Perception of the Vibration Intensity of Smartwatches in the Notification Scene

Tao Qin, Le Chang, and Haining Wang(✉)

Hunan University, Changsha 410082, China
haining1872@qq.com

Abstract. Existing smartwatches often use vibration for reminders and feedback, especially in the notification scene. In the notification scene, the intensity of the vibration directly affects whether the user can receive the notification. Therefore, establishing the relationship between notification vibration and user perception is essential to improve the efficiency of notifications and user experience. In the literature, while some studies have examined the relationship between vibration and perceptions of mobile phones, no connection has been established between vibration intensity and vibration perceptions of watches, particularly in the context of notifications. In this paper, intensity perceptions of various vibration intensities at three common watch frequencies are studied. Ten adult subjects (5 males and 5 females) were recruited and asked to wear experimental watches and evaluate the vibration perceptions using to a Likert scale. Our research results include the perceived differences in vibration intensity at three frequencies and the corresponding appropriate intensity range values. These findings can provide guidance for designing notification vibrations in smartwatches.

Keywords: Smartwatch · Vibration · Vibration intensity · Intensity perception

1 Introduce

Due to the product characteristics of smartwatches requiring wearable use, vibration is widely applied as a tactile feedback interaction method in their operation and feedback, particularly in notification scenarios. In notification scenarios, the vibration intensity of a smartwatch directly determines the level of notification perception by the user. Therefore, establishing the relationship between the vibration intensity of a watch product and the user's perception is of great significance for improving the efficiency of watch notifications and providing a good user experience. Currently, there are many related studies on vibration experience, and the addition of vibration can improve user experience and improve user cognition of the device, enabling users to better understand message behavior [1–3]. During the process of receiving vibration, user perception is often influenced by different parameters. For example, I. Hwang et al. studied various factors that may affect vibration perception intensity [4], including vibration frequency, amplitude, duration, and other factors. The change in intensity has a significant impact on the user experience, as Tan et al. found that vibration intensity can enhance the level of

A. Marcus et al. (Eds.): HCII 2023, LNCS 14032, pp. 270–283, 2023.
https://doi.org/10.1007/978-3-031-35702-2_20

user experience on mobile phones [5], while Christian Schönauer et al. found that users tend to overestimate vibration intensity [6]. Similarly, vibration frequency also affects the level of perception. In another article by Hwang I, it was found that frequencies below 100Hz give rise to a stronger perception intensity [7]. In addition to the above studies, some scholars have also conducted research on vibration perception for specific populations. For example, Liu SF et al. studied the differences in vibration perception between elderly and young people and proposed vibration schemes that may have better perception for the elderly [8]. However, in current vibration experience research, most studies focus on vibration research for mobile devices, such as smartphones, or on vibration type design. There is a lack of research on vibration perception for smartwatches, particularly in specific scenarios such as notification scenarios, which is an important vibration application scenario that still lacks related research. Therefore, this study takes notification scenarios as the vibration research scenario to investigate the problem of vibration intensity perception by users on smartwatches and provide appropriate intensity ranges under different frequencies.

This study aimed to investigate differences in vibration intensity perception among users of smartwatches at three distinct frequencies (80 Hz, 145 Hz, and 235 Hz). Ten participants (5 males and 5 females) with an average age of 24.1 years were recruited for the vibration perception experiment. Subjective evaluations of vibration intensity were collected from the participants using a 7-point scale. Participants used a specific adjustment program and experimental phone to experience vibrations in a set notification scenario. The experiment collected rating data for subsequent analysis. The expected research outcomes include differences in vibration intensity perception across the three frequencies and appropriate intensity value ranges for each corresponding frequency.

2 Methods

2.1 Participants

Ten undergraduate students from Hunan University in China were recruited to participate in the study. The participants included five males and five females with a minimum age of 22, a maximum age of 27, and an average age of 24.1 years. All participants had no hand-related diseases, functional impairments, or vibration disorders, and they all had right-hand dominance. Additionally, the recruited participants had previous experience using wearable devices and passed the screening for the vibration perception task in the recruitment questionnaire, indicating good sensitivity to vibrations.

2.2 Materials

Vibration Apparatus

The vibration apparatus comprised an adjustable vibration program for a mobile phone and a smartwatch prototype equipped with a vibration motor, which was used to simulate the real-world scenario of smartwatch users receiving notification vibrations. The first device was the RichTap adjustable vibration program developed by ACC TECHNOLOGY (Fig. 1). The RichTap program could adjust predefined vibration parameters, including vibration unit type, vibration intensity, vibration frequency, vibration duration, and specific internal parameters of the vibration unit, to design various vibration effects with ease. For this study, only one vibration unit set to the long vibration type was used in the experiment, and it was adjusted to a fixed vibration duration of 200 ms.

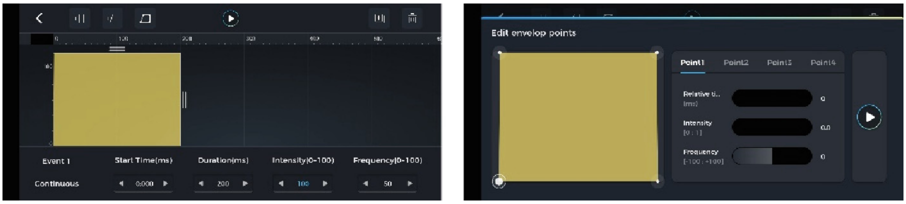

Fig. 1. RichTap application interface.

The second device was a smartwatch prototype embedded with a vibration motor (Fig. 2). To fully simulate the experience of using a smartwatch vibration, we connected the vibration motor fixed on the watch prototype to the experimental mobile phone equipped with the adjustable program through copper wires. This method enabled the vibration occurrence of the watch to be remotely controlled via the RichTap application. The vibration motor on the watch was secured and sealed with hot melt adhesive. During the experiment, participants were required to wear the modified watch prototype on their right wrists and adjust the watch band according to their wrist size until it was stable and comfortable. As this experiment aimed to investigate the vibration perception of smartwatches in notification scenarios, there was no specific posture requirement for participants wearing the watch; and they were instructed to maintain natural and common postures to match the real-world use of smartwatches.

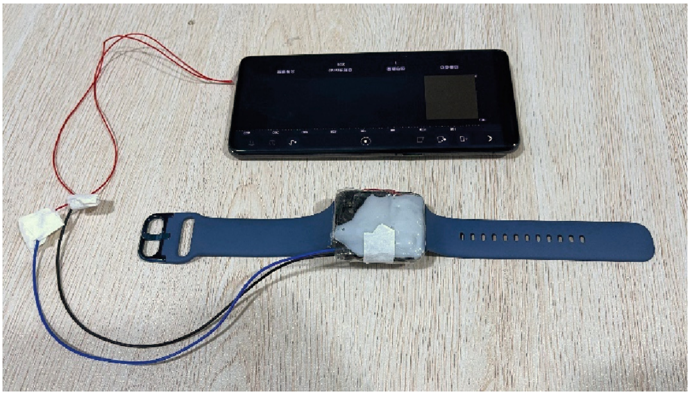

Fig. 2. Vibration smartwatch prototype.

Intensity Perception Scale

The experiment employed a self-designed seven-level intensity perception rating scale to collect data, as shown in Fig. 3. The scale rating instruction was "The extent to which the vibration characteristics in notification scenarios provide feedback, the perceptibility and perceptiveness of vibration effects or textures, and whether they capture your attention." Descriptions for scores of 1 and 7 in the scale are as follows: "Almost Imperceptible" and "Extremely Perceptible". Additionally, in the scale's rating instructions, a vibration intensity of 4–5 points was considered appropriate for vibration notification strength, and this rating data will be used to calculate the corresponding intensity value in the subsequent data analysis. Participants in the experiment were required to perform the intensity perception rating after experiencing the vibration at least three times.

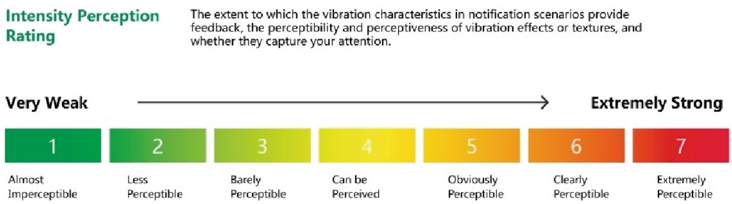

Fig. 3. Intensity perception scale.

2.3 Procedures

All experimental studies were conducted in the laboratory of Hunan University. Participants signed informed consent forms and provided basic information before participating in the experiment. Three sets of experiments were conducted at different vibration frequencies: 80Hz, 145Hz, and 235Hz. The vibration intensity was adjusted in increments of 10, from intensity level 10 to 100, for a total of 10 adjustments per experiment. Thus, each complete experiment included at least $3 \times 10 = 30$ vibration experiences and corresponding ratings.

Prior to the formal experiment, participants were led by experimenters to become familiar with the software and to complete a vibration task (without rating) to ensure that they fully understood the purpose, process, and complete vibration sensation. During the formal experiment, participants completed the three sets of vibration intensity experiences in the order specified in the experimental table. In each score, participants were required to complete at least three full vibration experiences before rating them according to the scale. If a participant had any ambiguity or needed to modify their previous rating, they were allowed to re-experience and modify their rating in a timely manner. After completing a set of vibration tasks, participants were required to rest for at least 5 min to ensure the sensitivity of their hand vibration perception. Each experiment lasted approximately 35 min. Part of the experimental process is shown in Fig. 4.

The rating data during the experiment were recorded on paper by experimenters and then uploaded to a computer for subsequent analysis. It should be noted that the vibration intensity values used in the experiment were program-set values and did not represent the

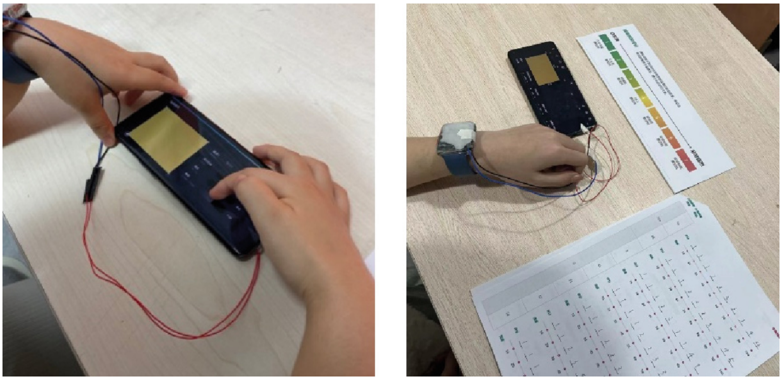

Fig. 4. Left: Adjusting vibration parameters in RichTap; Right: Intensity perception rating scale and questionnaire.

actual vibration amplitude. Therefore, after the experiment, the vibration intensity was measured using a vibration measuring instrument (SV 103, SVANTEK, Poland), and the measurement results were expressed in vibration acceleration peak-to-peak value in mm/s^2. The relationship between the measured actual vibration acceleration and corresponding intensity levels is detailed in Table 1.

Table 1. Peak-to-peak vibration acceleration in each frequency.

Intensity	P-P (mm/s^2)		
	80Hz	145Hz	235Hz
10	0.512	0.546	0.535
20	0.971	1.091	0.708
30	1.381	1.553	0.921
40	1.827	3.130	1.421
50	2.137	4.149	1.685
60	2.524	5.162	2.256
70	2.880	5.612	3.101
80	3.256	6.107	3.807
90	3.551	7.480	4.337
100	3.665	8.448	

3 Result

3.1 Perceived Score of Each Frequency Intensity

The rating data for each frequency are presented in Table 2, including the mean and standard deviation. Additionally, rating-intensity profiles were plotted for different frequencies, as shown in Fig. 5.

Table 2. Vibration intensity perception score of each frequency.

Intensity	Frequency	Mean (M)	Standard Deviation (SD)
10	80Hz	1.700	0.823
	145Hz	1.500	0.707
	235Hz	1.400	0.699
20	80Hz	2.200	1.135
	145Hz	3.300	1.059
	235Hz	2.600	1.350
30	80Hz	2.900	1.197
	145Hz	4.700	1.252
	235Hz	3.500	1.354
40	80Hz	3.900	0.876
	145Hz	5.900	1.101
	235Hz	5.000	1.333
50	80Hz	4.900	1.101
	145Hz	6.500	0.850
	235Hz	5.900	1.197
60	80Hz	5.800	0.919
	145Hz	6.800	0.422
	235Hz	6.500	0.972
70	80Hz	6.500	0.707
	145Hz	6.900	0.316
	235Hz	6.600	0.699
80	80Hz	6.800	0.422
	145Hz	7.000	0.000
	235Hz	6.900	0.316

(*continued*)

Table 2. (*continued*)

Intensity	Frequency	Mean (M)	Standard Deviation (SD)
90	80Hz	7.000	0.000
	145Hz	7.000	0.000
	235Hz	7.000	0.000
100	80Hz	7.000	0.000
	145Hz	7.000	0.000
	235Hz	7.000	0.000

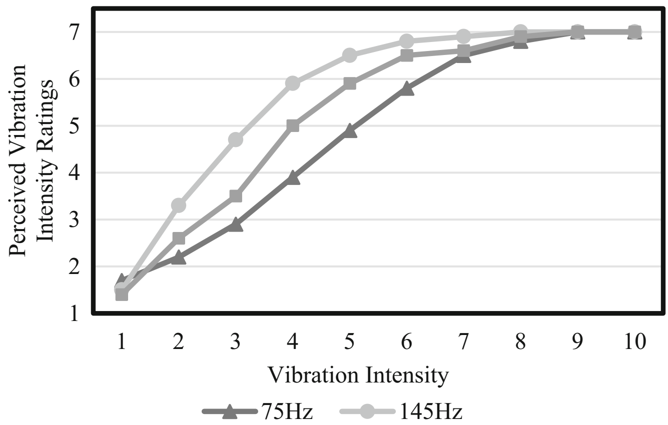

Fig. 5. Distribution of perceived vibration intensity ratings.

As revealed by the curve distributions in Fig. 5, there are differences in the perceived intensity of vibration across different frequencies. Overall, the perceived intensities of vibration across the three frequencies were ranked as 145 Hz > 80 Hz > 235 Hz. Furthermore, Fig. 1 also shows the differences in perceived intensity ratings at different intensities. The rating curves appear to be dispersed in the middle intensity range (e.g. 30–60), while they exhibit a clustering tendency in the lower and higher intensity ranges (e.g. 10–20, 70–100). One-factor ANOVA is required to explore the differences in perceived intensity across different intensities.

After verifying the homogeneity of variances using a statistical test (Table 3), one-way ANOVA was conducted on the rating data for different frequencies. Post hoc multiple comparisons were performed on the intensity rating data that showed significant differences ($P < 0.05$) to determine the specific differences among the three frequencies, which are presented in Table 4 and Table 5. Since the vibration perception ratings for intensity levels 90 and 100 were both 7 for all three frequencies, the analysis of differences between these two intensity levels was omitted.

The data in Table 4 and Table 5 show that there was at least one significant difference between the three frequencies for intensity levels 30–60. Specifically, the differences between each frequency for these intensity levels were as follows: (1) at intensity level 30, there was a significant difference between 145Hz and 80Hz as well as between 145Hz and 235Hz, and it can be concluded from Fig. 5 that the perceived intensity of vibration at 145Hz was significantly higher than that of the other two frequencies at intensity level 30; (2) at intensity level 40, there was a significant difference between 80Hz and both 145Hz and 235Hz, and it can be concluded from Fig. 5 that the perceived intensity of vibration at 145Hz and 235Hz was significantly higher than that of 80Hz; (3) at intensity level 50, there was a significant difference between 80Hz and both 145Hz and 235Hz, and it can be concluded from Fig. 5 that the perceived intensity of vibration at 145Hz and 235Hz was significantly higher than that of 80Hz; (4) at intensity level 60, there was a significant difference between 80Hz and 145Hz, and it can be concluded from Fig. 5 that the perceived intensity of vibration at 145Hz was significantly higher than that of 80Hz.

In summary, the perceived intensity of vibration at 145Hz was highest when the intensity levels were between 20 and 80, and it was significantly higher than the other experimental frequencies at intensity level 30. The perceived intensity of vibration at 80Hz was the lowest among the three experimental frequencies.

Table 3. Variance homogeneity test at different intensities.

Intensity	Levene	Df1	Df2	Sig.
10	0.417	2	27	0.663
20	0.309	2	27	0.737
30	0.176	2	27	0.84
40	0.553	2	27	0.581
50	2.077	2	27	0.145
60	3.221	2	27	0.056
70	5.295	2	27	0.011*
80	6.031	2	27	0.007*

* Levene's test for homogeneity of variances was significant ($p < 0.05$).

4 Comfort Intensity Range of Each Frequency

To calculate the comfortable vibration intensity values corresponding to different perceptual ratings at each frequency, it is necessary to conduct curve fitting analysis on the rating data. Firstly, a Pearson correlation analysis was performed on the vibration intensity and perceptual ratings at each frequency, and the specific data are listed in Table 6. Significant correlations were found between the perceptual ratings and vibration intensity at all frequencies, as shown in Table 7, and regression analysis was subsequently conducted on the rating data.

Table 4. Significance of differences in vibration intensity perception scores.

Intensity	Df2	Sig.
10	0.420	0.661
20	2.197	0.131
30	5.214	0.012*
40	8.015	0.002*
50	5.822	0.008*
60	4.017	0.030*
70	1.194	0.319
80	1.080	0.354

* is statistically significant at the 0.05 level.

Table 5. Post hoc multiple comparisons for vibration intensity perception ratings.

Intensity	Frequency 1	Frequency 2	Sig.
30	80Hz	145Hz	0.004 *
		235Hz	0.300
	145Hz	235Hz	0.044 *
40	80Hz	145Hz	0.000 *
		235Hz	0.037 *
	145Hz	235Hz	0.083
50	80Hz	145Hz	0.002 *
		235Hz	0.044 *
	145Hz	235Hz	0.216
60	80Hz	145Hz	0.010 *
		235Hz	0.064
	145Hz	235Hz	0.415

* The significance level of the difference between means is 0.05.

The results of the curve regression analysis are presented in Table 7 and Fig. 6, with the relevant data listed. The fitted functions were all statistically significant. The fitting results for 80Hz, 145Hz, and 235Hz explained 98.9%, 99.9%, and 96.7% of the rating data, respectively, and the fitting coefficients were significantly different at the 0.05 level.

We calculated the corresponding intensity values for the perceived ratings of 4 and 5 at three different frequencies, and the results were presented in Table 8. Due to the adjustment unit for vibration intensity being an integer in RichTap software, the fitted vibration intensity was rounded to the nearest integer before actual vibration measurements were conducted, and the results were recorded in Table 8. Based on the data in

Table 6. Correlation analysis between ratings and vibration Intensity.

Frequencies	Pearson correlation	Sig. (two-tailed)
80Hz	0.995**	0.000
145Hz	0.867**	0.001
235Hz	0.930**	0.000

** In 0.01 level (two-tailed), the correlation was significant.

Table 7. Regression analysis results of rating curves.

Frequency	Unstandardized coefficient			t	p	F	R^2
		B	Standard error				
80Hz	Constant	0.740	0.149	4.980	0.001	726.369	0.989
	B	0.065	0.002	26.951	0.000		
145Hz	Constant	-1.057	0.154	-6.873	0.000	1739.606	0.999
	B1	0.282	0.012	24.429	0.000		
	B2	-0.003	0.000	-13.696	0.000		
	B3	$1.245E^{-5}$	0.000	8.736	0.000		
235Hz	Constant	-5.218	0.695	-7.503	0.000	233.671	0.967
	Ln(B)	2.743	0.179	15.286	0.000		

Table 8, the suitable ranges of vibration intensity and the difference in values for the three frequencies were determined as follows: (1) 80Hz: intensity range of 50–66, a difference of 13 intensity units; (2) 145Hz: intensity range of 23–30, a difference of 7 intensity units; and (3) 235Hz: intensity range of 29–41, a difference of 12 units.

According to the analysis above and the fitted rating curves in Fig. 6, we found that: (1) 145Hz had the lowest suitable intensity value and the smallest range among the three frequencies; (2) the suitable intensity value at 235Hz was less than 50, and the range of values was lower than 50; and (3) the suitable range of intensity values for 80Hz was similar to that of 235Hz, with the value being greater than 50.

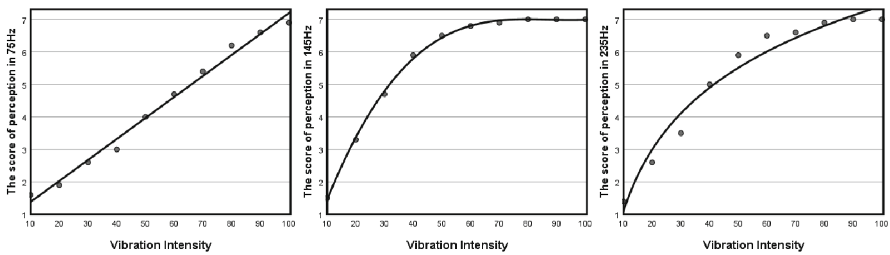

Fig. 6. Curves of rating for three frequencies.

Table 8. Appropriate vibration intensity range at each frequency.

Frequency	Perceived rating	Fitted vibration intensity	RichTap intensity value	P-P (mm/s^2)
80Hz	4	50.153	50	2.137
	5	65.538	66	2.742
145Hz	4	23.039	23	0.550
	5	29.712	30	0.898
235Hz	4	28.805	29	0.696
	5	41.476	41	0.932

5 Gender Differences

Table 9. Gender difference analysis results at the three frequencies.

Intensity	Frequency	Mean (M)		Standard Deviation (SD)		Sig.
		Male	Female	Male	Female	
10	80Hz	2.000	1.400	1.000	0.548	0.273
	145Hz	1.800	1.200	0.837	0.447	0.195
	235Hz	1.600	1.200	0.894	0.447	0.397
20	80Hz	2.800	1.600	1.304	0.548	0.094
	145Hz	3.800	2.800	1.095	0.837	0.143
	235Hz	3.000	2.200	1.414	1.304	0.380
30	80Hz	3.400	2.400	1.342	0.894	0.203
	145Hz	5.000	4.400	1.581	0.894	0.481
	235Hz	4.000	3.000	1.414	1.225	0.266
40	80Hz	4.000	3.800	1.000	0.837	0.740
	145Hz	6.000	5.800	1.000	1.304	0.792
	235Hz	5.400	4.600	1.140	1.517	0.373
50	80Hz	5.400	4.400	1.342	0.548	0.161
	145Hz	6.600	6.400	0.894	0.894	0.733
	235Hz	6.200	5.600	1.095	1.342	0.461

(*continued*)

Table 9. (*continued*)

Intensity	Frequency	Mean (M)		Standard Deviation (SD)		Sig.
		Male	Female	Male	Female	
60	80Hz	6.200	5.400	1.095	0.548	0.182
	145Hz	6.800	6.800	0.447	0.447	1.000
	235Hz	6.800	6.200	0.447	1.304	0.359
70	80Hz	6.800	6.200	0.447	0.837	0.195
	145Hz	6.800	7.000	0.447	0.000	0.347
	235Hz	6.800	6.400	0.447	0.894	0.397
80	80Hz	6.800	6.800	0.447	0.447	1.000
	145Hz	7.000	7.000	0.000[a]	0.000[a]	
	235Hz	7.000	6.800	0.000	0.447	0.347

a. Since the standard deviation of both groups is 0, t-value cannot be calculated.

To control for variables, a gender difference analysis was conducted assuming no significant differences in vibration intensity perception between males and females. According to the independent sample t-test analysis results in Table 9, the p-values for males and females at each intensity level were all greater than 0.05, indicating that the hypothesis cannot be rejected from a statistical standpoint. Therefore, it can be concluded that there is no gender difference in vibration intensity perception at the three frequencies. Since all the ratings at 90 and 100 were 7, gender differences analysis for these two intensity levels were omitted.

6 Discussion

Our experimental objective was to investigate the differences in vibration intensity perception at three different frequencies and provide appropriate vibration intensity ranges for each frequency based on rating data. The main findings of our study revealed that the vibration perception level was most apparent at a frequency of 145Hz, which could meet the vibration requirements at lower intensity settings. The appropriate moderate vibration intensity range for this frequency was 23–30.

In terms of the differences in vibration intensity perception at different frequencies, we found that the most significant difference was observed at a fixed intensity level for 145Hz, followed by 235Hz and then 80Hz. Similar findings were reported by S. Kasaei et al. [9], who found that vibrations at frequencies above 250Hz were weakly perceived, which limited their study. However, Hwang I's research [7] found that frequencies below 100Hz were perceived more strongly than those above 100Hz. It was speculated that the inconsistency of the vibration generator caused the differences. The vibrations in our study were controlled by RichTap software, and the same intensity level did not correspond to the same amplitude for different frequencies, as shown in Table 2. In Hwang I's study, the amplitude was given and the differences in perception at different frequencies were compared. Further research is needed to determine the specific differences that cause these inconsistencies.

Furthermore, we fitted the intensity-rating curve and calculated the appropriate intensity values for ratings of 4–5 according to the user perception rating scale. Table 8 shows the appropriate intensity value ranges for each frequency. From the perspective of value, the appropriate intensity values for 145Hz were the lowest, followed by 235Hz and then 80Hz. However, the intensity values were all below 70% of the maximum intensity, and particularly, the intensity values for 145Hz and 235Hz were below 50%. From the perspective of the difference between the upper and lower limits, the appropriate range for 145Hz was the narrowest, followed by 235Hz and then 80Hz, which both had wider ranges. Both aspects indirectly confirmed the trend of differences in intensity perception at different frequencies. In Christian Schönauer et al.'s study [6], it was mentioned that users tend to overestimate the intensity of vibration and perceive it as too strong. This finding was similar to the results of our study, in which the comfortable intensity values for each frequency were relatively low.

We did not find significant gender differences in our research analysis, which may be related to the different frequency values used. Burström L et al. found significant gender differences in vibration perception thresholds at 31.5Hz, but not at 125Hz [10]. In the future, it may be necessary to expand the frequency range or sample size for further research.

7 Conclusion

This study investigates the perception of vibration intensity at different frequencies in notification scenarios, using subjective rating methods. Based on intensity-rating data, the appropriate range of intensity values for each frequency was determined by fitting curves. The results show that, among the three experimental frequencies, vibration perception was strongest at 145Hz, with the smallest appropriate range of intensity values. Although gender differences were analyzed, no significant differences were found. It is speculated that this may be due to differences in frequency parameter selection, which requires further research and analysis.

Based on the above conclusions, when designing vibration feedback in notification scenarios, frequencies around 145Hz should be given priority as they can satisfy the vibration perception requirements with relatively low intensity. However, the range of intensity values should also be considered to avoid ineffective feedback due to vibrations that are either too weak or too strong.

Since the recruited participants were all undergraduates at Hunan University, with ages under 30, further research and analysis with a larger sample size may be necessary for other age groups. Additionally, due to limitations such as equipment and time, only a small number of frequencies and intensities were studied. Future work could focus on a wider range of frequencies or other relevant vibration factors to further explore this area.

References

1. Henderson, J., Avery, J., Grisoni, L., Lank, E.: Leveraging distal vibrotactile feedback for target acquisition. In: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. ACM, New York, NY, USA, pp. 1–11 (2019). https://doi.org/10.1145/3290605.3300715
2. Hachisu, T., Suzuki, K.: Representing interpersonal touch directions by tactile apparent motion using smart bracelets. IEEE Trans. Haptics **12**(3), 327–338 (2019)
3. Zhao, S., Israr, A., Fenner, M., Klatzky, R.L.: Intermanual apparent tactile motion and its extension to 3D interactions. IEEE Trans. Haptics **10**(4), 555–566 (2017)
4. 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)
5. Tan, J., Ge, Y., Sun, X., Zhang, Y., Liu, Y.: User experience of tactile feedback on a smartphone: effects of vibration intensity, times and interval. In: Rau, P.-L. (ed.) HCII 2019. LNCS, vol. 11576, pp. 397–406. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-22577-3_29
6. 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
7. 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. Jul-Sep; 6(3), 352–362 (2013). https://doi.org/10.1109/TOH.2013.2. PMID: 24808331
8. Liu, S.-F., Yang, Y.-T., Chang, C.-F., Lin, P.-Y., Cheng, H.-S.: A study on haptic feedback awareness of senior citizens. In: Zhou, J., Salvendy, G. (eds.) ITAP 2018. LNCS, vol. 10926, pp. 315–324. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-92034-4_24
9. Kasaei, S., Levesque, V.: Effect of vibration frequency mismatch on apparent tactile motion. In: 2022 IEEE Haptics Symposium (HAPTICS), Santa Barbara, CA, USA, pp. 1-62022https://doi.org/10.1109/HAPTICS52432.2022.9765602
10. Burström, L., Lundström, R., Hagberg, M., Nilsson, T.: Vibrotactile perception and effects of short-term exposure to hand-arm vibration. Ann Occup Hyg. **53**(5), 539–547 (2009). https://doi.org/10.1093/annhyg/mep027. Epub 2009 Apr 29 PMID: 19403839