stylus tip material equaled 0.289..

6. CONCLUSION

Limited studies have explored the influence of stylus tip material on handwriting input. This study used an experimental method to investigate the influence of stylus tip material on handheld device handwriting input performance. The results showed that stainless steel, plastic, and wood stylus tips yielded fast handwriting input speeds, and plastic stylus tips yielded the highest degree of ease of handwriting input. Rubber stylus tips yielded the slowest handwriting input speed and the lowest degree of ease when writing. In addition, an extremely high or low friction coefficient decreased the ease of handwriting input. A high friction coefficient also abruptly slowed down handwriting input speed. Moreover, when the handwriting box was sufficiently large, all types of stylus tip materials yielded extremely high handwriting input accuracies.

In summary, the optimal stylus tip material is plastic. Rubber should be avoided. The optimal friction coefficient between stylus tip materials and touch screens was 0.289, and should not exceed 0.377. The input box on touch screens should not be smaller than 2 cm × 2 cm.

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