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南方科技大学 · 中国深圳
Southern University of Science and Technology Shenzhen, China

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主办单位：世界华人华侨人机交互协会（ICACHI）、南方科技大学
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HapticMetric: A Smartphone Haptic Experience Computing System

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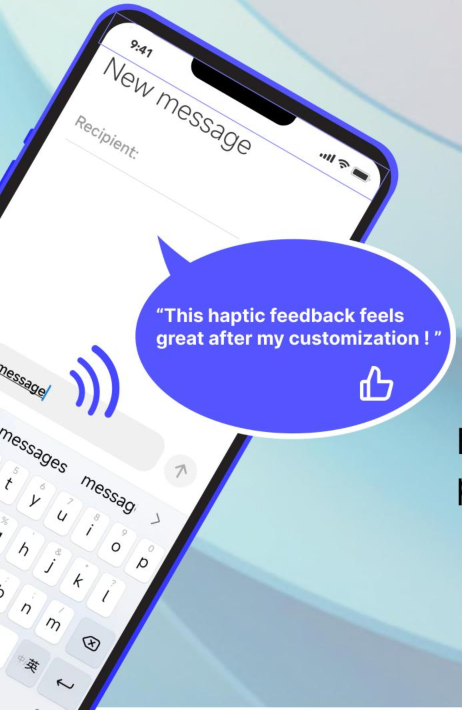
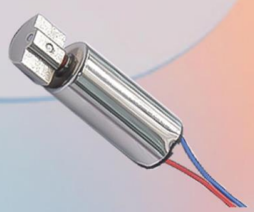
Background Haptics Play an Essential Role in Smartphones

Smartphones widely use haptic feedback in features like typing and app editing. Modern devices incorporate advanced X-axis linear actuators to enhance the vibration experience, with some manufacturers adopting ultra-wide versions to meet rising user demands. Both industry and academia focus on optimizing vibration design, targeting frequency and intensity to improve user perception and experience. Designers aim to better align haptic feedback with real-world smartphone interactions.





Miniaturization →

Miniaturization →

Eccentric Motors

Eccentric Wheel within the Vibration Motor

X-axis linear actuator

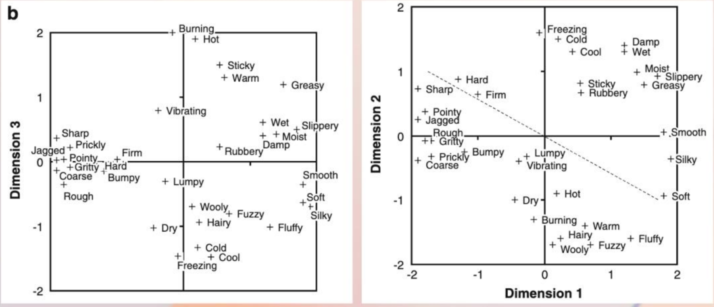
Both industry and academia focus on optimizing vibration design, targeting frequency and intensity to improve user perception and experience. Designers aim to better align haptic feedback with real-world smartphone interactions.

Background

However,When designing vibrations, how should researchers and designers describe smartphone haptics? How can they establish a connection between vibration design and user perception in the practical contexts of smartphone usage?

Labels			Pressure Features
absorbent	bumpy	compressible	Maximum
crinkly	fuzzy	hairy	Minimum
metallic	nice	porous	Greatest slope change
scratchy	slippery	smooth	Variance
solid	springy	squishy	Mean
textured	thick	thin	Skewness
hard	cool	rough	Kurtosis
sticky	soft	unpleasant	

Wu et al.

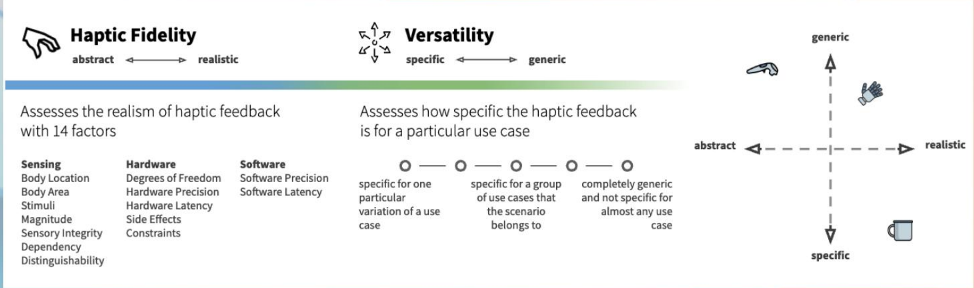


Guest et al.

Table 2: List of 13 adjective pairs used for adjective rating in E ment II (translated from Korean to English).

Pair No.	Adjective 1	Adjective 2
1	slow	fast
2	sparse	dense
3	blunt	sharp
4	bumpy	smooth
5	hard	soft
6	jagged	aligned
7	thick	thin
8	vague	distinct
9	heavy	light
10	deep	shallow
11	dark	bright
12	gentle	brisk
13	dull	clear

Hwang et al.



Muramatsu et al.

Better smart phone vibration experiences

Quantify the user's subjective experience data

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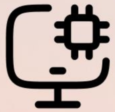


Obtain a psychophysical computation method

→

Guide the future design of haptic scenes.

we hope to quantify the user's subjective experience data to obtain a psychophysical computation method that can guide the future design of haptic scenes.

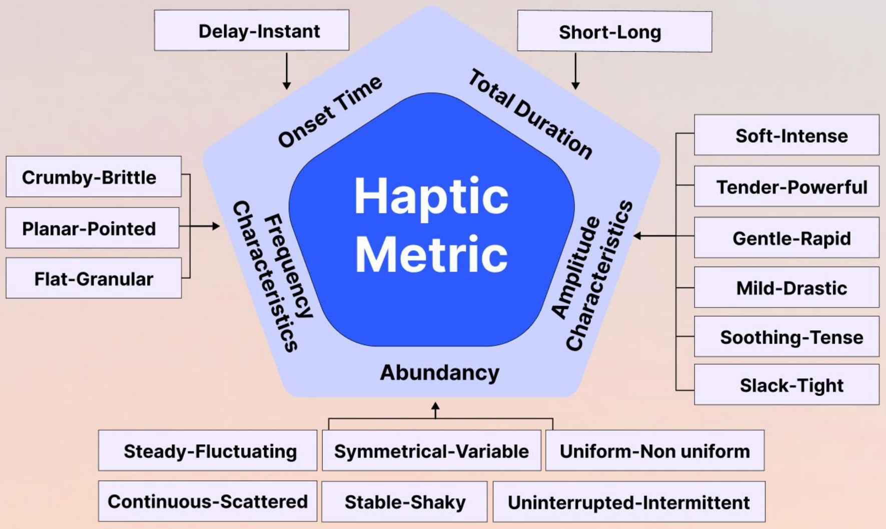
Overview

This paper presents the following contributions.

We present
(1) HapticMetric, a smartphone-based haptic experience computing system, integrating 5 physical factors and 17 adjective pairs linked to vibration scenarios.

(2) User studies with 144 trials across 12 vibration scenarios on 4 smartphones to refine and validate the system.

(3) Psychophysical metrics to guide and enhance haptic experience design for users and designers.

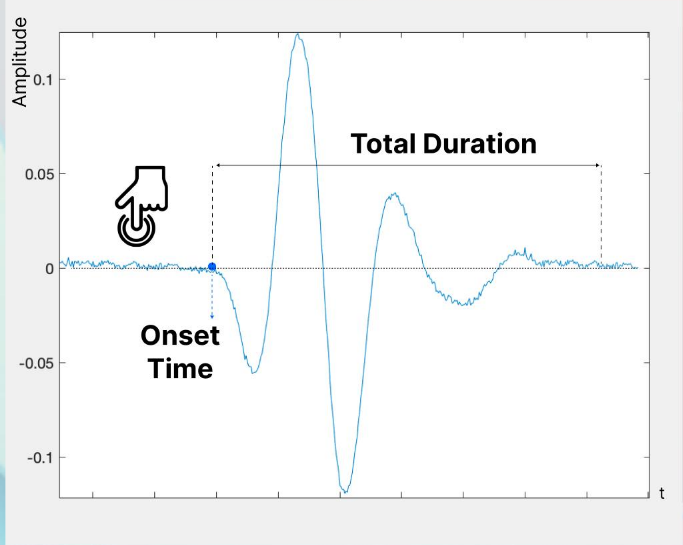


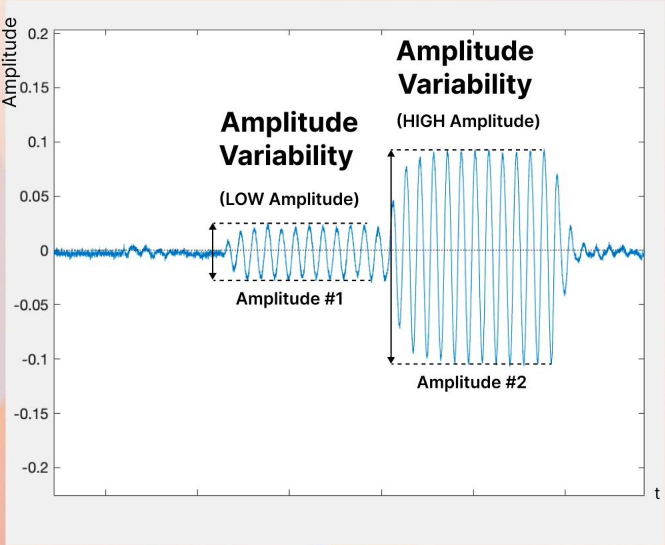
Haptic Metric

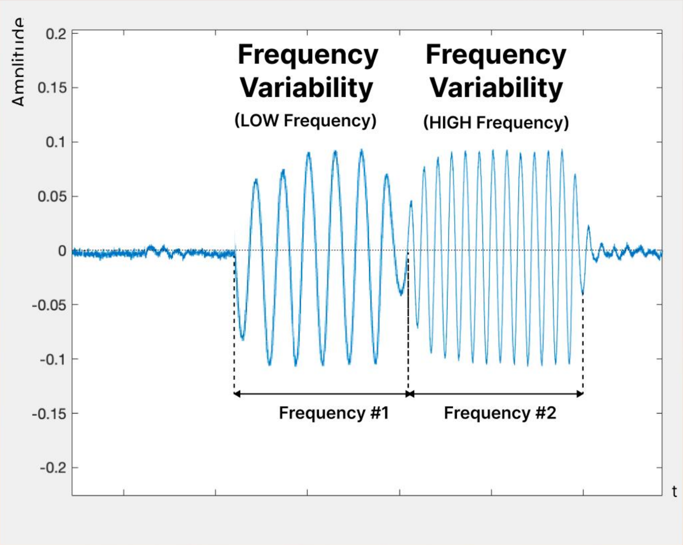
Study process

Study Design Identify the Physical Factors

We categorize the key physical factors of smartphone vibration waveforms, 8 physical factors of smartphone vibration







Onset Time: The response time.
Total Duration: The overall length.

Overall Amplitude: The overall perception of amplitude.

Overall Frequency: The overall perception of frequency.

Add four:

Amplitude Variability: The degree of amplitude fluctuation.
Frequency Characteristics: Specific frequency attributes like frequency range, representing periodicity or rhythm.

Frequency Variability: The degree of frequency fluctuation.
Amplitude Characteristics: Specific amplitude attributes like mean amplitude and peak amplitude, representing intensity.

Study Design Select Sensory Adjectives

We have selected six adjectives corresponding to the **six Foundational Physical Factors** to vividly describe the psychological perceptions elicited by smartphone vibrations. For the **two Specialized Physical Factors**, "Amplitude Characteristics" and "Frequency Characteristics," we have chosen additional adjectives through a literature review, aiming to enhance user perception and expand the possibilities for waveform design.

6 Foundational Physical Factors	**Onset Time**	Delay	Instant
	Total Duration	Short	Long
	Overall Amplitude	Tender	Powerful
	Overall Frequency	Crumby	Brittle
	Amplitude Variability	Steady	Fluctuating
	Frequency Variability	Symmetrical	Variable
2 Specialized Physical Factors	**Amplitude Characteristics**	Near to Far-Far to Near, Weakening-Strengthening, Uniform-Non-uniform, Soft-Intense, Uninterrupted-Intermittent	
	Frequency Characteristics	Disperse-Concentrated, Gentle-Rapid, Stable-Shaky, Continuous-Scattered, Mild-Drastic, Soothing-Tense, Planar-Pointed, Jarless-Elastic, Sparse-Dense, Flat-Granular, Slack-Tight, Round-Sharp, Smooth-Textured	

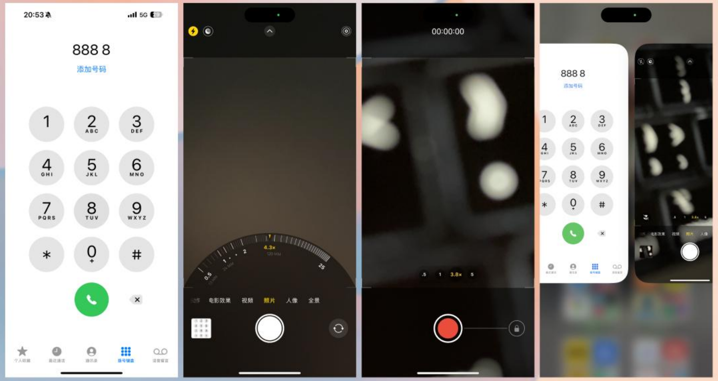
Study Design Smartphones and Scenarios Selection

We selected four smartphones by searching for the best-selling brands in the global market in 2023

iPhone 14 Pro Max (Apple Taptic Engine)
Samsung Galaxy S23 Ultra (AAC Technologies SLA 0620)
OnePlus 11 (AAC Technologies CSA 0916)
Xiaomi 13 Pro (AAC Technologies ESA 1016)

Pressing

Sliding



Sliding Category: downward, upward x3
Alarm Setting, Contact Alphabet Index, Swiping Up to Access Recent Tasks

Short Press x2
Camera Shooting, Keyboard Typing

Sliding Category: leftward, rightward x2
Horizontal Switch Setting, Camera Zoom Adjustment

Long Press x5
Camera Continuous Shooting, Album Long Press Editing, Apps Long Press Editing, Wired Charging, Long Press to Power Off

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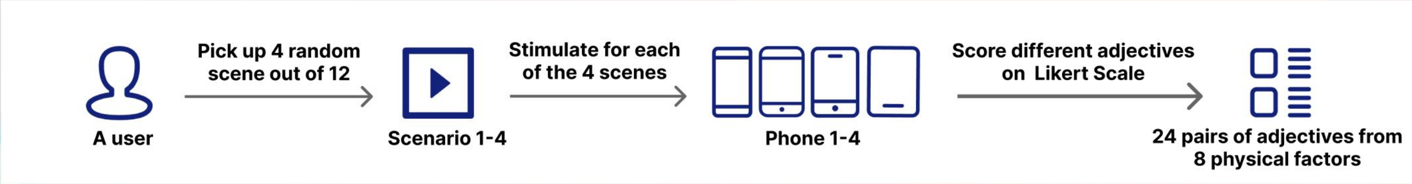
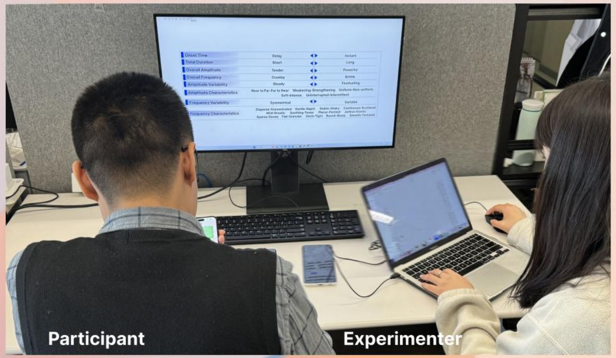
User Study

Procedure



- Participants：36 (15 females, 21 males), aged 19-55 (M = 28.06, SD = 6.88).
- Scenarios: 12 scenarios, 144 total trials, 4 scenarios per participant.



Our goal is to refine our computing system from the user's perspective after collecting data, optimizing the selection of physical factors and adjectives.

- Randomly select 1 of 12 scenarios.
- Compare haptic feedback from 4 smartphones (single/double-handed).
- Rate 24 adjective pairs on a 7-point Likert scale.

Data Cleaning and Analysis

Data Collection: 576 datasets (12 scenarios × 12 trials × 4 smartphones).

Data Cleaning:

- Used **Z-score** method; removed 40 outliers (>2 SD).
- Final dataset: 536 samples.

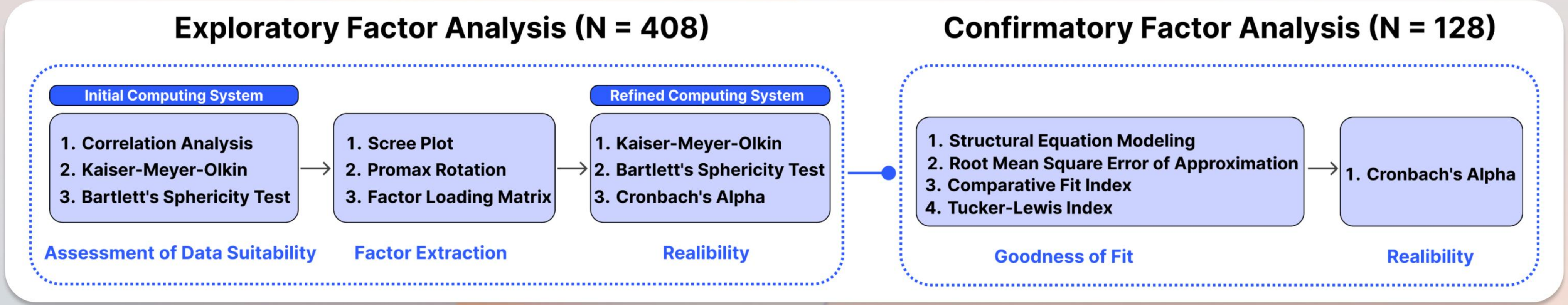
Data Analysis (Factor Analysis):

- EFA(**Exploratory Factor Analysis)** Sample: 408 samples.
- CFA (**Confirmatory Factor Analysis)**Sample: 128 samples.

Onset Time	Delay	Instant
Total Duration	Short	Long
Overall Amplitude	Tender	Powerful
Overall Frequency	Crumby	Brittle
Amplitude Variability	Steady	Fluctuating
Amplitude Characteristics	Near to Far-Far to Near Weakening-Strengthening Uniform-Non-uniform Soft-Intense Uninterrupted-Intermittent	
Frequency Variability	Symmetrical	Variable
Frequency Characteristics	Disperse-Concentrated Gentle-Rapid Stable-Shaky Continuous-Scattered Mild-Drastic Soothing-Tense Planar-Pointed Jarless-Elastic Sparse-Dense Flat-Granular Slack-Tight Round-Sharp Smooth-Textured	

Factor Analysis Procedure

The data was divided into two parts: a sample(N=408) for Exploratory Factor Analysis (EFA) and an independent sample (N=128) for Confirmatory Factor Analysis (CFA).



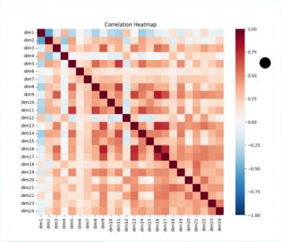
Are the factors correlated (i.e., are there correlations among the adjective pairs)?

Which factor do the 20 adjective pairs belong to?

Do the new samples still apply to the validation of EFA?

Exploratory Factor Analysis

Assessment of Data Suitability



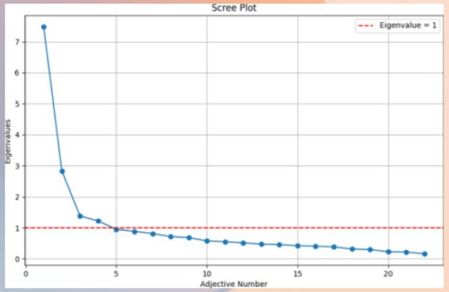
- Correlation Analysis Heatmap

  There were 250 correlation coefficients greater than 0.3.

- Kaiser-Meyer-Olkin Test： KMO=0.88
- Bartlett’s test of Sphericity： $p < 0.05$

Factor Extraction

We excluded “Onset Time” and “Total Duration” due to their representation by single adjective pairs and strong independence from other factor categories.



- Scree Plot indicates there are 3-5 factors in 22 pairs of adjectives.
- Used Principal Axis Factoring with promax rotation due to high intercorrelations (50% > 0.3).
- Compared 3, 4, and 5-factor models; 3-factor model showed best fit and interpretability.

Exploratory Factor Analysis

System Refinement and Reliability

Refinement criteria:

- Retained adjectives with loading > 0.50.
- Removed adjectives with significant loadings on multiple factors.

15 ADJECTIVES LOADING SCORE ON THEIR RESPECTIVE FACTORS

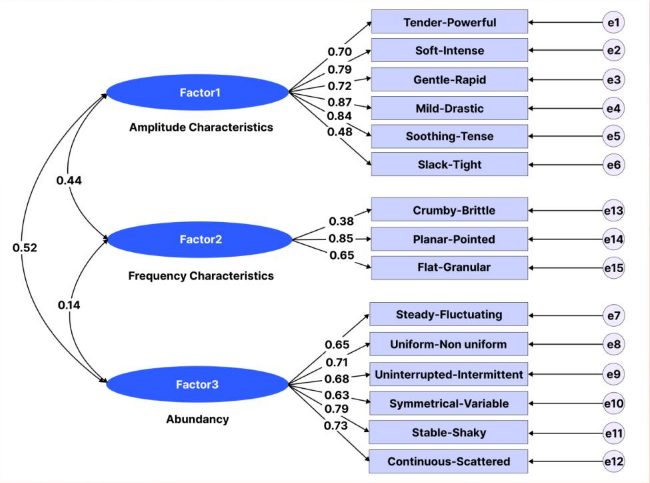
Adjectives	Loading Score		
	Factor1	Factor2	Factor3
Tender—Powerful	0.6891		
Soft-Intense	0.774		
Gentle-Rapid	0.8419		
Mild-Drastic	0.8707		
Soothing—Tense	0.7517		
Slack-Tight	0.6822		
Crumby—Brittle		0.3971	
Planar-Pointed		0.7657	
Flat-Granular		0.5058	
Steady—Fluctuating			0.7022
Uniform—Non-uniform			0.7871
Uninterrupted-Intermittent			0.5274
Symmetrical-Variable			0.8622
Stable-Shaky			0.6377
Continuous-Scattered			0.7134

According to these refinement criteria, we screened 22 words down to 15 words.

Confirmatory Factor Analysis

Structural Equation Modeling (SEM)

We used Structural Equation Modeling(**SEM)** in AMOS to validate the model (N=128), confirming the structure, effectiveness, and independence of the three factors: Amplitude, Frequency, and Abundancy.



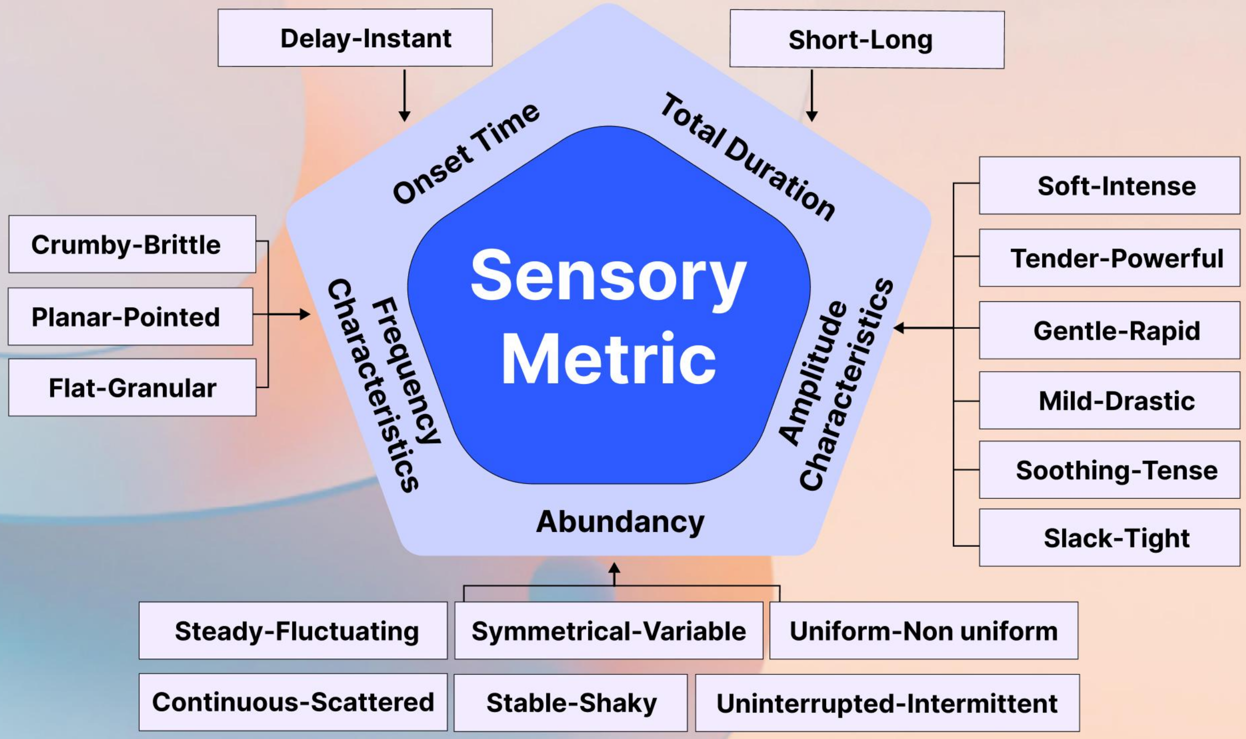
Goodness of Fit

- Root Mean Square Error of Approximation(RMSEA) = 0.078 (reasonable fit; RMSEA ≤ 0.05).
- Comparative Fit Index (CFI) = 0.924, Tucker Lewis Index (TLI) = 0.905 (both > 0.90; good performance).

This further proves that the final 3 factors and 15 words we identified are reliable.

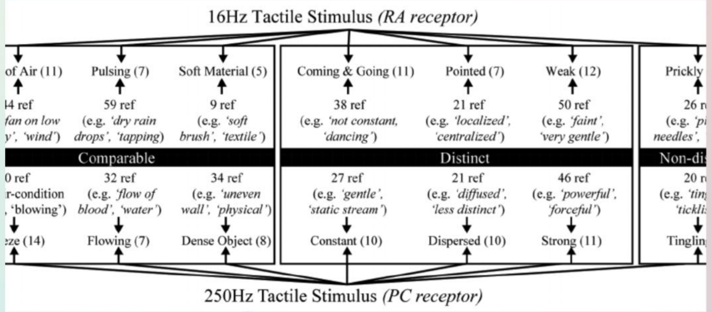
Refined Computing System

We consolidated related factors into Amplitude, Frequency, and Abundancy, and merged time-related factors into a revised 5-factor system. To validate the reliability of this system, we calculated Cronbach's alpha, which yielded an overall value of 0.85 (most sub-scales: $\alpha > 0.8$; all sub-scales: $\alpha > 0.6$). This demonstrates that the 5-factor model is robust and reliable for evaluating haptic experiences.



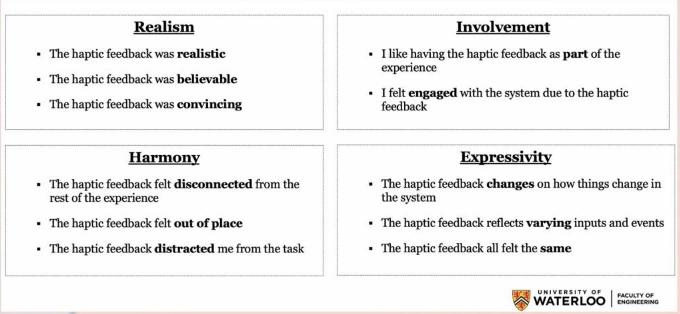
Discussion

Differences with Other Vibration Perception Models and Systems



Marianna Obrist et al.

Guest et al.



Ahmed et al.

Breezy	Distressing	Gritty	Painful	Sexy	Tickly
Bristly	Doughy	Grooved	Parched	Shaggy	Tight
Brittle	Downy	Gummy	Pat	Shallow	Tortuous
Bumpy	Drenched	Hairy	Pebbly	Sharp	Tough
Burning	Dry	Hard	Persistent	Significant	Tranquil
Bushy	Dull	Heavenly	Pert	Silky	Transient
Callous	Effervescent	Horny	Placid	Sinuous	Translucent
Calming	Elastic	Hot	Plastic	Slack	Trim
Chafed	Enjoyable	Hydrous	Pleasurable	Slick	Uneven
Chalky	Erotic	Icky	Pliable	Slimy	Unyielding
Chapped	Evocative	Icy	Plush	Slippery	Vague
Chilly	Exciting	Impacting	Pointed	Sludgy	Velvety
Clammy	Feathery	Important	Pointy	Slushy	Veneered
Clean	Filmy	Indented	Poked	Smear	Vibrating
Clear	Fine	Inflexible	Polished	Smooth	Viny
Coarse	Firm	Intense	Porous	Soapy	Viscous
Cold	Flabby	Irregular	Pounding	Soft	Vivid
Comfortable	Fleecy	Irritable	Powdery	Solid	Warm
Compliant	Fleeting	Irritating	Pressed	Soothing	Watery
Compressed	Fleshy	Itchy	Pressure	Spiky	Waxy
Consequential	Flexible	Jagged	Prickly	Spiny	Weird

Dimensional Categorization

HapticMetric organizes adjectives systematically and links them to physical factors.

Focus on Physical Descriptors

Uses only objective adjectives to describe physical perceptions.

Direct Connection to Physical Factors

Explicitly ties its five factors to measurable physical vibration properties.

No Emotional Bias

HapticMetric avoids emotional descriptors, focusing solely on objective, measurable physical perceptions.

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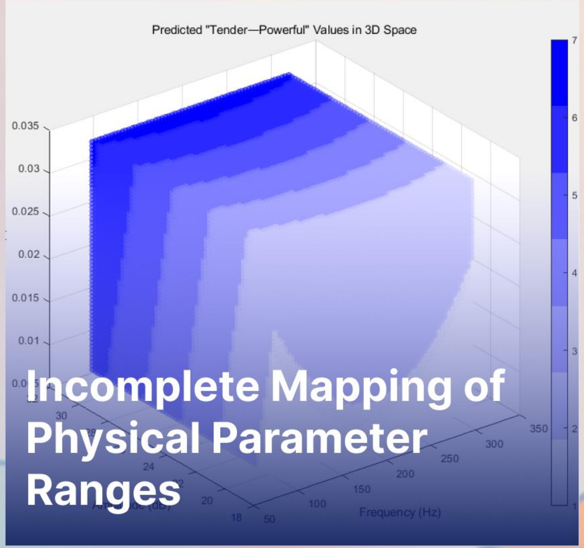
Discussion
Limitation and Future Work

Hardware Influence on Perception

Haptic experience is affected by hardware (motor type, placement, phone materials). Future work will control these factors to isolate their impact.

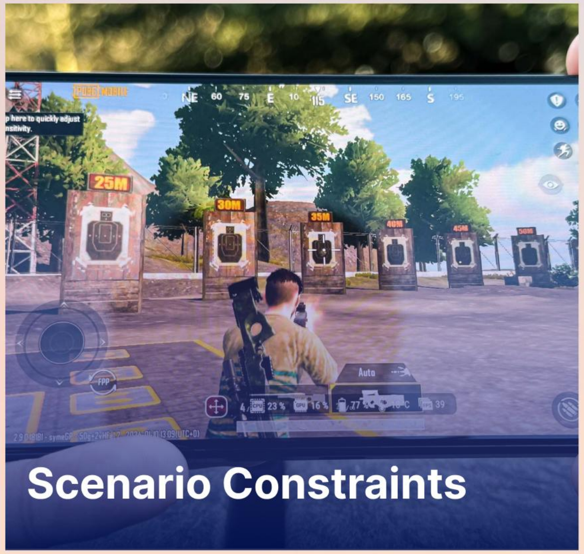


Incomplete Mapping of Physical Parameter Ranges

Specific ranges for physical factors (e.g., duration, frequency) are undefined. Future research will establish these to build a complete design guideline.

Limited Personalization

User preference variability is noted but not fully explored. Developing customizable feedback settings is a key direction.



Scenario Constraints

Focused on system vibrations; future work will include notifications, gaming, and music-related scenarios to broaden applicability.

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Thank you !