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From Touch to Feel: Can Piezo Haptics Improve Automotive Touchscreen Interaction?

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ABSTRACT

As touchscreen interfaces replace many physical controls in vehicles, safe and intuitive interaction becomes increasingly important. This study evaluated piezo-actuated haptic feedback versus conventional audio-only feedback across 11 use cases in parking and driving contexts. In a within-subject experiment with 23 participants in a fixed-based driving simulator, haptic feedback was rated as more satisfying, helpful, and supportive, particularly for scrolling or confirming actions while driving, despite showing no significant differences in objective performance measures. Participants described haptics as more engaging, though some noted habituation effects and inconsistencies. Audio-only feedback was seen as more stimulating but less consistently preferred. Findings suggest that contextual haptics improves perceived usability. Additionally, the study highlights the potential of semantic haptics—enabled by piezo technology—to convey meaning through expressive tactile patterns. Future research could explore adaptive multimodal systems and assess long-term effects under real-world conditions.

KEYWORDS

Piezo; haptic; automotive; user experience (UX); human–machine interface (HMI)

1. Introduction

In recent years, consumer electronic devices have significantly shaped automotive human–machine interfaces (HMI) (Riener et al., 2016). The widespread adoption of touch-based interactions has led to a shift from physical buttons to digital, smooth display surfaces with little to no tactile feedback (DeGuzman et al., 2024). This transition has also influenced in-car activities, with interfaces increasingly catering to entertainment, communication, and personalization, rather than focusing solely on driving functions (Pennington, 2020; Deloitte Insights, 2021; Mercedes-Benz USA, 2025).

Despite their advantages, touchscreen-based HMIs present safety and usability challenges, particularly in driving scenarios. Future automated driving (Level 3–4) will increase the share of non-driving-related activities (NDRAs), but safety–critical interactions will remain essential (SAE International, n.d.). Current touchscreen designs, which often lack eyes-free operation, require multiple interaction steps and increase the risk of driver distraction (Ahmad et al., 2015). This conflicts with fundamental safety requirements, as growing display sizes and reduced tactile elements demand more visual attention, making interaction less intuitive (Mishra and Chaudhary, 2021).

Technological advancements have introduced piezo-actuated haptic feedback to computing (Tech Advisor, 2023), prototyping (Boréas Technologies, 2023), and automotive UI (Aito, 2019a, 2019b). Despite the benefits of piezo haptic feedback, its effectiveness and user experience (UX) across various interaction types in automotive UI remain insufficiently explored, limiting a deeper understanding of its potential impact on driving performance and safety.

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This study aims to investigate the effectiveness and UX of piezo-actuated haptic feedback in automotive HMIs. Specifically, it addresses the following research questions:

1. How do users perceive the satisfaction, helpfulness, and appropriateness of piezo haptics in automotive tasks?
2. How does the addition of piezo haptic feedback impact objectively measured interaction efficiency and effectiveness, compared to conventional audio-only feedback?
3. Can piezo haptic feedback reduce visual–manual workload during touchscreen interactions while driving?

By exploring these questions, this study seeks to provide insights into the potential of piezo haptic feedback in automotive touchscreen UI design, bridging the gap between technical advancements and real-world usability in automotive UI design.

2. Related work

Research on haptic cutaneous interaction has evolved from a focus on technical aspects of haptics toward gaining more understanding on the UX. Not only is analyzing equipment increasingly more capable of measuring what objectively could be felt (GREWUS GmbH, 2024), but tools that convey how haptics are subjectively felt provide insights on factors such as immersion, enjoyment, and expressivity, and have progressively become more available, such as the Haptic Experience Inventory (HXI) (Shi and Schneider, 2024). Other explorations focused even more on interpretation of haptic experiences, by investigating verbal descriptions of cutaneous haptic feedback (Picardi et al., 2024; Heijboer et al., 2019), researching factors such as intensity or semantic qualities as in the Haptic Experience (HX) framework (Kim and Schneider, 2020), or by exploring methods for shaping haptics to enhance the affective engagement (Schneider et al., 2017). Moreover, recent studies have explored how distributed haptic sensations delivered at non-fingertip locations can impact influence factors such as user enjoyment (Lee et al., 2024).

While visual feedback alone on touchscreens presents usability challenges, additional feedback has been introduced in automotive UI. Audio cues provide sound-based confirmation of interactions, while haptic feedback (Vinot et al., 2016) uses electromagnetic actuators (e.g., voice coils, linear resonating actuators) to simulate physical button presses. Recent research shows that combining these modalities can significantly affect drivers' attention and performance during infotainment tasks, particularly under real or simulated driving conditions (Buchner et al., 2024). Most current automotive haptic implementations (Audi of America, n.d.; Mercedes-Benz Group AG, n.d.; Porsche Newsroom, n.d.) rely on electromagnetic actuators to mimic the feel of mechanical switches (Kern et al., 2022). However, these systems suffer from latency, low fidelity, and limited interaction types, as they primarily focus on press-based interactions rather than the continuous touch-based controls commonly found in consumer electronics (Breitschaft et al., 2022).

Although current electromagnetic-based actuators offer a broad frequency range (De Fazio et al., 2022), piezo actuators offer better active damping, a higher-fidelity alternative, providing even faster response times, and an even broader frequency range, which enables more precise and dynamic haptic sensations (Chen et al., 2023). Unlike traditional haptic systems that primarily simulate button presses, piezo actuators support a wider range of haptic interactions, including sliding, scrolling, and gestural inputs, ultimately supporting different haptic fidelities and semantics (Breitschaft et al., 2022).

Existing research on haptic feedback for automotive touchscreens has primarily focused on electromagnetic actuators and their usability in button-based interactions (Pitts et al., 2010; Pitts et al., 2012; Pitts et al., 2012; Pitts et al., 2009). While prior studies indicate that haptic feedback enhances UX, perceived usability, or a possible reduction in visual demand (Tunca et al., 2018; Beruscha et al., 2017), they also suggest it does not always lead to measurable improvements in objective performance (Breitschaft et al., 2019). Moreover, most studies have not systematically evaluated different haptic interaction types, particularly the distinction between press-based haptics (used for example in a press confirmation) and search-based haptics (which support automotive UI exploration without visual

attention). Search-based haptics could be critical for reducing driver distraction and enhancing safety (Breitschaft et al., 2022), yet their role in automotive interfaces remains underexplored. In addition, the potential for haptic patterns to convey semantic meaning—such as indicating rejection or confirmation through their shape, rhythm, or intensity—has received little systematic attention.

To develop such haptic interactions, several tools, frameworks, and corresponding evaluation strategies (Ledo et al., 2018) have been developed. Academic tools, such as VibViz (Seifi et al., 2015), Macaron (Schneider and MacLean, 2016), and VIREO (Terenti and Vatavu, 2023), and industry or open-source tools as Lofelt (Lofelt GmbH, 2021), Syntacts (Pezent et al., 2021) and Haptrix (Haptrix, 2025) allow researchers and practitioners to develop and share vibration patterns with more conventional actuators. More recently, Terenti and Vatavu (2024) introduced the Wear + Touch framework that explores how wearable vibrotactile feedback can be integrated into touchscreen interaction. Although this active research field highlights the importance of enabling researchers and practitioners to create expressive haptic interactions, their applications, both in piezo technology and its affordances, and automotive settings and use cases remain limited.

In summary, the literature suggests that haptics can enhance UX and acceptance in vehicles, but prior studies have been dominated by electromagnetic actuators and press-based interactions. At the same time, research in UX underscores the importance of semantic, expressive qualities, and design tools are beginning to support their creation. What is missing is a systematic empirical study of piezo-based haptic feedback in real automotive touchscreen use cases. To our knowledge, no prior study has systematically evaluated the semantic dimension of piezo haptic feedback in a driving context across multiple interaction types. This work addresses that gap by examining both subjective UX and objective performance in a controlled driving simulator study.

3. Materials and method

3.1. Experimental setup

The study was conducted in a Driving Simulator Lab from BMW in Munich, utilizing a fixed-based and stationary "seating buck," designed to replicate a realistic automotive interior without vehicle motion simulation. The mockup setup (Figure 1) included: 1) two automotive seats and doors; 2) a speaker system; 3) a middle console; 4) a dashboard with pedals and a steering wheel; and 5) a three-screen driving simulation setup displaying a highway driving scenario. The haptic display, positioned in the center stack area (next to the steering wheel in the picture), replicated the placement of a central information display (CID) in modern vehicles.

The haptic display is an automotive-grade 10.1" touch display (with a weight of approximately 1.5 kg) equipped with a piezo actuator. The actuation principle, as illustrated in Figure 2, is based on the Edison system (Boréas Technologies, 2025). To minimize vibration propagation, the display was mounted on the dashboard using rubber dampening rings. The haptic feedback system incorporated an Adaptive Signal Tuning (AST)-based closed-loop control mechanism, ensuring precise haptic feedback with minimal transient vibrations. The UI was developed using Protopie (n.d.), which managed visual, audio, and haptic feedback channels through a custom toolchain (Figure 3). A JSON file containing all haptic parameters was integrated into the front-end system through a client interface, enabling synchronized and dynamic control of tactile feedback. Audio feedback followed conventions from BMW's operating system "ID 8.5" (the company's in-vehicle infotainment and control user interface, introduced in mid-2023), serving as the reference for comparison throughout the study.

3.2. Development of tasks and interaction scenarios

A workshop with five experts was conducted to develop realistic use cases reflecting daily automotive interactions in parking (P) and driving (D) modes. The expert panel consisted of two psychologists, two UI designers, and one computer scientist with a background in HCI. Each expert had over 3 years of experience in automotive research and development (R & D) or series development.



Figure 1. Driving simulator and seating buck with interior mockup.

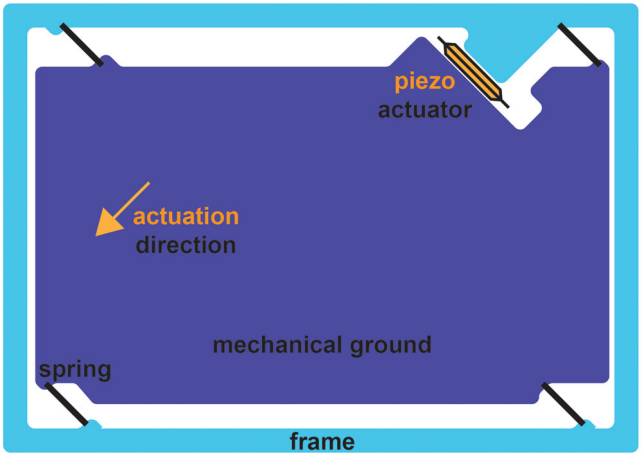


Figure 2. Schematic cross-section of haptic display.

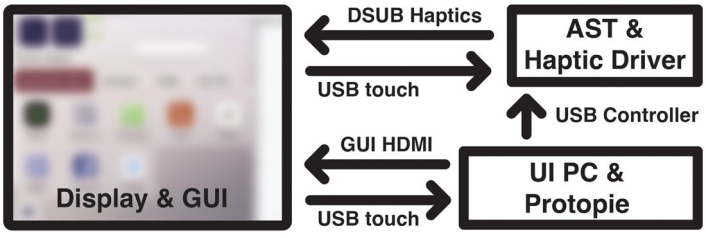


Figure 3. Illustration of the toolchain flow for a haptic display.

Three feedback modalities were implemented: Visual (graphical UI-based cues), Audio, and Vibrotactile Haptic (piezo-actuated touch feedback). As a starting point for the user flow and selection of use cases, BMW's operating system "ID 8.5" (Julich, 2023) was taken. Table 1 outlines all use cases, categorized by mode and feedback type. Use cases 0–11 represent primary test scenarios, covering functions like calls, audio adjustments, navigation, and media interactions. Use cases A and B were trials designed for an occlusion test, where participants first trained, and then performed tasks under visual occlusion (Plato glasses, Figure 4) to simulate the divided attention in real driving conditions.

Some haptic use cases included audio cues that were inherently connected to the function: the start and end of a ringtone for incoming or outgoing calls, and the playback balance from music after a song has been selected. No other sound cue. These additional audio elements are reflected in Table 1. For clarity, the term "Haptic" will be used to refer to this combined modality throughout the article.

Table 1. Overview of all use cases and the study's interaction flow. "P" indicates parking mode, "D" indicates driving mode. Haptic feedback elements are underlined for clarity. UC0 (home screen) served as the common starting point for all use cases and was not evaluated. For examples of the graphical UI used in the interaction flow, see Figure 5.

UC	Mode	Use case	Interaction flow	Haptic	Audio-only
0	P/D	Home screen	All UCs started here	N/A	N/A
1	P	Incoming call	An incoming call pops up with 2 buttons (pick up and decline)	Call Accept, Call Decline + stopping of ring tone	stopping of ring tone
2	P	Set Destination	Open app container, open navigation app, input a destination with keyboard, select to start navigation, and finally end navigation	Tap on selecting app, keyboard, and start, and End Navigation to stop	Tap sound on selecting app and keyboard
3	P	Manipulate map	Open app container, open navigation app, rotate the map 90 degrees and zoom into the map until the scale corresponds to 1 km	Tap on selecting app, Slider Step every 10 degrees and every 0.2 km	Tap sound on selecting app
4	P	Equalizer	Open app container, open sound settings, move the first three vertical sliders three steps downward, and the last ones three steps upwards	Tap on selecting app, Slider Step for slider step, Anchor for middle	Tap sound on selecting app
5	P	Sort Apps	Open app container, drag the WhatsApp application to the first position in the app launcher	Tap on selecting app, Long Press for drag mode, Tap for release	Tap sound on selecting app
6	D	Outgoing call	Open app container, open call app, quick scroll to H, and call John Harris	Tap on selecting app and call, Slider Step on scrolling through quick scroll + call sound	Tap sound on selecting app, call sound
7	D	Spotify	Open app container, open Spotify app, play the last song in the summer hits playlist	Tap on selecting app and song, scrolling Slider in vertical list + music playback	Tap sound on selecting app + music playback
8	D	Balance	Open app container, open sound settings, move the balance indicator to the driver position, and from there to the passenger seat	Tap on selecting app, Anchor when passing center axis of top view car	Tap sound on selecting app
9	D	Speed lock	Open the YouTube app, try to start the video (which is not permitted during driving), and receive a rejection cue	Tap on selecting app, Call Decline for play	Tap sound on selecting app
10	D	Incoming Call	An incoming call pops up with 2 buttons (pick up and decline)	Call Accept, Call Decline + stopping of ring tone	Tap sound on selecting app + stopping of ring tone
11	D	Massage	Open app container, Open seat settings app, toggle massage on, select one of the three massage program buttons, and toggle off	Tap on selecting app, Energizing, Relaxing, Caring, Toggle On/Off	Tap sound on selecting app
A	P	Equalizer	Open app container, open sound settings, move the first three vertical sliders three steps downwards and the last ones three steps upwards	Tap on selecting app, Slider Step for slider step, Anchor for middle	Tap sound on selecting app
B	P	Set Destination	Open app container, open navigation app and input a destination with keyboard (end navigation was not in scope)	Tap on selecting app and input keyboard	Tap sound on selecting app and keyboard

This study's interaction flow in each use case was structured as follows: starting from the home screen, selecting an app or function from the menu, and performing a final interaction within the app. Key feedback moments were integrated into the interaction flow to assess the efficiency of haptic and audio-only feedback.

Based on the predefined interaction flow, the haptic feedback and the graphical user interfaces were carefully designed, prototyped, and refined during the expert workshop. Figure 5 shows the key graphical UI designs created specifically for this study, including the home screen, keyboard, app container, and equalizer. Because the BMW ID 8.5 screen designs could not be used directly—due to confidentiality at the time of conducting this study and differences in screen resolution between the haptic display and ID 8.5—the original wireframes were adapted to the 10.1" display and rendered in a simplified and non-stylized form.

For auditory feedback, the study adopted the click sound from BMW's ID 8.5 (Julich, 2023) operating system for all tap interactions listed in the audio-only feedback column of Table 1.

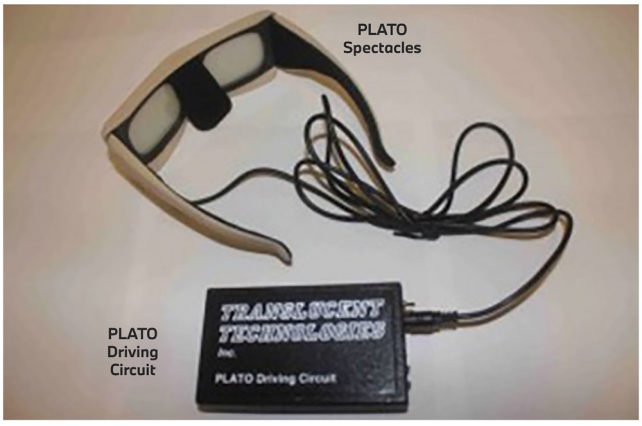


Figure 4. The plato occlusion glasses and controller.

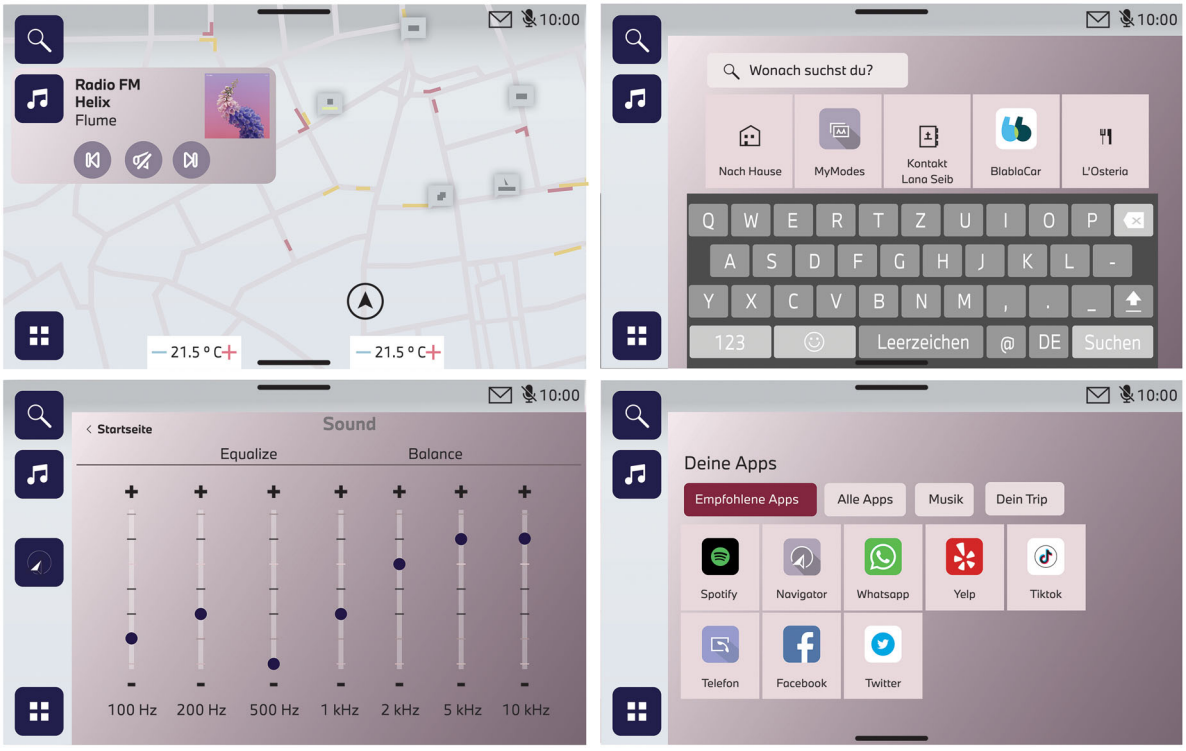


Figure 5. Designs of various stages in the interaction flow including the home screen, keyboard, app container, and equalizer (clockwise from top left).

For the haptic feedback use cases, four of the five experts iteratively ideated, conceptualized, programmed, and tested haptic patterns on the prototype. During this process, each pattern underwent 3–5 iterations based on expert feedback. The design process leveraged the unique properties of piezo haptics, particularly their precision, speed, and wide frequency range, to create the expressive tactile experiences. Special attention was given to designing haptic patterns with semantic intent—translating emotional tones into tactile form. "Call Decline" was designed as a sharp, vibrating "buzz of rejection." The massage previews were based on metaphors like a "weightless tap" (Careful), "rhythmic press" (Energize), and "soft exhale" (Relax), each chosen to match the semantics of the function they represent.

A 3-axis accelerometer mounted on the top-right corner of the display captured precise measurements, with a PicoScope 3405D (Pico Technology Ltd, 2025) used for signal analysis. Figure 6 provides an overview of the 13 haptic feedback patterns, showcasing accelerometer readings (X-axis in red, Y-axis in yellow) that capture the intensity, frequency, and duration of each haptic event, highlighting

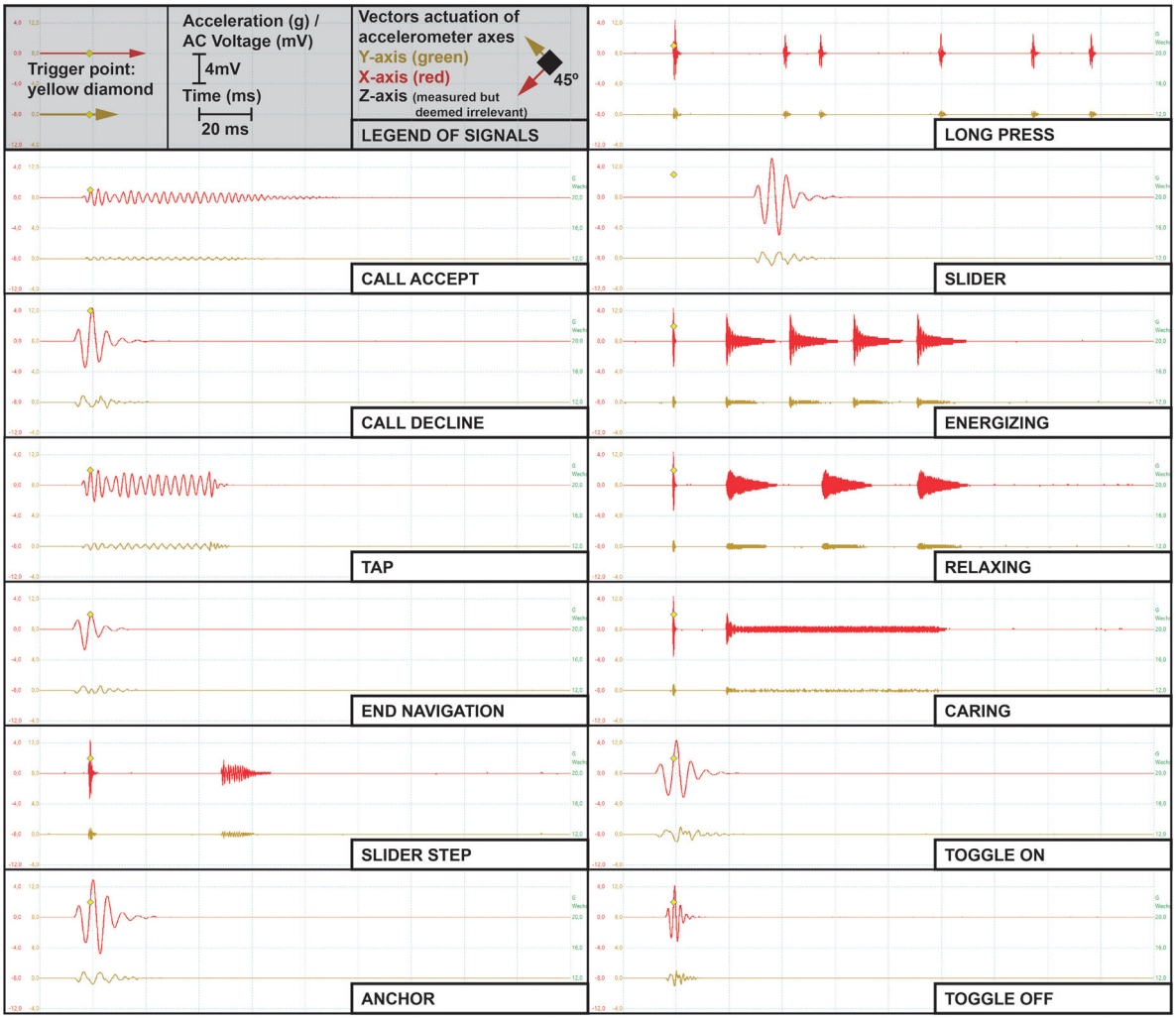


Figure 6. Overview of the extensive array of haptic feedback patterns, including the setup (top right).

their distinct tactile characteristics. The top right of the figure illustrates the setup and the legend, while patterns 12 and 13 correspond to Use Cases A and B.

3.3. Participants

A total of 23 participants were selected following NHTSA guidelines (Federal Register, 2023) to ensure balanced distribution across age groups and gender (11 females, 12 males), with a mean driving experience of approximately 2.5 years and a median of 11 months. Additionally, individuals with extensive prior knowledge or awareness of haptics, as well as those with prior UI/UX design experience or involvement in the development of automotive interfaces, were excluded to minimize potential bias. Four participants were left-handed, and all participants held a driver's license, with driving experience ranging from 1 month to 12 years, 11 months. A G*Power analysis indicated that for a within-subject design, this sample size ($N = 23$) is sufficient to detect large differences between conditions with a power of 0.946 in a two-tailed test setup.

3.4. Protocols

The study followed a structured four-phase protocol. In the first phase, participants were welcomed, provided informed consent, and completed a preliminary questionnaire regarding their prior experience with automotive UIs. They were then seated in the seating buck, and the experiment procedure was explained.

The second phase involved the driving simulation, where participants engaged with Use Cases (UC) 1–11, first with audio-only feedback and later with haptic feedback. The order of conditions was systematically varied, with 12 participants starting with audio-only and 11 with haptics. In both conditions, participants began each task from a stationary position at a motorway rest area. For the driving phase, participants accelerated onto a simulated highway featuring an infinitely looping Bavarian landscape with gentle curves and straight sections, under sunny weather and very light traffic conditions. They were instructed to remain on the highway for the entire drive. Each condition, including both parked and driving phases, lasted approximately 30 min, depending on task completion time. During each use case, participants and the investigator communicated only *via* microphone and loudspeaker. First, after each use case (UC1–UC11), participants rated the feedback on 3 custom seven-point Likert scale: satisfaction ("How satisfied were you with the feedback?"), helpfulness ("How helpful was the feedback in supporting you?"), and appropriateness ("How appropriate was the feedback for the given task?"). For example, after completing UC4 (Equalizer), participants were asked "How helpful was the feedback in supporting you during this task?" (1 = strongly disagree, 7 = strongly agree). In UC10 (Incoming Call), only appropriateness was assessed separately for the Accept and Decline patterns. Subsequently, they were able to provide qualitative feedback after every rating. The ratings and qualitative feedback were recorded and later transcribed. Participants were informed of the particular modality they would be evaluating, to see that their feedback was directed toward that modality rather than the graphical user interface, background sounds, or the driving simulator itself.

In the third phase, participants were instructed through microphone and loudspeaker to practice Use Cases A and B multiple times before proceeding with the occlusion test. They were then asked to wear plato occlusion glasses (see Figure 4), which alternated between visible and obscured states at fixed 1.5-second intervals for both phases, following NHTSA guidelines (Breitschaft et al., 2022). This rhythm reflects typical driver glance durations and is commonly used in safety-related visual–manual interface evaluations. For each trial, task completion time was recorded as the objective performance measure. Use cases were first executed without occlusion glasses three times as a baseline, then three times under occlusion conditions.

In line with established HMI research, often conducted in driving simulators (Tunca et al., 2018), the fourth and final phase combines previous objective and subjective ratings with standardized post-test surveys. These include the Van der Laan (1997), UEQ (Schrepp et al., 2017), an adapted Visual Analog Scale-based (VAS) NPS (Reichheld, 2003), and Kano (Berger et al., 1993) questionnaires with adapted wording.

The Van der Laan scale measures user acceptance in terms of usefulness and satisfaction, and has previously been applied in predictive HMI evaluations (Hecht et al., 2020), while the User Experience Questionnaire (UEQ) assesses various dimensions of UX such as stimulation, efficiency, and dependability, and has been applied to compare touchpad and gesture infotainment modalities in driving simulators (Čegovnik et al., 2018). The adapted VAS-based NPS (Net Promoter Score) captures users' willingness to recommend the system, and the Kano model (developed by Noriaki Kano) helps identify if a feature delights or frustrates users—both metrics are commonly used in industrial practice at the company where some of the authors are employed. In this study, we used a slightly adapted wording of the Kano items to improve comprehensibility but applied the standard Kano evaluation for classification.

With these questionnaires, this phase assessed the participants' overall experience and preferences. The Van der Laan scale used a five-point range (1 = strongly disagree, 5 = strongly agree), the UEQ employed a 7-point scale (1 = strongly disagree, 7 = strongly agree), and the VAS-based NPS used a five-point scale (0 = not at all likely, 5 = extremely likely). The Kano model applied its standard five-category format. All questionnaires were completed on paper immediately after each test session (audio-only and haptic). Figure 7 provides a visual overview of this process, illustrating the study's timeline, the distribution of use cases across parking (P) and driving (D) modes, and the systematic order permutation of audio-only and haptic conditions.

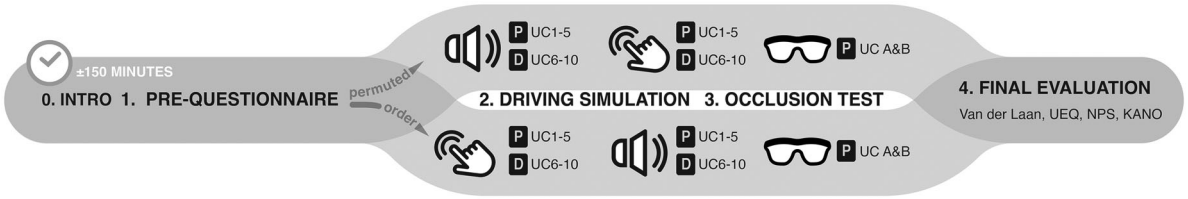


Figure 7. Schematic illustration of the protocol.

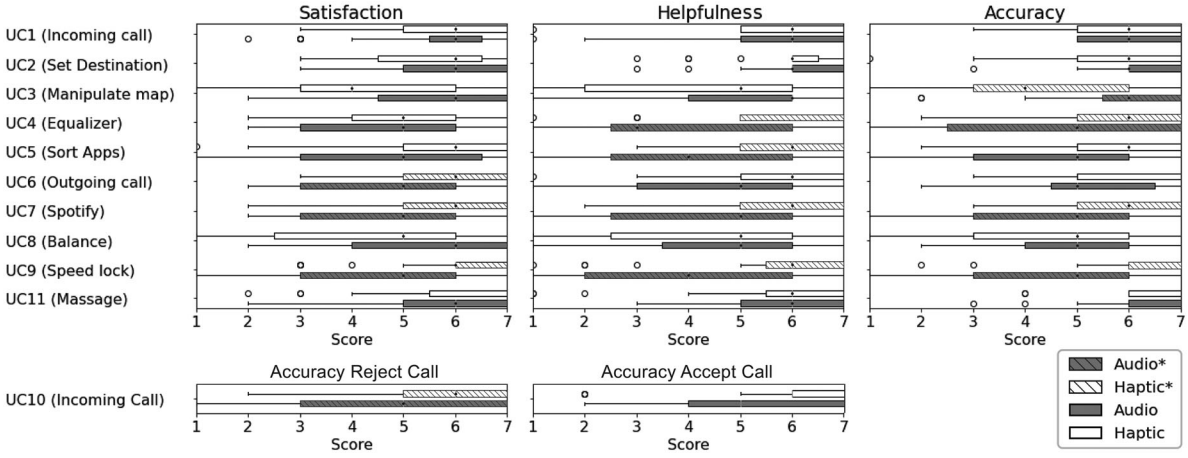


Figure 8. Boxplots comparing haptic (white) and audio-only (grey) conditions across 11 use cases for satisfaction, Helpfulness, and accuracy. Hatched boxes indicate cases where the difference between audio-only and haptic conditions reached statistical significance (Wilcoxon signed-rank test, p <.05). Note: Use case 10 differs from the others; instead of satisfaction, helpfulness, and accuracy, participants evaluated the accuracy (or "semantic fit") of haptic feedback for accepting or rejecting an incoming call. As a result, this use case appears as an empty row in the chart.

3.5. Data analysis methods

Subjective feedback was collected, and quantitative data were analyzed using the self-developed python programs. Mean values and standard deviations were calculated across the 23 participants for each use case. The Shapiro-Wilk test was conducted to assess data normality. Since all responses in this study deviated from a normal distribution, the Wilcoxon signed-rank test was applied to evaluate statistical significance ($p < 0.05$). Since the Shapiro–Wilk test showed non-normality, Wilcoxon signed-rank tests were used for paired comparisons. Results are reported with N, W, z, p, and effect size r. Full tables are provided in Appendix A, Table 3–Table 7.

4. Results

4.1. Use cases

We investigated the effect of haptic feedback across 11 use cases (UC1–UC11), using 3 subjective evaluation metrics: Satisfaction, Helpfulness, and Accuracy for UC1–UC9 and UC11 and the Accuracy (i.e., Semantic Fit) for UC10. Participants (N = 23) rated each scenario under both haptic and audio-only feedback. The results were analyzed using descriptive statistics and the Wilcoxon signed-rank test. Full test statistics are provided in Appendix A – Statistical Test Results, Table 3.

Figure 8 presents participant ratings across 11 use cases for the three metrics, comparing haptic and audio-only conditions. Hatched boxes indicate statistically significant differences ($p < 0.05$) between two conditions. Note that Use Case 10 follows a different pattern: Instead of the standard three metrics, participants evaluated only the accuracy of haptic feedback for accepting or rejecting an incoming call. Overall, haptic feedback led to statistically significant improvements in Satisfaction in three use cases (UC6, UC7, and UC9), helpfulness in four use cases (UC4, UC5, UC7, and UC9), and accuracy in four use cases (UC4, UC7, UC9, and UC10). While the effect was not universal, for example, Accuracy was

significantly lower in UC3 (Manipulate Map) with haptics, these results show that haptic feedback meaningfully enhanced the UX in several interaction-heavy or visually constrained contexts.

When grouped by *Parking* and *Driving* these two scenarios, a clearer pattern emerges. In *Parking* (UC1–UC5), where participants could rely more on visual feedback, significant improvements were limited to three metric-case combinations: accuracy in UC4 (Equalizer), and helpfulness in UC4 (Equalizer) and UC5 (Sort Apps). In contrast, *Driving* (UC6–UC11) showed stronger and more frequent effects: 8 out of 17 metric-use case combinations were significantly better with haptic feedback, including all three metrics in both UC7 (Spotify) and UC9 (Speed Lock). This suggests haptics provided greater value in driving conditions, where users are more visually and cognitively engaged and benefit more from tactile reinforcement.

Parking scenarios (UC1–UC5)

- UC1 (Incoming Call) and UC2 (Set Destination) showed no significant differences across any metric. In these static, low-effort interactions, participants generally found both audio and haptic feedback equally effective.
- UC3 (Manipulate Map) revealed lower Accuracy with haptic feedback. Some users found the feedback excessive due to already rich visual information, with one calling it "unnecessary" and potentially distracting.
- UC4 (Equalizer) demonstrated significant advantages for haptic feedback across all three metrics. Seventeen participants appreciated the ability to count steps blindly using tactile cues—"It felt like you could feel where you are on the scale."
- UC5 (Sort Apps) showed a significant improvement in Helpfulness ratings. The haptic cue during long-press interactions was seen as intuitive and familiar, mirroring smartphone behavior. "You know exactly when it's ready to move or drop," one participant noted.

Driving scenarios (UC6–UC11)

- UC6 (Outgoing Call) saw significantly higher Satisfaction ratings with haptic feedback. Participants found it reduced the need to visually confirm list scrolling while driving. One described the experience as "actually enjoyable."
- UC7 (Spotify) had significant gains across Satisfaction, Helpfulness, and Accuracy. The rhythmic haptic taps while scrolling were praised for enhancing orientation without disrupting the music experience—"comforting" and "non-intrusive."
- UC8 (Balance) showed no significant differences. Several participants preferred audio-only feedback, finding the haptic signals unclear, particularly when crossing the midline. The entertainment audio was considered sufficient on its own.
- UC9 (Speed Lock) stood out as one of the strongest cases for haptic effectiveness, with significant improvements across all metrics. With no audio feedback in the baseline UI, participants described the haptic cues as "intuitive" and "self-explanatory without needing to look."
- UC10 (Incoming Call)—a variation focused on declining or accepting calls—showed significantly higher Satisfaction or "Fit" for the haptic condition when declining a call. Although Satisfaction, Helpfulness, and Accuracy were not measured separately, 17 participants said the haptic pattern for declining a call gave them confidence the action was successful: "I was sure the call was declined - no doubt."
- UC11 (Massage) yielded no significant differences. Both feedback types were understood and appreciated, though some participants regarded haptics here as a "nice-to-have" or "gimmick" rather than essential.

4.2. Occlusion test

Table 2 presents mean task completion times and standard deviations for both audio-only feedback and haptic feedback, across two use cases: UC A (Equalizer) and UC B (Set Destination), performed under Driving conditions with visual occlusion.

Table 2. Task completion time (s). Mean (M) and standard deviation (SD), averaged over three attempts, for use cases A (Equalizer) and B (Set Destination) with Audio-only and Haptic feedback in the driving (D) condition of the occlusion test.

Results occlusion test		Audio-only average of three runs		Haptic feedback average of three runs	
UC#	Use case name	M	SD	M	SD
UC A (Equalizer)	Equalizer baseline	15,58	2,84	16,87	4,27
	Equalizer measurement	13,77	3,94	14,03	3,77
UC B (Set Destination)	Navigation baseline	6,08	1,85	6,17	2,57
	Navigation measurement	5,72	1,36	5,53	1,65

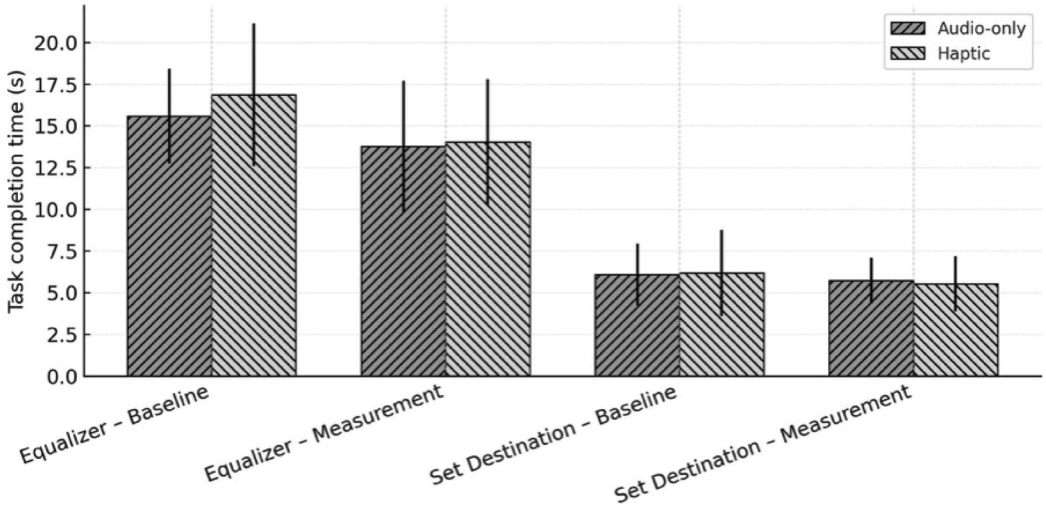


Figure 9. Mean task time (s) of three runs for use cases A (Equalizer) and B (Set Destination), Baseline vs Measurement, comparing Audio-only vs. Haptic. Error bars represent ±1 SD.

A 2×2 within-subjects analysis (Audio-only vs Haptic; Baseline vs Measurement) showed no main effect of Feedback and no Feedback vs. visual occlusion interaction for UC A (Equalizer) or UC B (Set Destination). As shown in Figure 9, the Measurement was slightly faster than Baseline (3 sets of practice rounds).

Across all comparisons, no statistically significant differences were found between feedback conditions. These results suggest that Haptic feedback did not objectively improve blind operation compared to existing audio cues or the absence of feedback. In practical terms, haptics did not reduce task duration or improve interaction efficiency under visual occlusion.

4.3. Kano, NPS, Van der Laan, and UEQ questionnaires

Figure 10 shows the Kano questionnaire results after applying the evaluation matrix (Berger et al., 1993) to paired Present/Not Present answers. For Haptic feedback, most participants classified it as either Attractive (11) or Indifferent (12), with no Reverse classifications. In contrast, Audio feedback showed a more diverse profile: 8 Attractive, 9 Indifferent, 2 Reverse, 1 Must-be, and 3 cases that could not be calculated due to the unclear wording from participants.

Although the Wilcoxon signed-rank test found no statistically significant differences (Present: $p = .054$; Not Present: $p = .069$), the Kano questionnaire indicates that Haptic feedback was consistently either liked or tolerated, while audio-only evoked stronger and polarized reactions, including some active rejections (Reverse).

As shown in Figure 11, the VAS-based NPS was significantly higher for Haptic feedback (Mean = 3.74) than Audio-only (Mean = 2.8; $p = .0433$), indicating participants were more likely to recommend haptics. On the Van der Laan Acceptance Scale, Haptic feedback was rated significantly more pleasing ($p = .013$). In contrast, Audio-only feedback was perceived as more activating ($p = .0034$). No

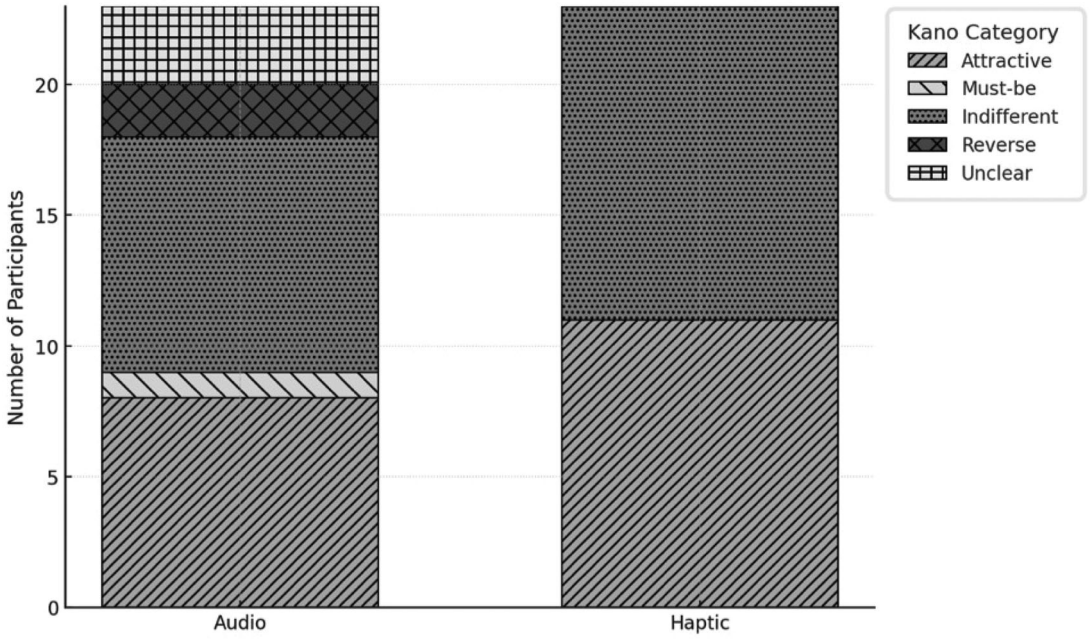


Figure 10. Kano questionnaire by modality (counts) responses for Audio-only and Haptic feedback. Haptic was mainly attractive or indifferent, while audio showed a more mixed profile including some reverse ratings.

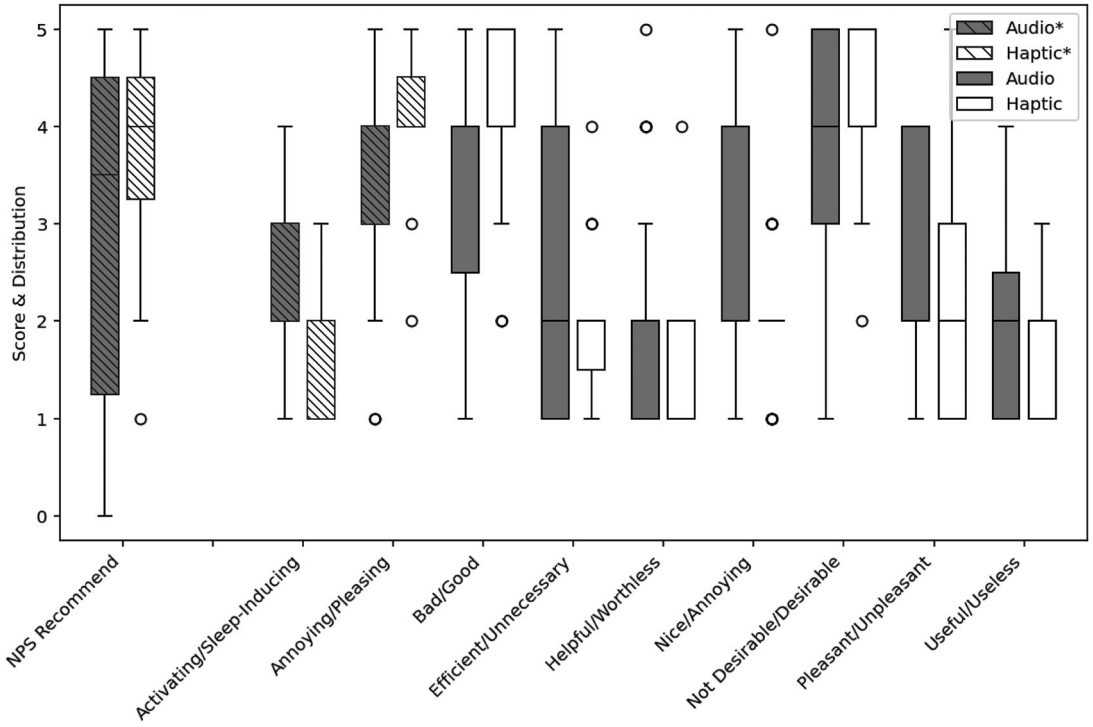


Figure 11. Results of VAS-based NPS (0–5 scale, left) and van der Laan questionnaire (0–5 scale, 9 right metrics), where significant differences between Audio-only and Haptic feedback were highlighted with hatching patterns.

significant differences were found for efficiency, helpfulness, or usefulness, suggesting comparable functional performance across modalities.

The UEQ results (Figure 12) reveal distinct hedonic strengths for each feedback type. Haptic feedback was rated significantly more *Exciting* ($p = .0024$), *Innovative* ($p = .0027$), and *Interesting* ($p = .0035$). Conversely, Audio-only feedback was rated more Creative ($p = .0015$) and *Original* ($p = .0013$). Haptics were also seen as more *Supportive* ($p = .0369$), while audio-only scored higher in *Value* ($p =$

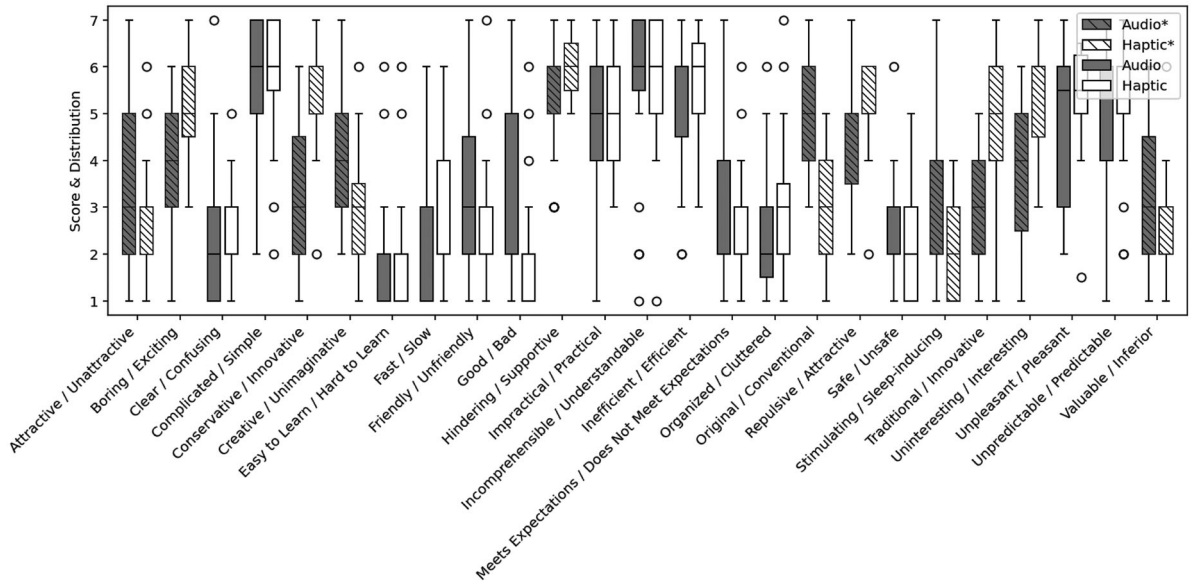


Figure 12. Results of UEQ questionnaire (0–7 scale), where significant differences between Audio-only and Haptic feedback were highlighted with hatching patterns.

.0441). No significant differences were found for more pragmatic dimensions such as *Clarity*, *Predictability*, *Efficiency*, or *Safety* ($p > .05$), suggesting that both modalities offer equivalent usability but with distinct affective profiles. However, the pattern of results highlights that multimodal feedback (Haptic and Audio) is perceived as more emotionally engaging and stimulating, while Audio-only feedback leans toward creative and novel expression.

5. Discussion

5.1. Research questions

This study addressed three core research questions related to the effectiveness, UX, and contextual relevance of piezo-actuated Haptic feedback in automotive touchscreen interactions.

Regarding RQ1, which explored how users perceive haptic feedback in terms of satisfaction, helpfulness, and appropriateness, subjective responses consistently favored Haptic feedback across several driving-related use cases. Participants particularly appreciated haptics in scenarios that required reduced visual attention or precise control, such as UC7 (Spotify) and UC9 (Speed Lock). In UC10, semantically distinct haptic cues for accepting and declining a call were well understood and positively received, highlighting the value of context-sensitive feedback design. These findings suggest that the enhanced UX is not merely due to the presence of Haptic feedback but closely linked to the unique characteristics of piezo technology. Its ability to deliver precise, fast, and expressive tactile cues enabled the creation of patterns that felt intuitive and meaningful to users.

For RQ2, which compared the interaction efficiency and effectiveness of Haptic feedback versus conventional Audio-only feedback (based on BMW ID 8.5), the objectively measured data, such as task completion times and performance under occlusion, showed no statistically significant differences between feedback conditions. This aligns with previous findings (Breitschaft et al., 2019), indicating that feedback modality alone does not significantly impact task efficiency or learnability. From a purely functional perspective, neither modality demonstrated clear superiority. However, combined with the subjective data, these results suggest that users may compensate for limited feedback by shifting their attention and cognitive resources away from the driving task—potentially leading to long-term safety concerns.

RQ3 examined whether piezo Haptic feedback could reduce visual–manual workload during touchscreen interactions while driving. Although objective measures from the occlusion test (UC A and B) showed no measurable improvement with haptics, subjective feedback indicated that participants felt more supported in visually demanding conditions. Driving scenarios demonstrated the broader benefits

of haptic feedback compared to parking, suggesting that even without measurable performance gains, haptics can enhance perceived ease of interaction and reduce reliance on visual input.

Although this study did not compare piezo-enabled haptics directly with electromagnetically actuated haptics, the findings do underscore the potential of piezo technology to support a wider range of interactions beyond simple press-based tasks. Furthermore, these results confirm earlier studies with electromagnetic actuated displays, which also found that Haptic feedback can lead to an increase in satisfaction with no objective performance gains.

Where prior related studies mainly have focussed on button and confirmation interactions, this study contributes to the research field with a systematic approach of piezo-based semantic haptics across various touch-based interaction types (e.g., scrolling, decline vs. accept), by both observing parking and driving conditions. Our findings do not highlight the discovery of new UX benefits, but instead, the results show a systematic application of piezo-based semantic haptics for scrolling, gestural, and context-sensitive interactions in the complex context of automotive conditions. Participants responded positively to semantically rich and dynamic feedback patterns—expressiveness made possible by the precision, speed, and frequency range of piezo actuators. These qualities suggest clear advantages over other tactile haptic technologies in enabling meaningful and contextual haptic design.

Our findings also connect to more recent literature on semantic and expressive characters of haptics (Kim and Schneider, 2020; Seifi et al., 2015; Terenti and Vatavu, 2024). Although such frameworks illustrate an increase of relevance and know-how on the topic of meaning and affective engagement in haptics, the practical application to automotive contexts remains limited. This work demonstrates how piezo technology can be used to create semantic haptic patterns and provides information on how novel UX tools (Protopie, n.d.) can be used in combination with a relatively advanced actuation method.

5.2. Use cases

Out of 32 metric-case combinations across 11 use cases, Haptic feedback led to significant improvements in 12 instances. These effects were more prominent in Driving scenarios (UC6–UC11), with eight significant improvements, compared to only three in Parking scenarios (UC1–UC5). This confirms that the effectiveness of Haptic feedback is highly context-dependent, offering greater value when visual attention is limited, and interaction complexity is higher. In the automotive context, these findings support the selective integration of Haptic feedback for high-demand driving tasks, while avoiding unnecessary redundancy in simpler, visually supported interactions during parking.

5.3. Questionnaire insights

The KANO analysis revealed that Haptic feedback was almost evenly divided between Attractive and Indifferent, showing that while not a "must-have," it added value without provoking rejection. Audio-only feedback, in contrast, elicited more polarized reactions—valued Attractive by some users and considered Reverse by others, indicating dislike when present. Notably, this highlights that Haptic feedback is generally accepted or appreciated, whereas audio cues create stronger but more divided reactions.

NPS and Van der Laan results further emphasized the subjective appeal of haptics. With a mean NPS of 3.74 on a 0–5 scale, Haptic feedback reached a moderately high "likely to recommend" level. As NPS is less commonly applied in HMI research, its main value here is to provide an additional industry-relevant perspective. On the Van der Laan scale, haptics were rated as more pleasing, while audio-only felt more activating, with functional dimensions showing no difference. This aligns with prior driving-simulator work (Hecht et al., 2020; Čegovnik et al., 2018; Krüger et al., 2021; Richardson et al., 2018), where new modalities boosted hedonic aspects but did not uniformly increase acceptance.

Participants rated Haptic feedback significantly higher in acceptance, pleasure, and desirability. Audio-only feedback was perceived as more activating, likely due to its immediate recognizability, while both modalities were rated similarly on functional dimensions such as efficiency and usefulness. These results suggest that haptics enhances affective experience, while audio-only tends to convey a sense of alertness.

The UEQ results also confirmed these patterns: Haptic feedback was rated as more exciting, innovative, and supportive, while Audio-only feedback scored higher in originality and creativity. Usability-related

dimensions such as clarity and efficiency showed no significant differences, indicating that both modalities perform similarly from a functional standpoint. Overall, haptics enhances emotional engagement, while Audio-only contributes expressiveness, making them complementary in a well-balanced multimodal design.

5.4. Limitations

Several limitations should be considered when interpreting these findings. First, although the driving simulator provided a controlled and realistic environment, it was a fixed-based setup without motion cues, which may affect how Haptic feedback is perceived compared to a moving vehicle. Second, the prototype toolchain introduced minor latency in both Audio-only and Haptic feedbacks, which may have influenced user perception. Additionally, haptic signals were statically tuned and could not adapt dynamically to user behavior or task context. Also, despite the use of vibration-dampening mounts, some Haptic feedback may have propagated through the cockpit structure, subtly altering the tactile and auditory experience.

Furthermore, this study compares 32 pairs without correction for multiple testing, for which some significant effects may reflect Type 1 errors. These results should be interpreted as exploratory. Also, a slightly adapted Kano questionnaire was used. While the evaluation matrix was applied in standard form, some wording differences may have influenced category mapping.

Future work should investigate latency-free, adaptive feedback systems in moving vehicles, evaluate long-term effects such as habituation, and explore broader user groups, including cross-cultural comparisons, to validate and extend these findings.

This study was conducted using a single vehicle interface platform, which may limit the generalizability of findings across different systems. Additionally, the short exposure time did not allow for evaluation of long-term habituation or user adaptation. Future work should assess sustained use and the potential for adaptive haptic personalization.

6. Conclusion

This study examined the effectiveness and UX of piezo-actuated haptic feedback in automotive touchscreen interactions, comparing it with conventional audio-only feedback across 11 use cases. Findings highlight the importance of task context: While fewer differences emerged in *Parking* scenarios, Haptic feedback was consistently favored in *Driving* tasks, particularly those involving scrolling, selection, or error confirmation.

Although objective performance measures showed no significant differences across modalities, subjective ratings revealed that Haptic feedback improved perceived satisfaction, helpfulness, and accuracy. Questionnaire results further supported its value in increasing engagement and supportiveness, while Audio-only feedback was perceived as more activating and expressive. This aligns with prior studies suggesting that haptic feedback improves perceived usability even when objective performance gains are not observed. These results suggest that Haptic feedback provides perceptual and emotional benefits, even if not always tied to measurable performance gains. However, inconsistencies in implementation and habituation effects may limit long-term acceptance. Beyond functional support, this study points toward a new design space of semantic haptics—tactile cues that convey meaning through form, rhythm, and timing. Enabled by the precision and speed of piezo technology, these patterns open up opportunities for more expressive and context-aware interaction in future in-vehicle systems.

Future research should focus on adaptive multimodal feedback systems (Vitense et al., 2003) tailored to task and context, assess long-term use and cultural differences (Vink et al., 2021), and evaluate the potential safety benefits in real-world driving conditions. For practitioners, our findings indicate that piezo technology should be considered alongside electromagnetic actuators, as it enables a wide design space and integrate more readily with advanced UI/UX prototyping tools. This way designers can go beyond button-like confirmations and experiment with scrolling, gestural, and semantic cues that convey concrete meaning for users. For researchers, the results highlight the importance of studying automotive UI in its own right, since it presents more complexity and safety demands than domains such as wearables. There is also a need to connect the “soft” side of haptics—its semantic, emotional, and

affective qualities—with what these signals actually deliver for driver and passenger in practice. Finally, both groups would benefit from developing multimodal design frameworks that incorporate audio, haptics, and visual cues in a uniform and context-aware manner.

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Author contributions

CRediT: **Stefan Heijboer**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; **Stefan Breitschaft**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software; **Yannick Forster**: Conceptualization, Investigation, Methodology, Project administration, Resources, Writing – review & editing; **Gijs Huisman**: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing; **Peter Vink**: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing; **Wolf Song**: Conceptualization, Formal analysis, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Ethics statement

The proposed study was approved by BMW Research Ethics Committee.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Declaration of interest statement

The authors declare no conflicts of interest related to the research, authorship, and/or publication of this article.

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Appendix A. Statistical test results

Table 3. Wilcoxon signed-rank test results for UC1–11.

Use cases	Metric	Mean audio-only	SD audio-only	Mean haptic	SD haptic	N nonzero	W	z	p	r
UC1 Incoming Call	Satisfaction	5,56522	1,50230	5,65217	1,30065	18	77	−0,37	0.705	−0,09
	Helpfulness	5,52174	1,72862	5,82609	1,33662	15	45	−0,85	0.382	−0,22
	Accuracy	6,00000	0,79772	5,82609	1,23038	10	22	−0,61	0.533	−0,19
UC2 Set Destination	Satisfaction	5,82609	1,46636	5,34783	1,49571	16	48	−1,06	0.285	−0,27
	Helpfulness	6,00000	1,04447	5,91304	1,04067	14	45	−0,47	0.627	−0,13
	Accuracy	6,17391	0,98406	5,60870	1,58800	14	33	−1,22	0.214	−0,33
UC3 Manipulate Map	Satisfaction	5,56522	1,53226	4,47826	2,01967	22	70	−1,82	0.067	−0,39
	Helpfulness	4,86957	1,96108	4,39130	2,21029	20	90	−0,54	0.586	−0,12
	Accuracy	5,95455	1,52682	4,13636	1,90976	18	23	−2,72	0.006	−0,64
UC4 Equalizer	Satisfaction	4,65217	1,82430	5,13043	1,51671	13	28	−1,22	0.213	−0,34
	Helpfulness	4,13043	2,15964	5,91304	1,62125	19	28	−2,68	0.007	−0,61
	Accuracy	4,47826	2,29366	5,82609	1,43502	20	51	−2,02	0.043	−0,45
UC5 Sort Apps	Satisfaction	4,69565	1,89340	5,43478	1,82971	19	57	−1,53	0.123	−0,35
	Helpfulness	4,00000	1,95402	5,82609	1,40299	20	31	−2,76	0.006	−0,62
	Accuracy	4,60870	1,92446	5,65217	1,49571	19	52	−1,75	0.078	−0,40
UC6 Outgoing Call	Satisfaction	4,47826	1,87979	5,60870	1,33958	20	51	−2,02	0.042	−0,45
	Helpfulness	4,52174	1,87979	5,52174	1,78044	19	56	−1,55	0.120	−0,36
	Accuracy	5,17391	1,64148	5,91304	1,44326	19	62	−1,35	0.173	−0,31
UC7 Spotify	Satisfaction	4,21739	1,75697	5,69565	1,60779	16	10	−2,97	0.003	−0,74
	Helpfulness	4,39130	2,01673	5,82609	1,43502	16	18	−2,61	0.009	−0,65
	Accuracy	4,65217	1,92138	5,82609	1,46636	16	30	−1,96	0.048	−0,49
UC8 Balance	Satisfaction	5,39130	1,58800	4,43478	1,97314	17	37	−1,87	0.058	−0,45
	Helpfulness	4,78261	1,67757	4,34783	2,08040	20	89	−0,6	0.547	−0,13
	Accuracy	5,00000	1,69031	4,59091	2,08530	18	73	−0,54	0.583	−0,13
UC9 Speed Lock	Satisfaction	4,39130	1,82755	5,91304	1,37883	20	34	−2,65	0.008	−0,59
	Helpfulness	3,73913	2,19953	5,60870	1,82755	16	7	−3,15	0.001	−0,79
	Accuracy	4,43478	1,92652	6,13043	1,32474	17	10	−3,15	0.001	−0,76
UC10 Incoming Call	Decline Call	4,65217	2,12365	5,73913	1,62976	17	34	−2,01	0.043	−0,49
	Pick-up Call	5,17391	1,69631	5,82609	1,61392	17	50	−1,23	0.216	−0,3
UC11 Massage	Satisfaction	5,56522	1,56165	5,91304	1,59297	16	50	−0,96	0.331	−0,24
	Helpfulness	5,65217	1,36877	5,69565	1,91726	16	58	−0,49	0.613	−0,12
	Accuracy	6,30435	1,10514	6,47826	0,89796	9	16	−0,83	0.392	−0,28

Each row reports mean and standard deviation for audio-only and haptic conditions, number of valid pairs (N), wilcoxon statistic (W), standardized z, significance (p), and effect size ($r = z/\sqrt{N}$).

Table 4. Wilcoxon signed-rank test results for occlusion tasks (UC A: Equalizer, UC B: Set destination).

Occlusion	Phase	Mean audio-only	SD audio-only	Mean haptic	SD haptic	N nonzero	W	z	p	r
UC A Equalizer	Baseline	15,04582	3,41949	16,33920	4,57973	25	114	−1,3	0.200	−0,26
	Measurement	13,36118	3,67262	13,58959	3,90547	25	159	−0,09	0.937	−0,02
UC B Set Destination	Baseline	5,89206	1,47150	6,01217	2,23356	25	117	−1,22	0.230	−0,24
	Measurement	5,46497	1,27288	5,35316	1,49954	24	117	−0,94	0.360	−0,19

Table 5. Wilcoxon signed-rank test results for the van der laan acceptance scales.

	Scale	Mean audio-only	SD audio-only	Mean haptic	SD haptic	N nonzero	W	z	p	r
Van der Laan	Useful	12.00000	6.78233	2.47826	0.99405	22	5	−3.94	<.001	−0.84
	Pleasant	2.00000	1.08012	1.50087	0.57737	18	45	−1.76	0.068	−0.42
	Good	2.45913	1.11726	2.16696	1.0274	16	44	−1.22	0.216	−0.3
	Nice	3.54087	1.11726	4.04174	0.84059	16	34	−1.76	0.073	−0.44
	Desirable	2.66783	1.31235	2.08348	0.81223	17	41	−1.68	0.086	−0.41
	Effective	2.45913	1.38382	1.91652	0.70218	19	58	−1.47	0.134	−0.34
	Assisting	3.45739	1.07933	4.12522	0.66536	19	34	−2.45	0.011	−0.56
	Worthwhile	2.04174	1.13575	1.50087	0.70712	19	56	−1.59	0.099	−0.36
	Harmonic	3.7913	1.18951	4.41565	0.81225	19	48	−1.87	0.057	−0.43

Table 6. Wilcoxon signed-rank test results for the user experience questionnaire (UEQ) – 6 aggregated scales and 26 bipolar items.

UEQ	Scale	Mean audio-only	SD audio-only	Mean haptic	SD haptic	N nonzero	W	z	p	r
UEQ aggregated scales	Attractiveness	5,03709	2,07673	2,58180	0,87552	26	2	−4,1	<.001	−0,86
	Perspicuity	4,25091	0,89687	4,92482	0,65356	20	24	−3,04	0.002	−0,68
	Efficiency	4,92437	1,23455	5.60824	0,82366	22	58	−2,21	0.027	−0,47
	Dependability	3,17391	0,97645	2.94565	0,66739	24	128	−0.63	0.546	−0,13
	Stimulation	4,06612	0,65616	4,45697	0,58817	23	62	−2.3	0.020	−0.48
	Novelty	3,77083	0,82395	3,30435	0,73335	22	54	−2,35	0.018	−0.5
UEQ bipolar items	annoying / enjoyable	12,50000	6,49359	3.09091	1,50899	20	0	−3,92	<.001	−0,88
	not understandable / understandable	4,95652	1,57365	5,56522	1,27947	16	42	−1,37	0.168	−0,34
	creative / dull	5,52174	1,74130	5.7808	1,17347	17	59	−0,83	0.392	−0.2
	easy to learn / difficult to learn	4,30254	1,33305	2,82428	1,34012	19	14	−3,28	<.001	−0.75
	valuable / inferior	1,95652	1,30145	1,78442	1,31736	16	62	−0,28	0.771	−0,07
	boring / exciting	3,30254	1,51616	2.34964	1,11722	21	51	−2,24	0.022	−0,49
	not interesting / interesting	3,78442	1,50239	5,13225	1,02055	18	14	−3.11	0.002	−0,73
	predictable / unpredictable	3,87138	1,56886	5,34783	1,08783	18	16	−3,03	0.002	−0,71
	fast / slow	4,95652	1,94441	5,30072	1,26623	20	84	−0,77	0.435	−0,17
	inventive / conventional	2,52174	1,31445	2,74275	1,42099	21	99	−0,57	0.558	−0,13
	obstructive / supportive	4,82428	1,27358	3,21558	1,10168	21	20	−3,32	<.001	−0,72
	good / bad	5,34783	1,20176	6,04167	0,64167	19	40	−2.19	0.025	−0.5
	complicated / easy	3,08696	1,76717	2,08696	1,28242	16	30	−1,96	0.044	−0.49
	unlikable / pleasing	5,86775	1,42357	5,86957	1,32876	15	56	−0.23	0.818	−0.06
	usual / leading edge	4,43659	1,24506	5,17391	1,00659	15	20	−2,3	0.020	−0,59
	unpleasant / pleasant	2,91667	1,38051	4,69565	1,45766	21	18	−3,37	<.001	−0,74
	secure / not secure	4,61051	1,71287	5,17391	1,00659	19	56	−1,59	0.109	−0,36
	motivating / demotivating	2,47826	1,17472	2,09058	1,01795	14	28	−1,51	0.125	−0,4
	meets expectations / does not meet expectations	3,60507	1,66140	2,21739	1,06144	14	2	−3,14	0.002	−0,84
	inefficient / efficient	3,08696	1,86298	2,78261	1,21428	20	91	−0,52	0.596	−0,12
	clear / confusing	5,21920	1,41290	5,86957	0,94659	16	30	−1,94	0.049	−0,48
	impractical / practical	2,56341	1,58325	2,52355	1,09824	17	75	−0,07	0.943	−0,02
	cluttered / organized	4,91486	1,41157	5,30435	1,19545	14	37	−0,97	0.323	−0,26
	attractive / unattractive	2,47826	1,40120	2,91667	1,50121	20	76	−1,06	0.281	−0.24
	friendly / unfriendly	3,56341	1,68953	2,43659	1,24506	20	44	−2,26	0.023	−0.51
	conservative / innovative	3,34601	1,65791	2,69565	1,39673	17	44	−1,51	0.127	−0,37

Table 7. Wilcoxon signed-rank test results for the net promoter score (NPS).

Scale	Mean audio-only	SD audio-only	Mean haptic	SD haptic	N nonzero	W	z	p	r
NPS	12,50000	6,49359	5,45455	3,59533	21	18	−3,37	<.001	−0,74