User Experience of Tactile Feedback on a Smartphone: Effects of Vibration Intensity, Times and Interval

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Abstract. Tactile feedback has been widely used in smartphones in recent years. To explore the factors impacting the user experience of smartphone tactile feedback, the current study tested three aspects of these factors: the intensity of vibration (weak, moderate and strong), feedback times (once or twice) and the interval between two vibrations (100 ms, 230 ms, 370 ms and 500 ms). Twenty-six participants evaluated their tactile experience after finishing each touch task under different conditions on a model phone with three gestures. The results showed that satisfaction with tactile feedback increased along with the increasing intensity of vibration. However, such tactile satisfaction decreased as the interval between two vibrations increased. There was a significant interaction between the intensity and interval of vibrations. The results of the current study can provide guidance for product design in the related field of touchscreen products.

Keywords: Vibration intensity · Vibration interval · Tactile feedback · User experience

1 Introduction

Tactile feedback of a touchscreen is an important aspect of smartphone design. As touchscreens became the main operation interface of smartphones, researchers had to pay much more attention to this issue during the preceding decade [1–4]. Researchers confirmed that tactile feedback could improve the effectiveness of interaction. For example, Fukumoto and Sugimura found that tactile feedback can reduce the operation time by approximately 5% to 15% in different situations [1]. Hoggan *et al*. [5] conducted two experiments to investigate the effects of vibration feedback on a physical keyboard, a touchscreen without feedback, and a touchscreen with tactile feedback in both lab settings and mobile environments; they observed that touchscreens with tactile feedback produce greater speeds and fewer text entry errors than those of standard touchscreen keyboards without tactile feedback in two experimental conditions.

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Altinsoy and Merchel investigated the differences in several aspects, including execution time, error rate, and subjective satisfaction with tactile and auditory feedback on a touchscreen. The results showed that a touchscreen with tactile feedback had a more positive effect than a touchscreen without feedback on the quality, error rate, and satisfaction [6]. Tactile feedback could not only provide simple information but also could present sophisticated information, such as spatial and temporal information [7, 8], to interface users.

Tactile feedback was useful for providing support to special (e.g., blind or elderly) users of mobile phones [9, 10]. With advancing age, cognitive ability, comprehension ability, learning ability and memory will decline, especially in the elderly. For example, Hertzum *et al*. [11] recruited three groups of subjects, consisting of young (12–14 years old), adult (25–33 years old), and elderly (61–69 years old) individuals, to investigate their performance of operating a touchpad. The results showed that young participants made fewer errors and completed tasks more quickly than did elderly participants. The elderly participants cannot adapt to new technologies such as smartphones and touchscreens. Vibration feedback can, to a certain extent, compensate for the deficiencies of the elderly users when using smartphones.

There are many factors that could influence the user experience of tactile feedback. Previous studies have explored some basic issues during the interaction, including operation mode, activation mechanism, button size, etc.[2]. Additionally, the gesture was another factor that could influence the efficiency of tactile feedback [12, 13]. To understand the relationship between usability and user experience, researchers also explored several parameters of vibration, such as the latency of tactile feedback after the user pressed on the touchscreen. Kaaresoja *et al*. [3] performed three experiments to investigate how tactile feedback latencies impacted the user performance and satisfaction. The researchers manipulated the time between the button press and tactile feedback from 18 ms to 118 ms in their experiment. The results showed that there were no significant differences in performance between these conditions. However, compared to other conditions, the shortest feedback latency was evaluated as being more pleasant to use. Hwang et al. proved that the perceived intensity of vibrotactile feedback for mobile devices was influenced by the direction, amplitude and frequency of motor vibration [14]. Hoggan and Brewster found that the waveform of vibration had a higher recognition rate than those of amplitude modulation and frequency for creating a texture [15]. Based on these studies, the physical parameter of vibration was the key factor of user experience of tactile feedback. To our knowledge, no research has explored the effect of vibration times and interval on user experience. Hence, we designed this study to investigate these new parameters of vibration design.

Evaluation of user experience of tactile feedback was also meaningful in optimizing interface design. Previous studies mainly focused on the usability of tactile feedback; however, few studies have focused specifically on evaluating the feeling of tactile feedback. Some studies involved this aspect but only considered the subjective satisfaction of vibration [3]. However, no research has explored the dimensions of users' vibrotactile experience. The general user experience questionnaire (UEQ) [16] could be used as a reference for the evaluation. The UEQ has been translated into many languages [17, 18] and used in different scenarios [19]. This scale was made up of 6 dimensions: Attractiveness, Perspicuity, Efficiency, Dependability, Simulation and Novelty. Another widely used experience scale, the Brand Experience Scale (BES) [20], was also considered for the vibrotactile experience questionnaire design. The BES included four dimensions: sensory, affective, intellectual, and behavioral. Compared to the UEQ, the BES considered more behavioral intentions. Both sets of dimensions are very important for a successful product. Hence, we developed a new questionnaire for evaluating user experience of tactile feedback based on these two scales.

In sum, the purpose of this study was to explore the effect of vibration intensity, vibration times and interval between two vibrations on users' experience of tactile feedback. We also developed a questionnaire to evaluate the user experience.

2 Methods

2.1 Participants

A total of twenty-six users (female: 10; male: 16) were recruited for participation in this experiment. Their ages ranged from 18 to 31 years old (Mean = 22.7, SD = 3.1). All of them had normal vision and were right-handed. All of them were users of smartphones with touchscreens.

2.2 Apparatus

The experiment was conducted on a prototype phone. The phone size was 145.3 mm × 69.3 mm × 6.98 mm; it had a 5.1-inch touchscreen. We designed 2 icons on the screen. One icon vibrated once when pressed, and the other vibrated twice when pressed. The interval between two vibrations could be manipulated. The intensity of vibration for both icons could also be adjusted.

2.3 Materials

The Vibrotactile Feedback Questionnaire was developed to measure the user experience of tactile feedback. The questionnaire included three dimensions: sensory, affective, and behavioral intention. The sensory experience focused on the sensory feeling of using tactile feedback, including the perceived intensity, location and timeliness of feedback. The affective experience referred to the emotional factors of using tactile feedback, such as immersion, preference and intimacy. The behavioral intention mainly concerns whether there is a willingness to buy the mobile phone it and whether one would recommend it to other users. There are 14 items in total in this scale. Each item described a kind of experience. The users needed to self-report if they agreed or disagreed with each description on a five-point Likert scale (1 = "strongly disagree", 5 = "strongly agree").

2.4 Experimental Design

A within-subjects design was used in this experiment, in which three within-subjects variables (the intensity of vibration, vibration times and vibration interval) were manipulated. The intensity of vibration had three levels (weak, moderate and strong). There were two choices of vibration times (once and twice). For the case of two vibrations, 4 intervals were established in the experiment (100 ms, 230 ms, 370 ms and 500 ms). These durations were determined by a pilot test. During the pilot test, five participants set the vibration interval first on the prototype phone and then clicked the icon to feel the vibration. Participants were asked to choose four level intervals that he/she liked best. Afterwards, we calculated the average of their choices.

2.5 Data Analysis

The General Linear Model with repeated measures was used to examine the main effects and interaction of each independent variable, using SPSS 24.0. As to post hoc analyses, the least significant difference (LSD) tests were performed on the significant main effects. In addition, the simple effect test was performed if a significant interaction existed.

3 Results

3.1 Effect of Vibration Intensity and Times

The descriptive results for the intensity of vibration and vibration times are displayed at Table 1.

Table 1. Descriptive statistics of TEQ for various vibration intensities and times (figures shown are mean values, with SD shown in parentheses)

Dimension	Times	Intensity		
		Weak	Moderate	Strong
Sensory	Once	3.15 (.85)	3.18 (.75)	3.78 (.86)
	Twice	3.28 (.69)	3.38 (.83)	3.51 (.72)
Affective	Once	3.13 (.71)	3.15 (.89)	3.45 (1.05)
	Twice	3.00 (.77)	3.08 (.84)	3.05 (.83)
Behavioral	Once	2.74 (.95)	2.88 (.98)	3.31 (1.13)
	Twice	2.84 (.89)	2.92 (.96)	2.93 (.91)

Sensory Experience. According to the results of the General Linear Model with repeated measures, the main effect of the intensity of vibration ($F(2, 50) = 9.49$; $p < 0.001$) was significant. The LSD tests revealed that the sensory experience of strong vibration ($M = 3.64$) was better than that of moderate ($M = 3.28$) and weak ($M = 3.21$) conditions.

The interaction between the intensity of vibration and vibration times was significant ($F(2, 50) = 4.53$; $p < 0.05$). The simple effect test revealed that when the vibration intensity was strong, the sensory experience of a single vibration was better than that of vibrating twice. However, when vibrations were weak or moderate, the sensory experience of a single vibration was worse than that of two vibrations (Fig. 1).

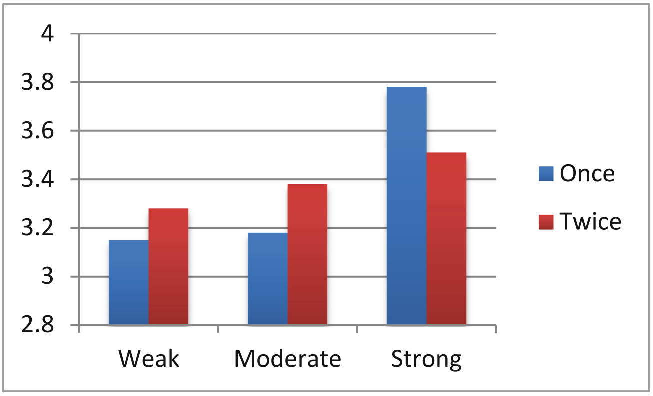

Fig. 1. Interaction effect between vibration intensity and times on sensory experience

Affective Experience. All the main effects of vibration intensity and times on affective experience are not significant, as are their interactions.

Behavioral Intention. According to the results of the General Linear Model with repeated measures, the main effect of the intensity of vibration ($F(2, 50) = 3.35$; $p < 0.05$) on behavioral intention was significant. The LSD tests revealed that the willingness to use and recommend the strong vibration ($M = 3.12$) was higher than that in the weak ($M = 2.79$) condition.

The interaction between vibration intensity and vibration times ($F(2, 50) = 3.68$; $p < 0.05$) was also significant. The simple effect test revealed that when the intensity of vibration was strong, the behavioral intention of a single vibration was higher than that of two vibrations. No significant simple effect was observed in weak and moderate conditions (Fig. 2).

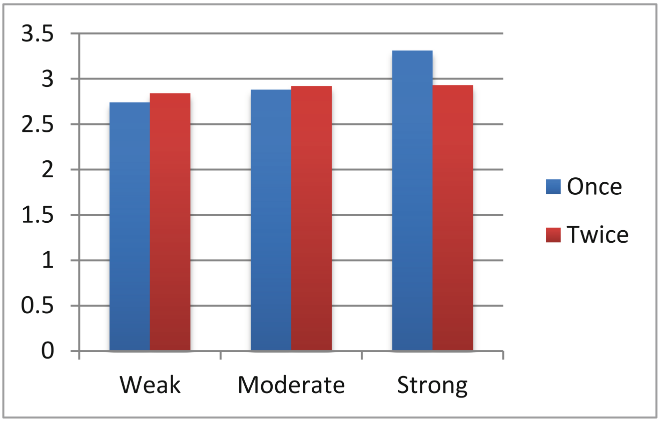

Fig. 2. Interaction effect between vibration intensity and times on behavioral intention

3.2 Effect of Vibration Intensity and Interval

The descriptive results for the intensity of vibration and vibration intervals are displayed in Table 2. According to the results of the General Linear Model with repeated measures, the main effect of interval was significant on all of the three dimensions. The results showed that the shorter the interval was, the higher the satisfaction. The trend of satisfaction from the highest to the lowest corresponds to intervals of 230 ms, 100 ms, 370 ms and 500 ms. There are no significant differences between 230 ms and 100 ms, also between 100 ms and 370 ms.

Sensory Experience. The main effect of interval ($F(3, 75) = 17.71$; $p < 0.001$) was significant. The LSD tests revealed that the sensory experience of the interval of 230 ms ($M = 3.61$) was significantly improved compared to that in 370 ms ($M = 3.35$) and 500 ms ($M = 3.04$) conditions. The satisfaction at the interval of 100 ms ($M = 3.55$) was significantly higher than that at the interval of 500 ms ($M = 3.04$). The satisfaction at the interval of 370 ms ($M = 3.36$) was significantly higher than that at the interval of 500 ms ($M = 3.04$). No interaction effect was observed.

Affective Experience. The main effect of interval ($F(3, 75) = 17.18$; $p < 0.001$) on the affective experience was significant at the level of 0.01. The LSD tests revealed that the affective experience of the interval of 100 ms ($M = 3.24$) was significantly higher than that of the intervals of 370 ms ($M = 3.00$) and the interval of 500 ms ($M = 2.62$). The affective experience of the interval of 370 ms ($M = 3.00$) was significantly improved compared to that of the interval of 500 ms ($M = 2.62$).

Table 2. Descriptive statistics of TEQ for various vibration intensities and intervals (figures shown are mean values, with SD shown in parentheses)

Interval	Sensory experience			Affective experience			Behavioral intention		
	Weak	Moderate	Strong	Weak	Moderate	Strong	Weak	Moderate	Strong
100 ms	3.39 (.70)	3.52 (.87)	3.73 (.91)	3.12 (.84)	3.27 (1.01)	3.32 (.97)	2.92 (.93)	3.17 (1.07)	3.14 (1.01)
230 ms	3.45 (.91)	3.56 (.75)	3.81 (.84)	3.30 (.89)	3.36 (.79)	3.28 (1.03)	3.14 (1.00)	3.14 (.98)	3.23 (1.16)
370 ms	3.37 (.77)	3.39 (.97)	3.30 (.78)	2.98 (.92)	3.14 (1.07)	2.88 (.90)	2.88 (1.11)	2.97 (1.24)	2.74 (.95)
500 ms	2.89 (.84)	3.05 (.98)	3.18 (.82)	2.59 (.94)	2.55 (.96)	2.71 (.90)	2.40 (.97)	2.38 (1.05)	2.62 (.97)

Behavioral Intention. The main effect of interval (F (3, 75) = 16.38; $p < 0.001$) was significant at the 0.01 significance level. The LSD tests revealed that the behavioral intention at the interval of 230 ms (M = 3.17) was significantly higher than that at the intervals of 370 ms (M = 2.87) and 500 ms (M = 2.47). The behavioral intention at the interval of 100 ms (M = 3.08) was significantly higher than that at the interval of 500 ms (M = 2.47). The behavioral intention at the interval of 370 ms (M = 2.87) was significantly higher than that at the interval of 500 ms (M = 2.47).

Suitability of Vibration Intensity. On the item of vibration strength being comfortable, the main effects of vibration's intensity (F(2, 50) = 3.83; $p < 0.05$) and interval (F(3, 75) = 5.89; $p < 0.001$) were significant. The LSD tests revealed that the intimacy of the strong condition (M = 3.60) was higher than that of the weak condition (M = 3.14). It was indicated that strong was the most comfortable intensity of vibration for users.

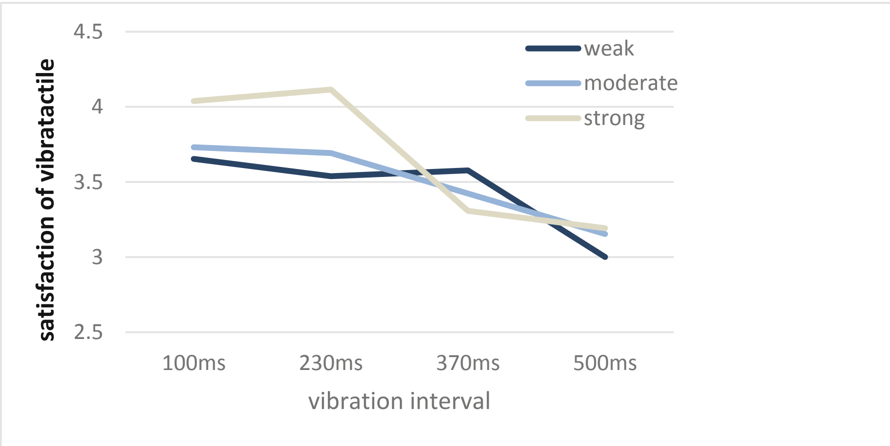

Fig. 3. Interaction effect between vibration intensity and intervals on timeliness of feedback

Timeliness of Feedback. On the item of timeliness of feedback, the main effect of vibration interval (F (3, 75) = 10.71; $p < 0.001$) was significant. The LSD tests revealed that users felt the timeliness of feedback with the interval of 230 ms

(M = 3.78) was significantly higher than that of intervals of 370 ms (M = 3.44) and 500 ms (M = 3.16). The timeliness of feedback with the interval of 100 ms (M = 3.81) was significantly higher than that of intervals of 370 ms (M = 3.44) and 500 ms (M = 3.16). The satisfaction at the interval of 370 ms (M = 3.44) was significantly higher than that at the interval of 500 ms (M = 3.16). The descriptive results for the vibration interval are displayed in Fig. 3. The difference between strong and weak intensities was larger at 100 ms and 230 ms than those at 370 ms and 500 ms.

4 Discussion

This paper investigated the effect of tactile feedback on user experience of touchscreen virtual button interaction. The vibration intensity, vibration times and the interval between two vibrations were compared under different conditions. The user experience was evaluated for three aspects. The results include several significant results that could be used in the future design of tactile feedback. In particular, vibration intensity was observed to have a significant effect on user experience, strong vibrations being significantly preferred to the other two intensity levels. Additionally, giving feedback only once was better than doing so twice when the intensity was strong. In the condition of giving feedback twice, the interval between two vibrations has a significant impact on user experience. Users preferred a shorter interval to longer intervals.

First, the user experience was enhanced by the increase of vibration intensity. This effect was significant on sensory experience, especially on the perceived suitability of vibration intensity and timeliness of feedback. These results confirmed the facts that perceived intensity was very important in vibration feedback.

Second, the effect of vibration times was affected by vibration intensity. When vibrations were strong, vibrating once was better than vibrating twice. However, when vibrations were weak or moderate, the effect was reversed. This phenomenon was clearly observed in sensory experience. The behavioral intention showed the same trend. These results implied that the satisfaction of vibration was a dynamic process. Perceived intensity was one of the main impact factors. When its level did not satisfy the need of users, other factors, such as vibration times, could compensate for its effect.

Finally, the user experience deteriorated with the increase of the interval between two vibrations. The best experience was observed at 230 ms in the strong vibration intensity condition. As a supplement of intensity, a shorter interval played a role, resulting in better sensory experience, affective experience and behavioral intension than those of longer intervals. The possible explanation was a long interval could be perceived as a response delay or stumbling. Hence, the user experience was poor.

Our research has some limitations. The main task of this experiment was to touch the icon and to feel the tactile feedback of the icon using distinct gestures. This task is simple and not involved in real-world tasks performed while using a smartphone. Hence, no performance could be recorded in this task. This limitation restricts the real-world applicability of the experiment. Future studies could design more realistic tasks to explore the effect of these parameters on users' experience and performance.

In a word, our experiment fills the research gap between the physical parameters of tactile feedback and the subjective user experience. The results of our study could provide some standards for vibration feedback design. The questionnaire for evaluating the tactile experience of vibration feedback could be used in future studies in this research field.

References

1. Fukumoto, M., Sugimura, T.: Active click: tactile feedback for touch panels. In: CHI 2001 Extended Abstracts on Human Factors in Computing Systems, pp. 121–122 (2001)
2. O'Sullivan, S.S., Evans, A.H., Lees, A.J.: Dopamine dysregulation syndrome an overview of its epidemiology, mechanisms and management. CNS Drugs **23**(2), 157–170 (2009)
3. Kaaresoja, T., Anttila, E., Hoggan, E.: The effect of tactile feedback latency in touchscreen interaction. In: World Haptics Conference, pp. 65–70 (2011)
4. Schönauer, C., Mossel, A., Zaiți, I.-A., Vatavu, R.-D.: Touch, movement and vibration: user perception of vibrotactile feedback for touch and mid-air gestures. In: Abascal, J., Barbosa, S., Fetter, M., Gross, T., Palanque, P., Winckler, M. (eds.) INTERACT 2015. LNCS, vol. 9299, pp. 165–172. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-22723-8_14
5. Hoggan, E., Brewster, S.A., Johnston, J.: Investigating the effectiveness of tactile feedback for mobile touchscreens. In: CHI 2008: Conference Proceedings of 26th Annual Chi Conference on Human Factors in Computing Systems, vols. 1 and 2, pp. 1573–1582 (2008). (in English)
6. Altinsoy, M.E., Merchel, S.: Audiotactile feedback design for touch screens. In: Proceedings of Haptic and Audio Interaction Design, vol. 5763, pp. 136–144 (2009). (in English)
7. Lee, J.H., Spence, C.: Spatiotemporal visuotactile interaction. In: International Conference on Haptics: Perception, Devices and Scenarios, pp. 826–831 (2008)
8. Sahami, A., Holleis, P., Schmidt, A., Häkkilä, J.: Rich tactile output on mobile devices. In: Aarts, E., et al. (eds.) AmI 2008. LNCS, vol. 5355, pp. 210–221. Springer, Heidelberg (2008). https://doi.org/10.1007/978-3-540-89617-3_14
9. Ghiani, G., Leporini, B., Paternò, F.: Vibrotactile feedback to aid blind users of mobile guides. J. Vis. Lang. Comput. **20**(5), 305–317 (2009)
10. Al-Razgan, M.S., Al-Khalifa, H.S., Al-Shahrani, M.D., AlAjmi, H.H.: Touch-based mobile phone interface guidelines and design recommendations for elderly people: a survey of the literature. In: Huang, T., Zeng, Z., Li, C., Leung, C.S. (eds.) ICONIP 2012. LNCS, vol. 7666, pp. 568–574. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-34478-7_69
11. Hertzum, M., Hornbaek, K.: How age affects pointing with mouse and touchpad: a comparison of young, adult, and elderly users. Int. J. Hum.-Comput. Interact. **26**(7), 703–734 (2010). (in English)
12. Bragdon, A., Nelson, E., Li, Y., Hinckley, K.: Experimental analysis of touch-screen gesture designs in mobile environments. In: CHI 2011, pp. 403–412 (2011)
13. Azenkot, S., Zhai, S.: Touch behavior with different postures on soft smartphone keyboards. In: International Conference on Human-Computer Interaction with Mobile Devices and Services, pp. 251–260 (2012)
14. Hwang, I., Seo, J., Kim, M., Choi, S.: Vibrotactile perceived intensity for mobile devices as a function of direction, amplitude, and frequency. IEEE Trans. Haptics **6**(3), 352–362 (2013)
15. Hoggan, E., Brewster, S.: New parameters for tacton design. In: CHI 2007 Extended Abstracts on Human Factors in Computing Systems, pp. 2417–2422 (2007)

16. Laugwitz, B., Held, T., Schrepp, M.: Construction and evaluation of a user experience questionnaire. In: Holzinger, A. (ed.) USAB 2008. LNCS, vol. 5298, pp. 63–76. Springer, Heidelberg (2008). https://doi.org/10.1007/978-3-540-89350-9_6
17. Rauschenberger, M., Schrepp, M., Cota, M.P., Olschner, S.: Efficient measurement of the user experience of interactive products. how to use the user experience questionnaire (UEQ). example: spanish language version. Int. J. Interact. Multimedia Artif. Intell. **2**(1), 39–45 (2013)
18. Cota, M.P., Thomaschewski, J., Schrepp, M., Gonçalves, R.: Efficient measurement of the user experience. A Portuguese version. Procedia Comput. Sci. **27**(1), 491–498 (2014)
19. Schrepp, M., Hinderks, A., Thomaschewski, J.: Applying the user experience questionnaire (UEQ) in different evaluation scenarios. In: Marcus, A. (ed.) DUXU 2014. LNCS, vol. 8517, pp. 383–392. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-07668-3_37
20. Brakus, J.J., Schmitt, B.H., Zarantonello, L.: Brand experience: what is it? How is it measured? Does it affect loyalty? Soc. Sci. Electron. Publ. **73**(3), 52–68 (2009)