Multisensory Integrated Haptic Interaction Design for Smartphones

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Abstract. Haptic feedback on smartphones often works together with visual and auditory channels to enhance immersion and immediacy. However, current designs rely largely on experience based parameter tuning and lack a systematic perceptual mechanism, which leaves notable room for improvement. This study presents a multisensory haptic design framework that integrates user intention, vibration features and perceptual experience. It establishes a mapping from interaction scenarios to perceptual feedback to improve the structure, transferability and user adaptation of haptic design. Experiments were conducted across ten common scenarios on three smartphones. Twenty four users participated, resulting in 348 samples that included vibration parameters, satisfaction ratings and interview data. The results show that the framework explains 67% of the variance in user satisfaction. Vibration parameters and device differences are the main influencing factors. The framework provides theoretical and methodological support for haptic interaction design on smartphones and other mobile devices.

Keywords: Haptic interaction · Multisensory integration · Smartphone · Interaction design · User experience.

1 Introduction

As mobile devices are used more frequently and for increasingly complex scenarios, haptic feedback has become an important channel for enhancing interaction awareness and operational efficiency. It is now widely adopted in smartphones, wearables, and other mobile devices [1, 2]. Compared with visual and auditory cues, haptic feedback offers advantages such as privacy, immediacy, and independence from the user's line of sight, making it suitable for fast-paced and multitasking scenarios. However, current haptic design still heavily relies on experience-based adjustments and built-in presets. It lacks a structured approach grounded in user perception, which results in significant experiential differences across devices and real scenarios. This makes it difficult to maintain consistency and support design transferability.

Most studies primarily explore how physical parameters such as vibration frequency, amplitude, and duration affect perceived intensity, or they focus on modeling basic physiological mechanisms and psychophysical thresholds [3, 4]. However, such studies are mostly conducted under controlled conditions, making it difficult to cover multidimensional factors in real interaction scenarios, including user goals, multimodal collaboration, and device implementation. There is still no theoretical framework that starts from the user's interaction intention and explains differences in haptic perception across devices.

To fill this gap, this study proposes a multisensory haptic feedback design framework for smartphones. The framework divides the user experience process into three modules: the user interaction layer, the explicit perception layer, and the implicit perception layer. These layers relate to user goals, feedback rhythms and structures, and perceptual interpretation. The framework aims to build a clear mapping among scenarios, rhythm, and perception. It integrates user preferences, system feedback patterns, and device implementation, and provides a structured foundation for haptic feedback that is interpretable, adjustable, and transferable.

We conducted a cross-device user study that covered ten typical interaction scenarios. Three mainstream smartphones were tested, and 24 participants took part in haptic experience sessions, satisfaction ratings, and short interviews. Vibration waveform parameters were collected for each scenario, and both quantitative modeling and qualitative analysis were used for validation. The results show that the framework explains 67% of the variance in user satisfaction. Physical parameters, device characteristics, and feedback structure all have significant effects. Users generally prefer short, clear, and rhythmically consistent feedback, showing higher satisfaction, especially in scenarios with well-defined operational rhythms. These findings verify the feasibility of constructing multisensory feedback structures based on user behavior and provide theoretical support and practical basis for the systematic implementation of rhythmic haptic design in smart terminals.

2 Related Work

2.1 Physiological Mechanisms and Psychophysical Foundations of Haptic Perception

Touch, as an important sensory channel besides sight and hearing, has gradually been regarded as the fifth dimension for enhancing the interactive experience of smartphones in recent years. Effective tactile design in human-computer interfaces must simultaneously satisfy physiological perceptibility and psychological distinguishability. That is, vibration stimulation needs to fall within the optimal response range of the skin's mechanoreceptors and deliver coherent and meaningful feedback through parameter differentiation. In haptic research, Verrillo and colleagues identified banded frequency sensitivity in cutaneous receptors, with Pacinian corpuscles showing minimal thresholds around 250 to 300 Hz and Meissner corpuscles responding more strongly to lower ranges near 10 to 50 Hz [5]. Brewster and Brown further quantified how frequency, amplitude, and temporal rhythm jointly influence perceived tactile intensity and can shift the urgency assigned to identical events [6]. Chang and collaborators extended this work by modeling temporal delay and showed that latencies above 40 ms reduce targeting accuracy and increase erroneous activations [7].

Despite establishing key physiological and psychophysical foundations for vibration design, these studies remain two shortcomings. Most experiments were run under ideal laboratory conditions with limited validation on actual smartphone hardware. Moreover, the modulatory effect of user intent, for example tapping and swiping, on perceptual thresholds has not been systematically quantified. To address these gaps, the present study proposes a framework that couples behavioral context with physiological sensitivity and empirically evaluates it in real smartphone interaction environments.

2.2 Theoretical Basis and Design Strategies for Multisensory Integration

In multimodal interaction, Wickens' Multiple Resource Theory indicates that sensory channels can process information in parallel with relatively independent resource pools, and that tactile cues can offload visual and auditory load when appropriately assigned [8]. Oviatt's modality appropriateness principle further suggests that each information type should be assigned to the channel with the greatest processing advantage. Rhythmic alerts are therefore more suited to tactile or auditory delivery, whereas spatial localization is best conveyed visually [9]. Spence and Driver introduced the principle of cross-sensory consistency, emphasizing that temporal and semantic alignment across channels is critical for reducing perceptual conflict [10]. Although these studies provide a foundation for tactile–visual–auditory coordination, two limitations remain. Most models are validated through two-channel experiments and lack systematic examination of three-channel collaboration in smartphone contexts. In addition, how users shift channel weighting during dynamic task switching remains unclear. Addressing these gaps, this study develops a multisensory framework centered on users' real-time scenarios, specifies when tactile cues should take priority, and validates these conditions through multitask smartphone interaction experiments.

2.3 Interaction Framework and Haptic Symbol Models

Brewster's Tactons encode vibration frequency, amplitude, and duration into discrete tactile icons, demonstrating that touch can distinguish information without visual input [6]. Later work by MacLean and Enriquez expanded these icons into multidimensional haptic symbols capable of conveying compound semantics and hierarchical cues [11, 13]. Experience-oriented approaches, such as Kim's Haptic Experience Framework, further evaluate perception through sensory, contextual, and affective dimensions [14–19]. Despite these advances, current work largely focuses on encoding isolated vibration events and their subjective evaluation. A longitudinal causal chain linking user behavior, haptic parameters, multimodal semantics, and device constraints has not been fully articulated. Moreover, most evaluations occur in controlled settings and rarely consider the variability of real smartphone use and hardware diversity [20, 21]. To bridge this gap, the present research proposes a multi-layered framework for designing and evaluating haptic feedback, providing systematic benchmarks for smartphone haptic interaction in real-world use.

3 Multisensory Framework for Smartphone Haptic Feedback

Grounded in observations, analysis, and synthesis across diverse real scenarios, this study proposes the multisensory smartphone haptic feedback framework illustrated in Fig. 1 . With a focus on user experience, the framework describes a causal chain that links operations to perceptions through three layers: user interaction, explicit perception, and implicit perception.

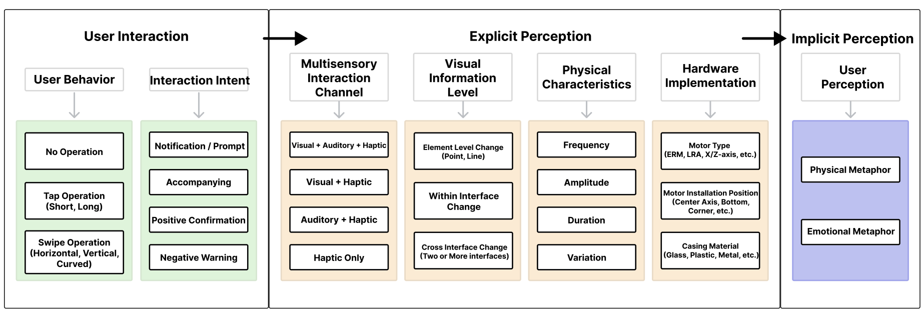

Fig. 1. Multisensory Haptic Feedback Framework for Smartphones

3.1 User Interaction Layer

Haptic feedback on smartphones is often driven by user interaction behaviors and the functional intentions behind them. These behaviors can be divided into passive reception and active operation. Passive reception includes situations such as incoming calls or system notifications that do not require user actions. Active operation includes Tap Operation, which may be short or long, and Swipe Operation, which can follow horizontal, vertical, or curved paths.

Aligned with functional goals and use contexts, smartphone haptics can be grouped into four types. Notification feedback occurs without active input, as in app alerts or reminders, using vibration to increase event perceptibility. Companion feedback is embedded within ongoing interaction, such as swiping, adding smoothness and a sense of engagement rather than conveying explicit information. Positive confirmation feedback verifies that an action has been successfully completed, for example in password entry or fingerprint authentication, and helps establish a clear interaction loop. Negative feedback highlights error or risk, such as authentication failure or restricted access, strengthening sensitivity to system warnings.

3.2 Explicit Perception Layer

The explicit perception layer describes how multisensory feedback produces immediate and consciously accessible effects. A first key dimension is modality combination. Different sensory channels can complement or reinforce each other. The integration of visual and tactile enhances confirmation of actions, while the pairing of tactile and auditory is more effective for alerts and warnings. Three-channel coordination remains more stable in highly demanding or noisy environments. Choosing the appropriate modality combination improves recognizability and allows the system to control the perceptual priority of feedback.

Another important dimension is the level at which visual information changes within the interface. This dimension describes whether the change occurs at the level of a single visual element, within the current interface, or across two or more interfaces. Different levels of change reflect how the system guides user attention. Changes that span across interfaces are more likely to be paired with noticeable haptic or multimodal feedback, which strengthens the user's perception of system state transitions.

The physical characteristics dimension of smartphone vibration is defined by four parameters shown in Fig. 2 and Fig. 3, which are frequency, amplitude, duration, and variation. These parameters describe differences in intensity, density, and rhythmic structure. Proper setting of these parameters helps improve the clarity and distinctiveness of system feedback and forms a structural foundation for later rhythm modeling and mechanism analysis.

The hardware implementation dimension also plays an important role in shaping how explicit feedback is perceived. Even with identical waveform parameters, the actual tactile sensation can differ across devices because of variations in motor type(such as X-axis or Z-axis linear motors, the Taptic Engine, etc.), motor installation position, and device materials. Vibrations produced in metal enclosures often feel crisp and compact, while those in glass enclosures tend to feel softer. These differences may influence how users perceive rhythmic clarity or interpret the intention of the feedback. Therefore, strategies to maintain perceptual consistency need to be considered when designing haptic feedback across devices.

3.3 Implicit Perception Layer

After users experience multimodal haptic feedback, they often form interpretations of system states and emotional responses beyond conscious awareness. The implicit perception layer focuses on the deeper associative mechanism that emerges from sensory experience. Users rely on cues such as rhythm, intensity, and modality coordination to construct judgments about system behavior and to shape their emotional attitudes. This perception layer not only influences how

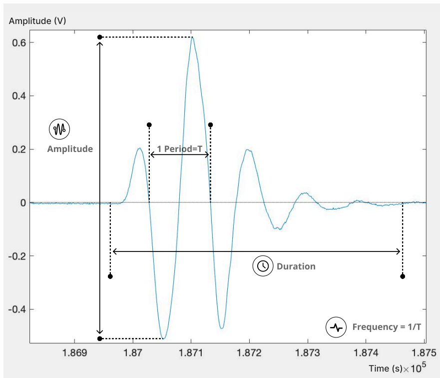

Fig. 2. Vibration Parameter Diagram

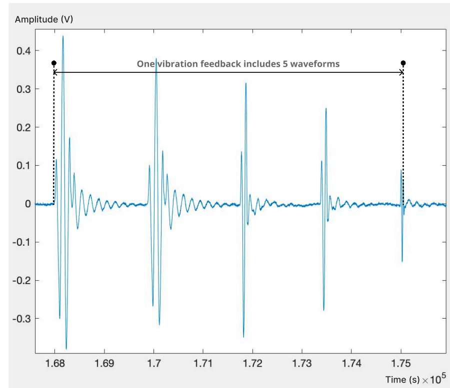

Fig. 3. Vibration Variation Diagram

users recognize interaction intentions but also plays a major role in defining the subjective quality and overall character of haptic feedback.

These associations often appear in the form of metaphors, which this study categorizes into physical metaphors and emotional metaphors. Physical metaphors refer to cases where users map haptic features to familiar physical experiences. For example, the clicking sensation of adjusting an alarm wheel can evoke the rotation of mechanical gears, and the textured feeling at the edge of a swiping gesture can map a damping structure. Such haptic design enhances the sense of physicality in system behavior and makes the interaction feel more natural to users.

Emotional metaphors reflect users' affective interpretations of feedback rhythm and intensity. Feedback that is steady in rhythm and gentle in intensity is often perceived as warm and friendly, making it suitable for accompanying interactions or positive confirmations. In contrast, feedback that is short and strong more easily conveys tension or a warning. This layered emotional perception improves the informational efficiency of haptic feedback and enriches the user's emotional experience.

4 Method

4.1 Devices and Scenarios Selection

To select devices for the study, we considered brand influence, user uasge, and the technology of haptic motor. Three smartphones was chosen, including iPhone 14 Pro Max (Apple Taptic Engine), OnePlus 11 (AAC Technologies CSA0916) and Xiaomi 13 Pro (AAC Technologies ESA1016). These devices differ in structural design, motor types, and material configuration.

For the scenarios, the study focused on typical high-frequency and highly interactive operations in daily use. Ten scenarios were selected, as shown in Table 1, covering functions such as input, swiping, editing, photography, and state feedback. All scenarios were triggered through active user operations rather than passive system notifications. These scenarios also provide clear distinctions in interaction behavior, modality structure, and semantic intention.

Table 1. Smartphone Haptic Feedback Scenarios

No.	Scenario	Behavior	Interaction Intention
1	Keyboard Typing	Tap	Positive Confirmation
2	Alarm Setting	Swipe	Accompanying
3	Contacts Alphabet Index	Swipe	Accompanying
4	Camera Zoom Adjustment	Swipe	Accompanying
5	Camera Shutter	Tap	Positive Confirmation
6	Album Long Press Editing	Tap	Positive Confirmation
7	Apps Long Press Editing	Tap	Positive Confirmation
8	Settings Horizontal Toggle	Swipe	Positive Confirmation
9	Swiping Up to Access Recent Tasks	Swipe	Accompanying
10	Fingerprint Unlock Failure	Tap	Negative Warning

4.2 Scenario Feature Identification

After selecting the scenarios and devices, the study analyzed the ten scenarios using the multisensory haptic feedback framework to identify their key features. This step clarifies the factors that shape user perception and provides the foundation for later variable encoding and model construction.

In terms of behavior, the ten scenarios include short tap confirmation operations as well as continuous navigation that relies on swipe operations, reflecting differences in interaction rhythm and feedback needs. Regarding interaction intention, some scenarios convey the result of a completed action, such as Camera Shutter or Settings Horizontal Toggle. Others emphasize accompanying feedback during the operation, such as Alarm Setting or Camera Zoom Adjustment. The Fingerprint Unlock Failure scenario represents a warning and failure condition.

At the multisensory interaction channel dimension, all scenarios involve both visual and haptic feedback, and some scenarios further incorporate auditory cues to form multimodal coordination. The presentation of visual feedback also varies across scenarios. Some scenarios provide immediate responses within the same interface, while others involve interface transitions at the system level. These differences reflect the varying requirements for feedback salience and attention management.

4.3 Physical Data Collection and Parameter Extraction

Data Collection System The study built a hardware system based on acceleration measurement, as shown in Fig. 4, to collect vibration feedback data from the three smartphones across the typical interaction scenarios. The system uses an ADXL354BZ three axis accelerometer, with sampling focused on the X axis to match the vibration direction of the X-axis linear motors used in all three devices. A Teensy 4.1 serves as the control core to drive the sensor and manage data transmission. The vibration signals are sampled by a Pico 5444D MSO oscilloscope at a sampling rate of 24 kS per second and are then transmitted through a serial connection to a ThinkPad laptop for storage and data analysis.

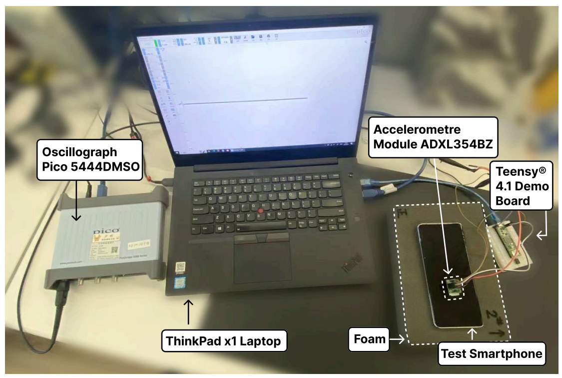

Fig. 4. Vibration Waveform Data Acquisition System

Vibration Parameter Extraction After collecting the waveforms, key physical parameters were extracted. These parameters include peak amplitude, duration, frequency, and variation. Using the Camera Shutter scenario on the Xiaomi 13 Pro as an example, the time-domain plot in Fig. 5 shows a peak to peak voltage of 0.14V and a vibration duration of approximately 0.0083 seconds. Fig. 6 shows the frequency-domain plot obtained through a Fourier transform, which has a fundamental frequency of 270 Hz. Because this waveform contains only one complete vibration cycle, its variation value is 1.

To further quantify perceived amplitude, the measured voltage values were normalized using a perceptual intensity conversion formula. Based on the Weber Fechner law [22], a constant term and base 10 were introduced to obtain the following equation.

$$S = 10 \times \log_{10}\left(\frac{U}{U_{\text{th}}}\right) \tag{1}$$

In this equation, S represents perceptual intensity in dB SL, U is the measured voltage amplitude, and U_{th} is the minimum detectable voltage for the human hand, which was measured as 0.001 volts in this study. The calculated perceptual amplitude for the Xiaomi device in this scenario is 21.46 dB SL. Table 2 lists the four vibration parameters for all three phones in the Camera Shutter scenario.

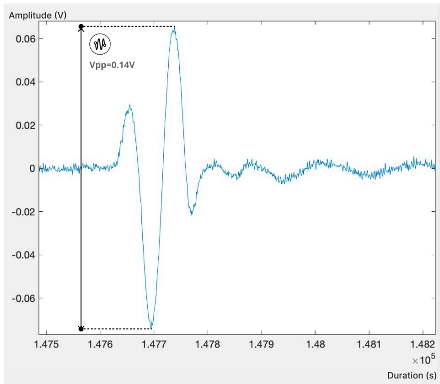

Fig. 5. Time-Domain Plot of the "Camera Shutter" on Xiaomi 13 Pro

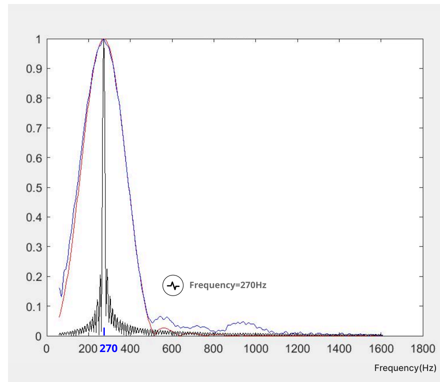

Fig. 6. Frequency-Domain Plot of the "Camera Shutter" on Xiaomi 13 Pro

Table 2. Vibration Parameters in the Camera Shutter Scenario

Smartphones	Frequency (Hz)	Amplitude (dB SL)	Duration (s)	Variation
1	295	19.78	0.0136	2
2	250	21.82	0.0080	2
3	270	21.46	0.0083	1

4.4 User Study and Data Collection

Participants The experiment included ten representative interaction scenarios. To obtain subjective ratings from twelve participants for each scenario, a total of 120 ratings were required. Since each participant evaluated five different scenarios, 24 participants were recruited for the study, including 10 men and 14 women, aged between 20 and 55 years old (M = 28.17, SD = 8.28). Each participant completed five scenarios, resulting in 120 samples across the ten scenarios. All participants were right handed, physically healthy, and reported no tactile perception impairments. They provided informed consent voluntarily and received monetary compensation corresponding to the duration of the study.

Procedure To ensure continuous attention and perceptual sensitivity during the study, each participant completed five scenarios, with each scenario involving two to three smartphones. The total duration for each participant was controlled between 60 and 85 minutes. The experimental procedure is shown in Fig. 7.

Questionnaire Participants completed a basic information form that included demographic variables such as gender and age.

Instructions The experimenter briefly introduced the overall procedure, scenario objectives, and rating mechanism, ensuring that participants fully understood the process before starting the trials.

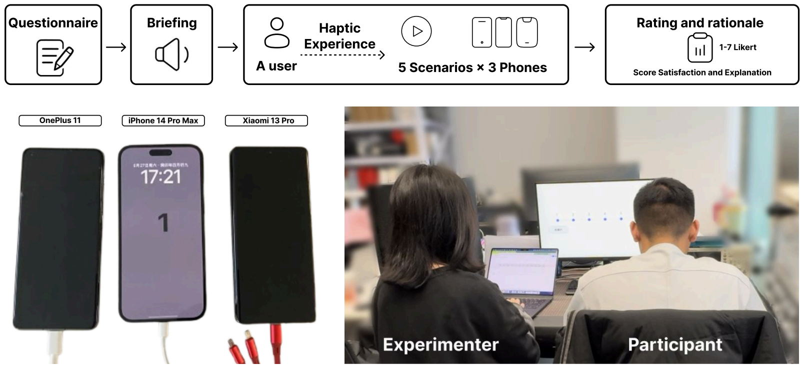

Fig. 7. User Study Procedure, Smartphones, and Environment

Haptic Experience Participants experienced the vibration feedback of each scenario on different smartphones. To strengthen perceptual contrast, the order of devices was randomized. Participants were encouraged to repeat the experience when needed to form a clear impression.

Rating and Explanation After each experience, participants rated the feedback of each device in that scenario on a seven point satisfaction scale and provided a brief explanation of the reason for their rating. These explanations supported deeper interpretation of their preferences.

4.5 Data Preprocessing and Coding

The study standardized and encoded the collected data based on the proposed multisensory haptic feedback framework. Two types of variables were included. The first type was continuous variables that describe the physical features of haptic feedback. The second type was categorical dummy variables that represent interaction behavior and device implementation characteristics.

Frequency, amplitude, duration, and variation were treated as continuous variables. They reflect the density, intensity, temporal length, and structural complexity of the vibration, and their raw measured values were directly used for modeling. User ratings were collected on a seven point Likert scale and were used as the dependent variable in the regression model.

Other variables related to modality features, interface structure, behavior type, interaction intention, and device type were encoded as categorical dummy variables. For the multisensory interaction channel, the value was set to 1 if auditory information was present and 0 otherwise. For the visual information level, scenarios involving interface transitions were coded as 1, while scenarios within a single interface were coded as 0. For user behavior, tap operations served as the reference group, and swipe operations were coded as 1. For interaction intention, confirmation scenarios served as the baseline, while accompanying and warning scenarios were coded as 1. At the device level, Apple served as the reference group, and OnePlus and Xiaomi were represented by two variables named Dev_ONE and Dev_MI. Table 3 shows the variable coding for Keyboard Typing (Scenario 1) and Fingerprint Unlock Failure (Scenario 10). Because the iPhone system does not support Fingerprint Unlock Failure, it was not included in data collection for that scenario.

Table 3. Variable Coding for Scenario 1 and Scenario 10

	Freq (Hz)	Amp (dB)	Dur (s)	Var ation	Mod _AVT	UI _Cross	Dev _ONE	Dev _MI	Act _Cross	Int _Comp	Int _Alert	Sat
1	270	23.80	0.0104	1	1	0	0	0	0	0	0	5.42
1	292	28.81	0.0068	1	1	0	1	0	0	0	0	4.61
1	160	28.57	0.0125	1	1	0	0	1	0	0	0	4.33
10	255	28.51	0.0450	3	1	1	1	0	0	0	1	4.50
10	531	29.08	0.0700	5	0	0	0	1	0	0	1	3.75

5 Results and Findings

5.1 Descriptive Statistics

Satisfaction Comparison A descriptive analysis was conducted on the users' subjective ratings. Fig. 8 presents the mean satisfaction scores of the three devices across the ten scenarios. Overall, the iPhone 14 Pro Max consistently achieved the highest ratings in all scenarios, with means above 5.0. The OnePlus 11 and Xiaomi 13 Pro received lower scores, with several scenarios falling below 4.0, indicating notable differences between smartphones. Scenario level differences were also evident. Alarm Setting (Scenario 2) received particularly high ratings, whereas Swiping Up to Access Recent Tasks (Scenario 9) and Fingerprint Unlock Failure (Scenario 10) showed consistently lower evaluations.

Parameter Correlations To explore how physical parameters influence user satisfaction, Pearson correlation coefficients between the four vibration parameters and satisfaction were calculated, as shown in Fig. 9. The results indicate that except for frequency, amplitude, duration, and variation all show negative correlations with satisfaction. Duration ($r = -0.32$) and variation ($r = -0.23$) exhibit similar trends, suggesting that users may prefer vibration patterns that are shorter, simpler, and clearer. This tendency aligns with the emphasis of the Explicit Perception Layer which highlights the role of temporal structure in enhancing perceptual clarity. The findings imply that rhythm optimization may be valuable for improving user experience.

5.2 Hierarchical Regression Model Analysis

Layered Logic To compute how different dimensions influence user satisfaction with haptic feedback, a four layer regression model was built based on the proposed perceptual framework. Physical parameters of vibration constitute the first

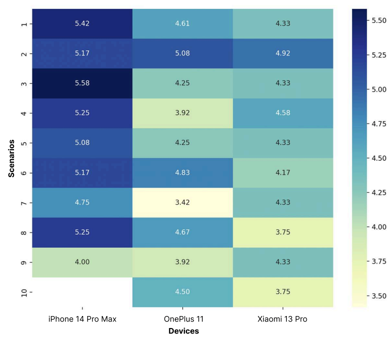

Fig. 8. Satisfaction Distribution of Three Devices Across Ten Scenarios

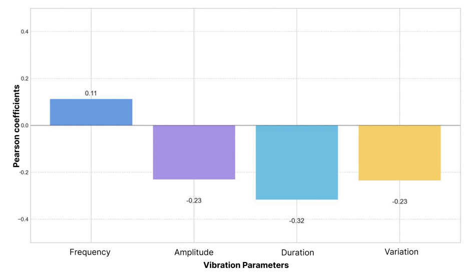

Fig. 9. Pearson Correlation Coefficients Between Vibration Parameters and User Satisfaction

layer. The second layer adds explicit perception design factors, namely modality combination and interface level changes. Device type forms the third layer and reflects differences in hardware implementation. Behavior type and interaction intention make up the fourth layer and describe user interaction factors. Variables were entered stepwise, and model contribution was examined through changes in ΔR^2 squared and F statistics.

Table 4. Hierarchical Regression Model Results

Predictor	Model 1		Model 2		Model 3		Model 4	
	β	t	β	t	β	t	β	t
Frequency	0.604	1.868	0.487	1.588	0.289	1.078	0.165	0.531
Amplitude	-0.281	-1.527	-0.300	-1.683	-0.008	-0.046	0.095	0.441
Duration	0.192	0.412	0.437	0.937	-0.069	-0.158	-0.697	-1.171
Variation	-0.765	-1.300	-0.931	-1.641	-0.306	-0.581	-0.102	-0.160
Mod_AVT			0.295	1.698	0.148	0.961	0.067	0.382
UI_Cross			-0.253	-1.247	-0.171	-0.991	-0.098	-0.459
Dev_ONE					-0.569	-2.730**	-0.765	-3.120**
Dev_MI					-0.624	-3.270*	-0.734	-3.562**
Act_Slide							0.281	0.899
Int_Comp							-0.108	-0.349
Int_Alert							0.553	1.179
R^2	0.251		0.398		0.615		0.666	
ΔR^2	0.251		0.148		0.217		0.051	
F	2.008		2.427		3.993**		3.078*	

Note: $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

Results The results of the hierarchical regression model are shown in Table 4. The basic physical parameters of vibration, including frequency, amplitude, duration, and variation, explained about 25% of the variance in user satisfaction ($\Delta R^2 = 0.251$). After adding perceptual design factors, including modality combination and interface level, the explanatory power increased to

40% ($\Delta R^2 = 0.15$, $p = 0.090$), indicating that design level variables may influence subjective perception. When device type was further included to represent hardware implementation, the model fit rose to 62% ($\Delta R^2 = 0.22$, $p = 0.006$). Satisfaction for the OnePlus 11 and Xiaomi 13 Pro was significantly lower than for the iPhone 14 Pro Max ($\beta = -0.57$ and -0.62, $p < 0.01$), suggesting a strong impact of hardware implementation on the overall experience.

Although behavior type and interaction intention did not produce a significant improvement in model fit ($\Delta R^2 = 0.05$, $p = 0.480$), they still offer structural value by helping organize contextual differences across scenarios. The final four layer model reached an R^2 of 0.666. This shows that the proposed perceptual framework can explain nearly two-thirds of the satisfaction differences, with most contributions coming from the physical, perceptual design, and hardware layers. These results provide supporting evidence for the framework and offer useful guidance for future haptic design in smart devices.

5.3 Qualitative Data Analysis

We analyzed users' tactile perception in representative interaction scenarios through open coding and thematic induction. Interviews with 24 participants across 10 scenarios were coded and grouped based on interaction intent. Three categories emerged: fine adjustment, rapid tapping, and functional switching. For each category, we identified perceptual keywords and common preference patterns.

For fine adjustment scenarios such as Alarm Setting, Contact Alphabet Index, and Camera Zoom Adjustment, users were highly sensitive to the clarity of the tactile granularity and the stability of the rhythm. Participant P10 described the Alarm Setting feedback as "a tight, condensed drop of water," which helped precisely locate the desired point. In Camera Zoom Adjustment, P19 noted that the vibration "gradually intensifies with the zoom level," creating a "natural and perceivable progression." Some users also reported that overly heavy and sticky textures disrupted smooth movement, especially during fast swiping, leading to a sense of interruption.

Rapid tapping scenarios, including Keyboard Typing and Apps Long Press Editing, emphasized crispness, immediacy, and consistency. In the Keyboard Typing, P5 stated that even slight latency "breaks the entire rhythm of writing." Frequent negative descriptions such as "dragged," "mushy," and "too spaced out" from participants P2, P8, and P11 indicated that any delay undermines input fluency. In Apps Long Press Editing, P2 described an ideal feedback as "like a check mark being completed," delivering a clear and decisive completion cue.

Functional switching scenarios such as Settings Horizontal Toggle, Camera Shutter, and Fingerprint Unlock Failure focused on synchronization between feedback and on-screen actions. Settings Horizontal Toggle were often described as similar to "pulling a zipper," and P19 highlighted that the feeling creates "a sense of ceremony," reinforcing the logic of change. For Camera Shutter, P11 depicted the vibration as "a fax swipe," offering immediate confirmation. In contrast, many users found the feedback for Fingerprint Unlock Failure to be confusing, reporting unclear pacing and abrupt segments that made it difficult to infer the system's intent.

6 Discussion

6.1 Synergy between Parameter Design and Hardware Differences

The hierarchical regression shows that vibration frequency, amplitude, duration and rhythmic variability explain 25.1% of the variance in user satisfaction, confirming these parameters as the physical substrate of haptic experience. Adding device type increases R^2 by a further 21.7%, indicating that an identical parameter set can feel completely different across handsets. The cause is not simply motor quality; rather, it is the whole hardware–software stack. Motor specification, mounting location and housing material jointly determine how vibration energy propagates and decays, while drive-layer shaping and latency suppression magnify those disparities.

Among the three tested phones, iPhone 14 Pro Max performs best. Its custom Taptic Engine, rigid mid-frame and glass back produce short, crisp and consistent feedback. When the motor sits far from the grip point, the shell absorbs vibration, or the trigger signal is delayed, users describe the sensation as "muffled" or "trailing", even at comparable amplitudes. High-quality haptics therefore require meticulous parameter tuning and implementation optimisation. Cross-device or multi-terminal design must calibrate hardware capability and scheduling in parallel to preserve rhythm and recognisability.

6.2 Rhythm–Intent Mapping

Scenarios with high satisfaction typically feature concise vibrations tightly synchronized with the gesture, whereas low-scoring warning feedbacks tend to be overly long or rhythmically fragmented. The negative correlations between satisfaction and both duration and variability confirm that users are more sensitive to temporal structure than to intensity or frequency in isolation.

Different interaction intents prefer distinct rhythmic patterns. A single short pulse works for confirmation, evenly spaced weak pulses suit continuous accompaniment, and dense high-contrast rhythms communicate warnings or errors. These patterns constitute a basic rhythm–intent map. Designers should start from interaction semantics, specify the temporal characteristics of the target action, and then derive pulse count and spacing that balance discriminability with comfort while preserving rhythmic coherence.

6.3 Layered Features of User Perception

Interviews reveal three jointly acting factors. Timeliness and rhythm coherence dominate. When vibration is synchronous and beat-stable users describe it as "immediate" and "seamless"; any delay beyond the perceptual threshold is judged "sluggish", decoupling action and feedback. Spatial focus and structural simplicity come next: feedback that stays near the touch point and has clear pulses is "neat", whereas device-wide or multi-segment feedback feels "abrupt" or "fragmented". Finally, a balance between force and granularity matters. Medium strength with distinct grains is likened to a "heartbeat", reinforcing confirmation; excessive force induces discomfort, whereas weak or blurry pulses erode recognisability.

Mechanistically, timeliness aligns with the explicit layer's need for rhythmic synchrony, spatial focus reduces attentional load, and force granularity tuning addresses the implicit layer's comfort threshold and affective tone. Haptic design should first ensure trigger latency and rhythm precision, then control propagation range and waveform simplicity, and finally fine-tune strength and granularity to achieve both recognisability and pleasure across scenes and devices.

6.4 Design Applications and Cross-Device Prospects

The proposed Use Interaction – Explicit Perception – Implicit Perception Framework offers a systematic route for haptic design. Practitioners can begin with user behaviour and intent, locate the target semantics, map them onto perceptual channels, visual hierarchy, parameter bounds and then verify hardware feasibility. The final sensation remains subject to physical and affective metaphors in the implicit layer. The framework thus supports causal design from behavioural origin to perceptual outcome, enabling rapid classification and generation of haptic strategies in everyday scenarios.

Its extensibility is high. By adapting motor type and materials, designers can transplant feedback to tablets, wearables or VR devices without altering interaction logic. The same structure also informs channel coordination, feedback priority and perceptual consistency in multimodal work, laying a theoretical foundation for cross-platform haptics.

6.5 Limitations and Future Work

This study presents scope and methodology limitations that require validation in broader interaction contexts. While the study examined ten scenarios and three mainstream devices, the results may not represent the diversity of system configurations or technologies. Future work will extend the framework to more devices, vibration systems, and multiple scenarios to assess its applicability. Current modeling focused on four core physical features. Further research will incorporate finer features such as onset/offset ramps, directionality and propagation, jointly modeled with device structural attributes to better align physical signals with perceptual layers and behavioral intent.

Qualitative analysis has not yet established systematic links between subjective language and physical parameters. Future work will integrate semantic modeling with physiological data to support multimodal evaluation and will explore adaptive tactile generation that responds to scenario demands, user states, and device properties.

Overall, this work verifies the feasibility of a multisensory haptic framework for smartphones. Future research will prioritize multi-device generalization, finer parameter modeling, and cross-modal adaptive feedback to build a scalable foundation for mobile haptic interaction.

7 Conclusion

This study proposes and validates a multisensory haptic design framework for structured vibration feedback on smartphones. The framework integrates user intention, rhythmic structure and perceptual features to build a mapping path. It provides systematic support for improving the adaptability and expressive accuracy of feedback. Through cross device experiments on ten representative scenarios and three mainstream smartphones, combined with vibration measurements, satisfaction ratings and interview data, the study demonstrates that the framework explains user experience differences well. Compared with traditional approaches that rely on intuition or focus only on vibration parameters, this work highlights the importance of grounding feedback design in task context, functional goals and multisensory integration. Future research can expand perceptual dimensions and device adaptation strategies to enhance the role of haptic design in multimodal and multi device experiences.

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