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Sensory Perception of Surface Textures in Handheld Operational Products: A Case Study of E-Bike Handgrips

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ABSTRACT

Handheld operational products including bicycles, e-bikes, and other personal mobility devices, the grip and tactile perception between hands and the product's handle have a direct impact on safety, comfort, and psychological state. While existing studies often focus on handle shape and size, relatively little attention has been given to the impact of surface textures. This research aims to fill that gap by investigate whether different surface texture can enhance anti-slip performance, comfort, and emotional stability under different usage contexts. A mixed-methods approach was employed. Twenty participants were recruited for two experimental sessions: i) Participants performed a simulated riding task under normal and slippery conditions. A seven-point Likert scale gathered subjective feedback on comfort, visual impressions, and anti-slip performance. Meanwhile, electromyography (EMG) recorded grip force to quantify the force levels associated with each texture; ii) Participants first watched an e-bike accident video to elicit an emotional response. They then completed a short real-world driving task using each of the three handgrips. During this session, galvanic skin response (GSR) was monitored to capture fluctuations in emotional arousal, and brief interviews before and after provided additional qualitative insights into user experience and perceived safety. Pre- and post-task interviews provided qualitative insights. Results revealed distinct advantages for each texture. Convex grips enhanced control and confidence, particularly in slippery scenarios, and required less muscular effort. Concave grips offered superior comfort during prolonged use. Smooth grips were acceptable in dry conditions but led to uncertainty and higher perceived exertion when wet. GSR and interview data suggested convex textures contributed to greater emotional stability. This study highlights the critical role of texture in shaping both functional and emotional user experiences. Convex textures are ideal for scenarios requiring grip security, while concave designs are preferable for sustained comfort. Findings can inform the design of a wide range of handheld products, improving safety and user satisfaction. Future research can investigate variations in concavity and convexity depth, as well as diverse user demographics and additional physiological metrics, to refine texture-based design strategies. By integrating these user-centered findings into product development, designers and engineers can more effectively meet the functional and emotional needs of individuals across various handheld operational contexts.

Keywords: E-bike, Handheld operational products, Human factors engineering, Surface texture, Haptic feedback, Physiological emotions

INTRODUCTION

In modern life, handheld products are ubiquitous, covering a wide range of fields—from everyday tools to control components in transportation. When people operate these products, they not only focus on their basic functionality but also increasingly value tactile perception, operational comfort, and overall user experience. Haptic perception plays a crucial role in object recognition, as it is influenced by tactile stimuli and neuronal excitability (Bahar and Owain, 2021). Researchers have confirmed that the shape and size of handheld product grips significantly affect users' sense of security, comfort, and psychological state (Zuo et al., 2016). Additionally, surface texture, as one of the key factors, is directly related to users' perception during gripping and operation. However, existing literature remains insufficient in exploring the effects of surface texture on users' force levels and physiological emotions in dynamic usage scenarios.

The role of surface texture extends beyond altering the friction experienced in the palm; it also influences users' psychological security and emotional states through haptic feedback. Existing studies suggest that the perception of product surface texture is a multidimensional process involving geometric, physicochemical, emotional, and associative dimensions. The geometric dimension pertains to the shape and arrangement of the texture (Rachel and Christian, 2023), while the physicochemical dimension encompasses attributes such as smoothness, stickiness, and temperature (Karana et al., 2009). The affective dimension relates to subjective feelings such as comfort and pleasure (Zuo et al., 2016). Additionally, smooth surfaces are typically perceived as glossy, sticky, and wet, whereas rough surfaces are associated with friction and vibration. Moderate roughness can enhance comfort, but excessive roughness may cause discomfort (Zhang et al., 2025). Nevertheless, most research has focused on haptic perception under static conditions, with limited studies examining the combined effects of different surface textures on users' force levels and physiological emotions in dynamic handheld operations.

During dynamic handheld operations, users must continuously adjust their grip strength to adapt to varying usage environments. These force variations directly impact hand muscle fatigue and the comfort of prolonged use. Furthermore, emotional state is a critical factor in driving safety, as excessive psychological stress may lead to distraction or operational errors. Therefore, investigating how surface texture affects force generation levels and physiological emotions can not only optimize the haptic experience of handheld products but also enhance safety and comfort.

To address this research gap, this study explores how surface texture influences users' force levels and emotional states in dynamic handheld operations, using an e-bike handlebar as an example. By integrating both subjective and objective data, we aim to answer the following questions:

i) Do different handlebar textures significantly affect users' muscle force generation levels?
ii) What is the correlation between users' physiological mood fluctuations and different handle surface textures?

The objective of this study is to provide a theoretical foundation and design reference for e-bike handlebar surface texture optimization and other handheld products. Through an in-depth, multidimensional analysis, we seek to offer innovative perspectives for enhancing user safety, comfort, and emotional stability.

METHODS

As illustrated in Figure 1, the study was conducted in three phases: i) preparation, ii) experimentation, and iii) analysis. In the preparation phase, we recruited volunteers from both within and outside the university, selected three e-bikes with distinct and representative handle textures, and identified appropriate vocabulary for evaluating visuo-tactile perception. In the experimental phase, participants performed predefined tasks. We quantified users' muscle force generation while operating handlebars with different textures using electromyography (EMG) to assess the impact of texture on force exertion. Participants' comfort and pleasure levels were evaluated using the Subjective Emotion Scale (SES), while their mood fluctuations during riding were tracked using galvanic skin response (GSR) physiological indicators. In the analysis phase, experimental data from EMG, GSR, and subjective evaluations were integrated to examine how surface texture affects users' tactile experience, force exertion levels, and emotional states.

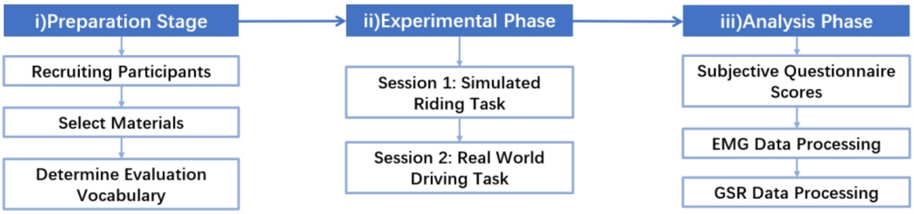

Figure 1: Research process.

PREPARATION STAGE

Participants

We recruited 20 participants, including 16 postgraduate students and 4 professionals who regularly use e-bikes in China including delivery workers and couriers. There were 9 females and 11 males, with an age distribution of 5 in the 18–23 age group, 1 in the 24–30 age group, 3 in the 31–40 age group, and 1 in the 41–50 age group. The usage scenarios were mainly on campus, commuting to and from work, and for the frequency of use, eight people used it more frequently, using it every day.

Figure 2: Experimental materials.

Testing equipment: ErgoLAB Electromyography, ErgoLAB Galvanic Skin Response, Likert sven-level scale subjective evaluation questionnaire (Table 1).

Table 1: Subjective evaluation questionnaire.

What you see and feel on this handle?		1	2	3	4	5	6	7	
1. The shape looks beautiful	Strongly disagree	○	○	○	○	○	○	○	Strongly agree
2. Looks non-slip	Strongly disagree	○	○	○	○	○	○	○	Strongly agree
3. Looks shiny	Strongly disagree	○	○	○	○	○	○	○	Strongly agree
4. Looks warm to me	Strongly disagree	○	○	○	○	○	○	○	Strongly agree
5. Non-slip to the touch	Strongly disagree	○	○	○	○	○	○	○	Strongly agree
6. Smooth to the touch	Strongly disagree	○	○	○	○	○	○	○	Strongly agree
7. Sticky to the touch	Strongly disagree	○	○	○	○	○	○	○	Strongly agree
8. Dry to the touch	Strongly disagree	○	○	○	○	○	○	○	Strongly agree
9. Feel comfortable when holding the handle	Strongly disagree	○	○	○	○	○	○	○	Strongly agree
10. Feel confident when driving with the handle	Strongly disagree	○	○	○	○	○	○	○	Strongly agree

The questionnaire is based on the framework of existing literature on material texture perception, which is adapted and expanded in the context of e-bike handlebar use. Zuo et al. (2016) proposed in their study that the texture perception of materials involves multiple dimensions such as visual, tactile, and emotional, and emphasized the close connection between the appearance of the material, the sense of touch, and the user experience. Referring to that study, we selected the following three main evaluation dimensions: Visual Perception, Tactile Perception, and Emotional Perception.

Experimental site: 10 meters long section (5 meters gentle + 5 meters bumpy).

Muscles tested: Brachioradialis muscle.

In the preliminary experimental design, in order to measure the degree of force exerted when twisting the handlebar of a motorized bicycle, we chose two muscle groups in the forearm to be tested, namely the ulnar lateral wrist flexor and the brachioradialis muscle. However, in preliminary tests, we found that the surface electromyographic signal (sEMG) of the brachioradialis muscle was more distinctive, with higher signal quality and relatively less interference from other muscles. Therefore, subsequent experiments were chosen to focus on the EMG signal of the brachioradialis muscle.

EXPERIMENTAL PHASE

Session 1: Simulated Riding Task

Step 1) First, participants were asked to observe the 3 handles, and then fill out the Likert 7-point scale subjective questionnaire. This step was designed to obtain the participants' initial visual perception evaluations, as well as the specific dimensions covered by the questionnaire (e.g., appearance preference, texture complexity perception, etc.).

Step 2) The EMG receiver was attached to the participant, and the instructions and precautions were explained to ensure the accuracy and reliability of the test data.

Step 3) Participants simulated driving for 1 minute, and then filled out the subjective questionnaire, and the experimenter instructed the participants to fill out the questionnaire (e.g., operating comfort, grip stability, etc.).

Step 4) Use a spray can to simulate a slippery scene on a rainy day, and let the participants fill out the Likert seven-level subjective slip resistance questionnaire, while the experimenter explains to the participants the key points of concern in the slip resistance questionnaire.

Figure 3: A participant is filling out a subjective questionnaire with a simulated driving experiment.

Session 2: Real-World Driving Task

Step 1) Attach myoelectric and electrodermal electrodes to the participant along with the signal receiver, explain the operation specifications and precautions to ensure the accuracy and reliability of the test data.

Figure 4: Schematic of a participant affixing myoelectric and electrodermal electrode pads and wearing a signal receiver.

Step 2) Participants sit still for 30 seconds.

Step 3) Participants watched a 1-minute video of a motorized vehicle accident to stimulate emotions.

Step 4) Participants drove a 10-meter-long road using three e-bikes with different textured handlebars in turn.

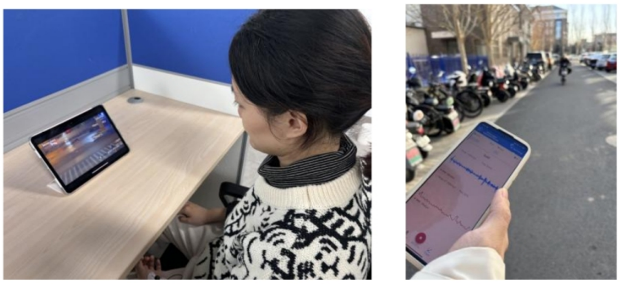

Figure 5: One participant was performing steps 3 and 4 of the experimental task.

RESULTS

Analysis Phase

Data Processing of Subjective Questionnaire Scores

After completing the subjective questionnaire collection, in order to explore the differences in the influence of different e-bike handlebar surface textures on user evaluation, the questionnaire rating data were processed by ANOVA. Through the one-way ANOVA test, the between-group sum of squares, within-group sum of squares, and the corresponding degrees of freedom were calculated to derive the F-value. Based on the pre-set significance level (usually 0.05), it was determined whether the F-value exceeded the critical value to determine whether there was a significant difference between the different handle types on each evaluation index.

Table 2: ANOVA results.

	Handle number (mean ± standard deviation)			F	p
	A(n=10)	**B(n=10)**	**C(n=10)**		
The shape looks beautiful	4.30±2.41	5.50±1.43	4.70±1.57	1.087	0.351
Looks non-slip	5.50±1.65	5.80±0.92	6.30±0.82	1.154	0.330
Looks shiny	3.60±2.41	3.40±1.90	4.30±2.16	0.475	0.627
Looks warm to me	4.40±1.71	4.00±1.70	4.00±1.76	0.179	0.837
Non-slip to the touch	2.50±2.22	3.50±1.90	5.90±0.88	9.826	**0.001****
Smooth to the touch	5.10±1.29	6.00±0.94	5.50±1.27	1.468	0.248
Sticky to the touch	4.10±2.08	2.70±1.49	2.50±1.84	2.293	0.120
Dry to the touch	3.20±1.62	5.00±1.25	5.40±1.65	5.981	**0.007****

Continued

Table 2: Continued

	Handle number (mean ± standard deviation)			*F*	*p*
	A(*n*=10)	B(*n*=10)	C(*n*=10)		
Feel comfortable when holding the handle	2.00±1.33	4.50±1.84	3.30±2.31	4.462	**0.021***
Feel confident when driving with the handle	4.90±1.85	6.20±0.79	6.50±0.53	5.008	**0.014***

* p<0.05 ** p<0.01

ANOVA was used to analyze ten dimensions: 'The shape looks beautiful,' 'Looks non-slip,' 'Looks shiny,' 'Looks warm to me,' 'Non-slip to the touch,' 'Smooth to the touch,' 'Sticky to the touch,' 'Dry to the touch,' 'Feels comfortable when holding the handle,' and 'Feels confident when driving with the handle.' As shown in Table 2, four dimensions—'Non-slip to the touch,' 'Dry to the touch,' 'Feels comfortable when holding the handle,' and 'Feels confident when driving with the handle'—showed significant differences (p < 0.05), while the remaining dimensions did not show statistical significance.

After analyzing the subjective questionnaire score data, it was concluded that the surface texture of different e-bike handlebars differed in each evaluation dimension. Convex textured handlebars (C) were rated the highest in terms of anti-slip performance and driving confidence. For comfort, concave textured handlebars (B) rated the highest (Figure 6).

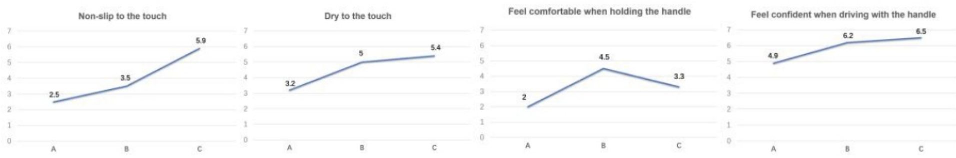

Figure 6: Analysis of variance (ANOVA) line graph for subjective evaluation scales.

EMG Data Processing

For the acquired EMG data, the average degree of force exerted by the participants on each handle was analyzed by calculating the average value.

The experimental data (Table 3) showed that the average muscle force of participants using the smooth textured handle (A) was significantly higher than that of the concave textured handle (B) and convex textured handle (C). This indicates that driving with smooth textured handles (A) was more strenuous, whereas participants drove with concave textured handles (B) and convex textured handles (C) with less effort.

Table 3: Means and standard deviations of participants' brachioradialis data.

Handle Type	Maximum_ mean	Maximum_ Standard_ Deviation	Minimum_ mean	Minimum_ Standard_ Deviation	Average_ mean	Mean_ Standard_ Deviation
Handle A	**166.039**	111.8818727	**7.1855**	1.357687433	**44.3262**	30.1745594
Handle B	**155.9729**	85.53259039	**6.9793**	2.115155421	**37.231**	20.93740839
Handle C	**151.842**	112.5641719	**6.5997**	1.698106269	**38.1365**	26.74006787

GSR Data Processing

In the picoelectric data processing session, the raw acquired picoelectric signals are first preprocessed, including removal of outliers and baseline correction.

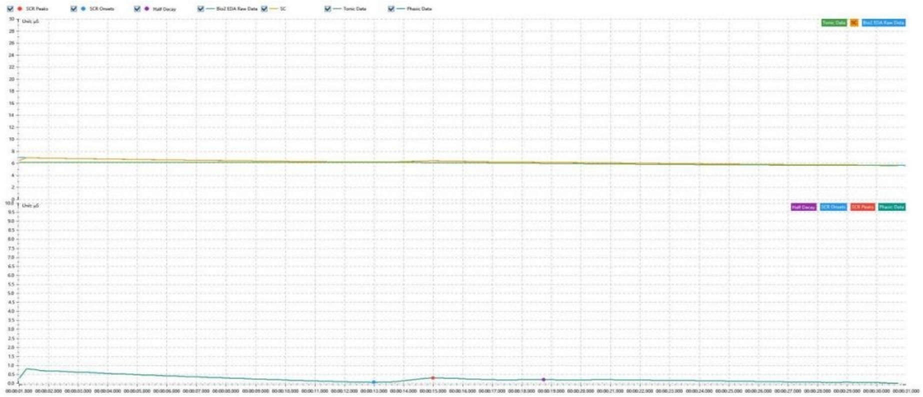

Figure 7: Filtered waveforms of GSR for one participant while sitting still.

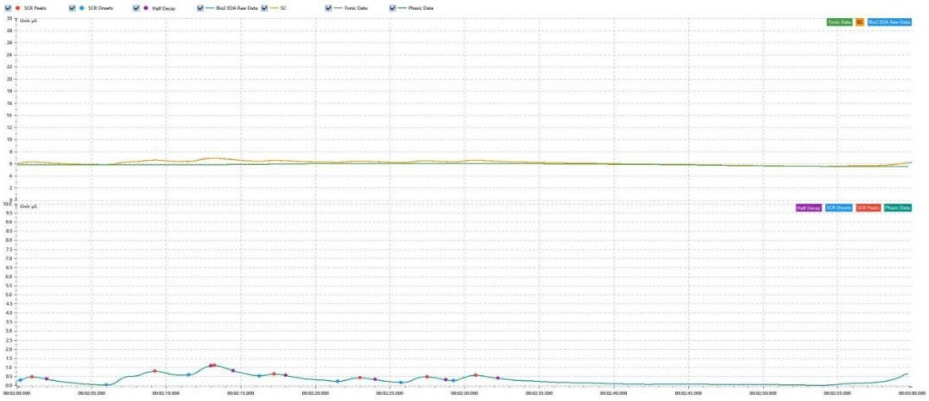

Figure 8: Filtered waveforms of GSR of the same participant while watching the video of the e-bike accident.

After preprocessing, a normality test was conducted to analyze whether the electrodermal activity (EDA) data followed a normal distribution. The commonly used Shapiro-Wilk test was applied, where the test statistic W value was calculated and compared with the corresponding critical value. Tonic (gradual signal) refers to the slowly varying component of the

EDA signal. It changes at a slow rate, typically increasing or decreasing gradually over time, making it suitable for assessing long-term emotional states such as anxiety or relaxation. Phasic (sudden signal) represents the rapidly changing component of the EDA signal, reflecting an individual's instantaneous response to short-term stimuli (e.g., a sudden fright). The figure above compares the phasic waveform of a participant during quiet sitting (Figure 7) and while watching an e-bike accident video (Figure 8). A noticeable spike in electrodermal activity can be observed, indicating that the participant's instantaneous emotional arousal was triggered.

Table 4: Analysis results of the normality test for GSR.

Name	Sample Size	Mean	Standard Deviation	Skewness	Kurtosis	Kolmogorov-Smirnov Test		Shapiro-Wilk Test	
						Test Statistic *D* Value	*p*	Test Statistic *W* Value	*p*
SC average	30	6.410	3.624	0.443	−0.684	0.153	0.072	0.947	**0.140**
Tonic average	30	5.548	3.403	0.384	−0.229	0.121	0.319	0.970	**0.546**
Phasic average	30	0.863	1.103	4.468	22.007	0.314	0.000**	0.461	**0.000****

* $p<0.05$ ** $p<0.01$

We performed normality test for SC mean, Tonic mean, and Phasic mean, the sample size of the study data was less than or equal to 50, thus Shapiro-Wilk test was used. As can be seen in Table 4: Phasic mean presents a total of 1 item that shows significance ($p < 0.05$), implying that Phasic mean does not have the quality of normality. The summary of data analysis shows that Phasic mean does not have the quality of normality. In addition, SC Mean, Tonic Mean has the quality of normality.

Table 5: Table of mean values of participants' galvanic skin response data.

Handle A	Participant Number	SC average	tonic average	phasic average	Unit: μS
	1	2.79	2.26	0.53	
	2	6.81	6.42	0.4	
	3	5.03	4.71	0.32	
	4	4.5	3.57	0.93	
	5	0.9	−0.04	0.94	
	6	11.05	8.88	2.17	
	7	14.13	13.17	0.96	
	8	6.66	6.2	0.47	
	9	3.87	3.19	0.68	
	10	10.65	10.03	0.62	
All averages		6.639	5.839	0.802	

Handle B	Participant Number	SC average	tonic average	phasic average	Unit: μS
	1	3.92	3.31	0.6	
	2	5.4	5.06	0.34	
	3	4.61	4.38	0.23	
	4	5.66	5.12	0.54	
	5	11.64	5.32	6.31	
	6	10.3	9.03	1.27	
	7	12.54	11.9	0.64	
	8	6.84	6.52	0.32	
	9	2.56	1.31	1.25	
	10	9.67	8.85	0.82	
All averages		7.314	6.08	1. 232	

Handle C	Participant Number	SC average	tonic average	phasic average	Unit:pS
	1	4.13	3.63	0.5	
	2	4.58	4.2	0.38	
	3	4.84	4.53	0.31	
	4	3.72	3.41	0.31	
	5	0.89	-0.11	1.01	
	6	8.97	8.1	0.87	
	7	11.48	10.77	0.71	
	8	6.3	5.9	0.41	
	9	1.1	0.42	0.67	
	10	6.75	6.39	0.37	
All averages		5. 276	4. 724	0.554	

Analysis of the skin electric data Table 5 comparing the Tonic values under the different textured handles revealed that the convex textured handle (C) had the smallest value, suggesting that the participant was more relaxed and stable, and was able to provide the user with a higher sense of security.

DISCUSSION

In this study, we investigated the effects of e-bike handlebars with different surface textures on users' muscle activation and emotional responses. The results revealed significant differences among the handlebars in terms of anti-slip properties, grip comfort, driving confidence, and physiological emotions. These findings align with Zuo et al.'s (2016) research on material texture perception, suggesting that surface properties (e.g., smoothness, stickiness) not only influence the haptic experience but also impact users' emotional responses.

EMG data indicated that friction was lower when using smooth-textured handlebars (A), requiring participants to apply greater grip force to maintain stability—reflecting a lower coefficient of friction. In contrast, concave (B) and convex (C) textured handlebars required less grip force, indicating better slip resistance. Subjective ratings also showed that concave (B) handlebars received the highest comfort scores and were particularly suitable for prolonged use, which is consistent with previous research highlighting the role of surface texture in reducing hand fatigue and enhancing comfort.

The GSR data revealed that when using smooth-textured handlebars (A), participants exhibited higher galvanic skin responses (GSR), indicating heightened emotional arousal—suggesting that users may feel nervous or uneasy while driving. In contrast, convex-textured handlebars (C) resulted in the smoothest GSR responses, indicating greater emotional stability. These findings suggest that convex-textured surfaces may enhance users' sense of security and psychological stability. The results further confirm that tactile perception not only affects muscle force generation but is also closely linked to users' emotional responses.

Different surface textures can trigger physiological mood fluctuations in users. The palm is often considered a "mental sweat zone" and is highly sensitive to psychogenic activities and sensory stimuli (Yin Han, 2018).

While most existing studies focus on the presence or absence of texture in static haptic perception, this study extends previous research by shifting the focus from static perception to dynamic handheld manipulation. The integration of electromyography (EMG) and galvanic skin response (GSR) data provides new insights into the user experience in dynamic operation contexts. In the design of handheld operating products, surface textures should be carefully considered for their impact on grip and comfort. Concave and convex textures, which enhance user safety and reduce emotional stress, should be prioritized to improve the driving experience.

However, this study has some limitations. Only three different bumpy textures were compared, and the experimental environment was relatively controlled, which may differ from real-world driving conditions. Future research could further refine texture variations to explore finer differences in bumpiness and validate the findings in more realistic settings. Additionally, individual differences in surface texture perception across different user groups should be explored to better inform product design.

CONCLUSION

This study provides an in-depth analysis of the effects of different e-bike handlebar surface textures on users' force generation levels and physiological emotions. The results indicate that:

- Smooth (A) handlebars, while performing moderately well under ideal conditions, exhibit lower slip resistance in slippery environments, potentially leading to higher emotional tension and increased muscular exertion.
- Concave (B) handlebars provide greater comfort during prolonged use, making them ideal for extended operating environments.
- Convex (C) handlebars offer the best slip resistance and driving confidence, making them suitable for scenarios that require a secure grip and enhanced safety.

When designing handheld operating products, designers should select appropriate surface textures based on specific usage scenarios. Special attention should be given to enhancing users' sense of security, comfort, and emotional stability by considering the impact of textures on slip resistance, grip comfort, and emotional responses. By optimizing surface texture design, the overall user experience can be significantly improved to better meet the needs of various operational conditions.

ACKNOWLEDGMENT

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