

Optimization of Interface Design Based on User Behaviors—With a Focus on the Adoption of Touch-Based UI in Home Appliances

Kaito Nozaki and Yang Wonseok

Shibaura Institute of Technology, Koto-ku, Tokyo, 135-8548, Japan

ABSTRACT

The rapid shift toward touch-based UI in modern consumer products has created a mismatch with the mental models users have developed through long-term use of products with physical controls. This mismatch can cause user confusion and reduce usability. Therefore, it is important to approach digitalization in a way that aligns with users' mental models. This research focuses on tasks involved in product use in order to identify the UI formats best suited to different operational characteristics. First, the functions of existing microwave ovens and washing machines were investigated and classified. Based on this classification, ten UI patterns representing different levels of digital integration were developed and evaluated through user testing. The results showed that, for microwave ovens, a fully digital UI received the highest usability ratings, suggesting that interface consistency may improve ease of use. In contrast, for washing machines, the interface operated entirely by physical buttons was rated highest. This finding suggests that tasks involving complex decision-making may be better supported by physical controls, which can enhance users' sense of control. These findings provide useful design implications for balancing the convenience of digitalization with users' established mental models and the operational characteristics of specific products. Ultimately, this research contributes to the design of safer, more intuitive, and more ergonomic UI for future household appliances.

Keywords: Home appliances, Operating characteristics, Touch-based UI

INTRODUCTION

In recent years, interface design in industrial equipment and automobiles has rapidly shifted from dedicated physical controls to touchscreen-based interfaces, a trend often associated with the shift toward software-defined vehicles (SDVs). Although software control enables flexible information presentation and feature scalability, it can also increase visual and cognitive demands, creating the new challenge of degraded operational performance. In an on-road study, Vikström (2022) reported that the task completion time in a touchscreen-equipped vehicle was approximately four times longer than that in a vehicle equipped with predominantly physical controls. Against this background, the Euro NCAP (2026) has begun to re-evaluate the role of physical operation. The underlying cause of this gap is not simply user

proficiency but structural differences between the two modalities. Physical buttons and dials provide tactile landmarks at the fingertip, such as geometry and resistance during actuation. As noted by Radwin and Jeng (1997), key travel and actuation force provide essential information for appropriate motor control. Physical controls also allow users to preposition their fingers on a button before action, supporting location and confirmation with reduced reliance on vision. By contrast, touch-based interfaces typically present a smooth glass surface that offers few physical cues to the fingertip. A biomechanical analysis by Bachynskyi et al. (2015) suggested that touch interactions on flat surfaces may increase physical load in terms of posture and musculoskeletal demand. Moreover, because there is no stable place to rest the finger, users may be forced to keep their fingers hovering above the surface, increasing uncertainty during usage. Minimalistic flat designs in digital interfaces can further exacerbate this issue, as demonstrated by Burmistrov et al.'s (2015) finding that interfaces lacking three-dimensional cues can increase cognitive load. Although prior research has clarified the characteristics of both physical and touch-based interfaces, the UI modality that is optimal for specific operational content has not yet been identified. Therefore, this research aims to identify task-appropriate UI modalities based on operational characteristics and task properties. To this end, we used microwave ovens and washing machines as case studies and examined how differences in UI modality for each task affected users' subjective evaluations.

Cognitive Change Associated With Lack Of Feedback

One of the most significant structural differences was the lack of haptic feedback. The distinct haptic click of physical buttons provides immediate confirmation of successful actuation at the fingertip, thereby reducing the need for visual confirmation. Akamatsu and MacKenzie (1996) showed that haptic information can reduce the target-selection time. In contrast, touch-based UIs typically lack such cues, increasing visual reliance and keeping the user's eyes on the display. Ramnath et al. (2020) reported that reaction times increased by more than 50 percent when interacting with infotainment functions via touch inputs while driving.

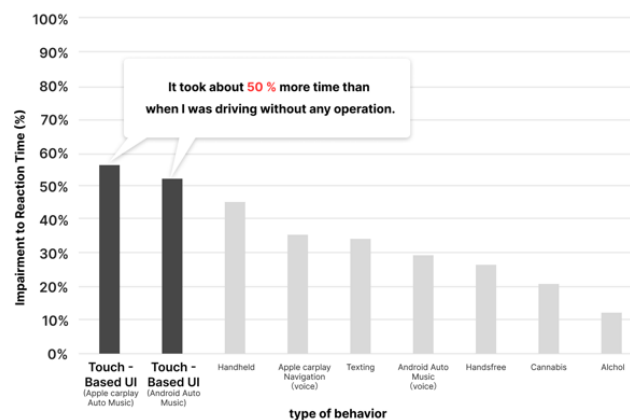


Figure 1: Reaction rate during operation.

Meanwhile, Hoggan et al. (2008) argued that the absence of haptic feedback can shift attention and cognitive resources toward the visual channel, whereas providing haptic feedback can support performance in touchscreen interactions. However, much of the existing literature focuses on improving feedback for isolated input actions. This paper presents comprehensive design guidelines for complex, multistep interaction processes, such as home appliances, leveraging the respective strengths of physical and digital interfaces according to task characteristics.

Product's Sense of Initiative to Users

While using an interactive system, users compare their intended actions with feedback from the system to verify that the system responded as expected. The sense of agency (SoA) emerging through this process is regarded as an important indicator of whether users feel that they can control the system appropriately (Cornelio et al., 2022). The widespread adoption of touch panels in home appliances may remove the physical feedback associated with operation, thereby attenuating SoA.

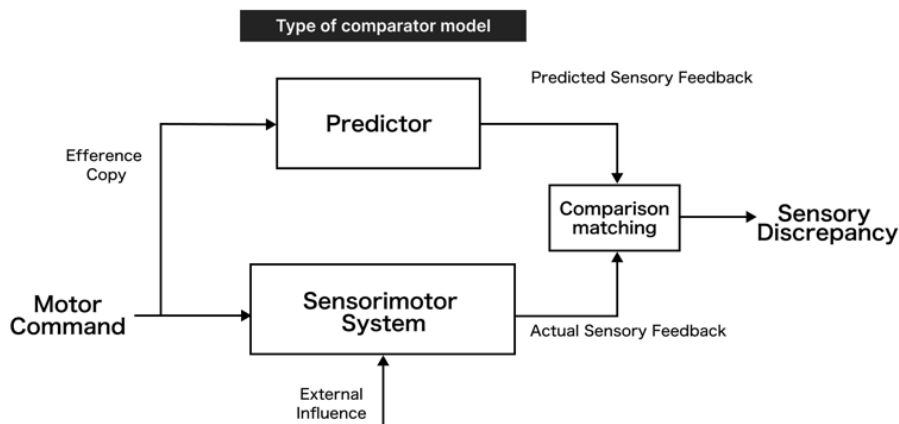


Figure 2: Comparator model.

According to the comparator model, SoA relies on the match between internally generated predictions of the sensory consequences of one's actions and actual sensory feedback (Murakami and Kitazaki, 2024). However, a lack of haptic information in touch-based UI may disrupt this matching process. Previous studies reported that a physical click and the presence of haptic feedback contribute to the formation of SoA (Cornelio et al., 2017). Providing haptic feedback has also been shown to strengthen the temporal binding between actions and outcomes (Evangelou et al., 2021). In addition, differences in input devices can modulate the strength of the SoA (Bergstrom-Lehtovirta et al., 2018). However, much of the existing literature focuses on isolated actions. Therefore, this research investigates how SoA changes across tasks with different characteristics and examines the suitability of optimal UI modalities in multistep operation processes, such as those found in home appliances.

The UI Design is Affected by Physical Cognitive Process

The interaction characteristics of UI, as well as the underlying sensorimotor and cognitive processes, are key factors shaping user performance. Bachynskyi et al. (2015) showed that touch-surface orientation and device configuration affect posture, muscle activity, and interaction performance. Meanwhile, Kay et al. (2013) reported that in touch input, a finger-lift response involves less execution time than a touch-down press, which can directly bias measured reaction-time values. Huang and Hou (2025) suggested that differences in input modalities could influence user trust and cognitive load. In alignment with these cognitive perspectives, Mathur and Moallem (2022) demonstrated that the spatial configuration of in-vehicle touchscreen interfaces—specifically the distinction between vertical and horizontal grid segmentation—induces significant variances in visual search efficiency and task success rates. Conversely, Xia (2023) argued that an information architecture predicated on user behavioral logic, as opposed to functional logic, facilitates a more precise mapping to the user’s mental model, thereby mitigating operational barriers and reducing cognitive friction in home appliance interfaces. Furthermore, Oulasvirta et al. (2018) modeled neuromotor control in button-pressing, and de Korte et al. (2008) reported that haptic feedback can alter movement behavior and muscle loading during interaction. Taken together, these findings indicate that UI design can shape interaction behaviors through both bodily and cognitive mechanisms. However, because most existing literature focuses on isolated low-level actions, this research examines concrete product-specific operations.

Research Method

In this research, the following three-step approach was conducted to present guidelines for optimal UI design from a usability perspective in a digitized interface.

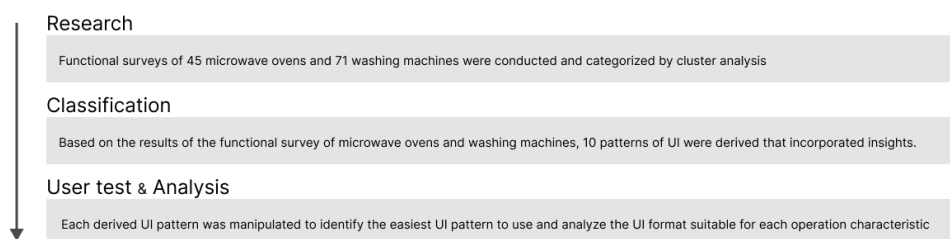


Figure 3: Research method.

Step1: Classification of Current Functions

After extracting functions from 45 current microwave ovens and 71 washing machines, classification was performed using quantification III and cluster analysis for each product. As a result, the current microwave oven and washing machine could be classified into three different patterns. The characteristics of microwave ovens and washing machines classified below are shown.

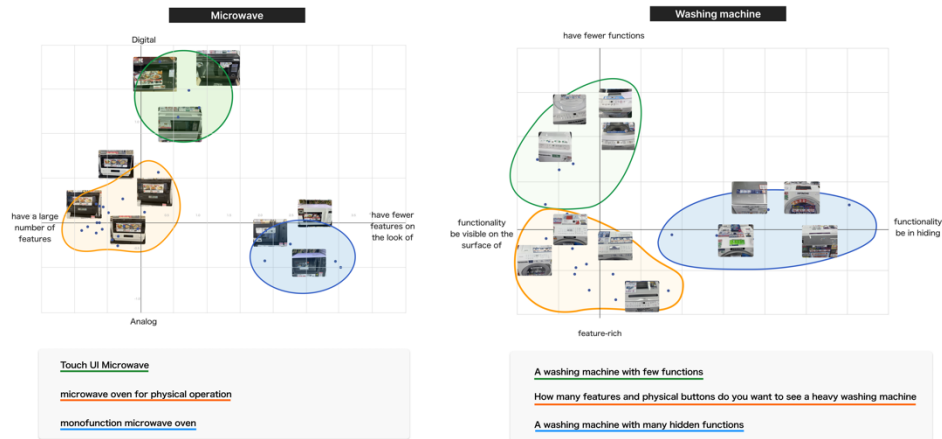


Figure 4: Positioning map (microwave & washing machine).

Step 2: Derivation of UI Patterns

The classification of functionality based on the current electronic range and washing machine. Each of the electronic range and washing machine 5 patterns are derived from the electronic range and washing machine. The following example shows the UI for 10 patterns.

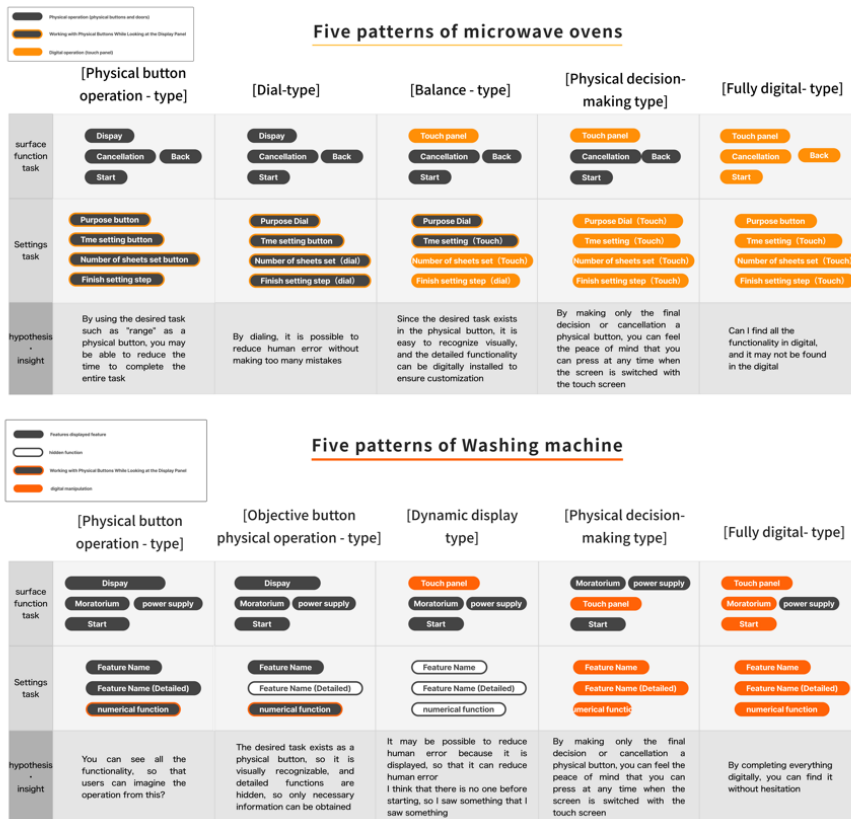


Figure 5: Guide of UI patterns.

Step 3: User Test

1) Experimental Method

A UI pattern sample was created and a user test was conducted on 30 subjects. The subjects were asked to complete the questionnaire before and after each sample was operated, and a total of 10 patterns of samples were evaluated.

2) Evaluation Method

The usability was quantified using the System Usability Scale (SUS) developed by the evaluation method (Brooke, 1986). In addition, I asked six questions that I extracted from the functional survey I created. To measure the subject's ability, affinity for digital technology was confirmed using ATI (Affinity for Technology Interaction), developed by Franke (2019). The designated task was performed for each microwave oven and washing machine, and a total of 10 UI patterns were generalized thereafter. The recommended UI format was reviewed for each task and operation characteristic.

Result

1) Microwave (Physical button operation - type / Dial-type / Balance - type / Physical decision-making type / Fully digital- type)

Table 1 presents the results of the SUS score and ATI in the microwave oven. First, a single regression analysis was conducted to examine the association between ATI and SUS scores, but no statistically significant relationship was confirmed. When comparing SUS scores based on UI pattern, the completely digital type showed the highest score in the microwave oven, followed by dial and physical button types. These results suggest that unifying operations into a single UI format in a microwave may contribute to improving subjective usability. In addition, a multiple regression analysis was performed with the SUS score of each UI pattern as the objective variable, as well as the evaluation score of the six items as the explanatory variable. Statistically significant effects were observed for all the four UI patterns.

Table 1: Microwave SUS and ATI results.

Pattern	SUS	Single Regression Analysis of SUS and ATI
Fully digital- type	64.6	n.s.
Dial-type	64.0	n.s.
Physical button operation - type	59.5	n.s.
Physical decision-making type	54.2	n.s.
Balance - type	49.5	n.s.

Table 2: Multiple regression analysis by microwave SUS and element.

Pattern	Appearance Assessment	Feature-Rich	Operational Imagination	Ease of Finding One's Purpose	Decisionability	Recognizability of Revocation
Fully digital type	n.s.	n.s.	P < 0.05	n.s.	P < 0.05	n.s.
Dial-type	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Physical button operation - type	P < 0.05	P < 0.05	P < 0.05	n.s.	P < 0.05	n.s.
Physical decision-making type	n.s.	n.s.	P < 0.05	n.s.	n.s.	n.s.
Balance - type	n.s.	n.s.	n.s.	P < 0.05	n.s.	n.s.

2) Washing Machine (Physical button operation - type / Objective button physical operation - type / Dynamic display type / Physical decision-making type / Fully digital type)

Similar to microwave ovens, Table 3 presents the SUS score and ATI results for the washing machine. First, a single regression analysis was conducted to examine the association between ATI and SUS scores, but no statistically significant relationship was confirmed. When comparing SUS scores based on UI pattern, the physical button operation type showed the highest score for washing machines, followed by the physical decision-making and the objective button physical operation types. These results suggest that tasks involving decision-making, such as “start” and “cancellation,” in the washing machine may contribute to improving subjective usability. In addition, a multiple regression analysis was performed with the SUS score of each UI pattern as the objective variable and the evaluation score of six items as the explanatory variable. A statistically significant effect was observed for all UI patterns.

Table 3: Washing machine SUS and ATI results.

Pattern	SUS	Single Regression Analysis of SUS and ATI
Physical button operation - type	61.6	n.s.
Physical decision-making type	56.7	n.s.
Objective button physical operation - type	51.8	P < 0.10
Fully digital type	48.3	n.s.
Dynamic display type	45.7	n.s.

Table 4: Multiple regression analysis by SUS and element of washing machine.

Pattern	Appearance Assessment	Feature-Rich	Operational Imagination	Ease of Finding One's Purpose	Decisionability	Recognizability of Revocation
Physical button operation - type	n.s.	n.s.	P < 0.05	n.s.	n.s.	P < 0.05
Physical decision-making type	P < 0.05	P < 0.05	n.s.	n.s.	n.s.	n.s.
Objective button physical operation - type	n.s.	n.s.	n.s.	P < 0.05	P < 0.05	P < 0.05
Fully digital-type	n.s.	n.s.	P < 0.05	P < 0.05	P < 0.05	n.s.
Dynamic display type	n.s.	n.s.	n.s.	n.s.	P < 0.05	n.s.

3) UI Format Assessment

In order to make it applicable to products other than microwave ovens and washing machines, the operation process was generalized based on three operation processes: “tasks during product configuration”, “tasks to start”, and “tasks to perform emergency cancellation”. “Start Task” and “Cancel Urgent Task” focus on transitions from UI format before performing the task, respectively.

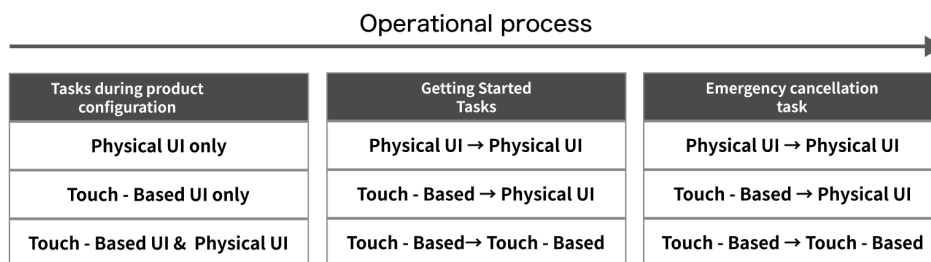


Figure 6: Classification in UI format.

The results of the unitary arrangement variance analysis confirmed the significant differences between the two items. Touch-Based UI & Physical UI was the most highly rated in “ease of operation imagination,” suggesting increased operational predictability using frequent features as physical UI. In addition, in “ease of cancellation,” the form using the physical UI for the final operation ranked high. Consequently, it is effective to assign a physical

UI that is easy to predict for daily operations and easy to recognize for emergency operations to improve operability and sense of security.

Table 5: UI format analysis results.

Order	Operational Imagination		Feature-Rich	
	UI Style	Point	UI Style	Point
First	Touch-Based UI & Physical UI	3.767	Touch-Based UI→ Physical UI	4.367
Second	Physical UI	3.525	Physical UI→ Physical UI	4.083
Third	Touch-Based UI	3.280	Touch-Based UI→ Touch-Based UI	4.000

CONCLUSION

This research examined how differences in UI modality associated with product digitization affect users' subjective evaluations. Adopting a consistent UI modality tended to yield higher ratings for microwave ovens. This suggests that, because microwave-oven use typically involves relatively few tasks from initiation to completion, minimizing burdens such as gaze shifts can enhance perceived ease of use. For washing machines, perceived usability improved when tasks involving decision-making were performed using physical controls. As washing-machine operation often requires many steps even within a single task, we inferred that users prefer to secure the final commitment through the certainty provided by physical feedback. Although the development of products with touch-based interfaces has accelerated with advances in ICT, our findings suggest that UI selection should not be treated as a binary choice in which every operation is assigned to either physical controls or touch-based interfaces. Instead, designers should analyze user behavior at the task level and allocate roles between physical and touch-based interfaces according to operational characteristics. These results extend prior work that has focused on isolated UI attributes by offering practical guidance for determining adoption policies for physical and touch-based interfaces in product design. Accordingly, the selection of appropriate UI modalities based on operational characteristics and usage contexts may improve usability not only for microwave ovens and washing machines but also for other products. Future studies should develop concrete design guidelines linked to the evaluation dimensions used in this research.

REFERENCES

- Akamatsu, M., & MacKenzie, I. S. (1996). Movement characteristics using a mouse with tactile and force feedback. *International Journal of Human-Computer Studies*, 45(4), 483–493.
- ATI Scale. (n.d.). Affinity for Technology Interaction (ATI) Scale. Retrieved February 18, 2026, from <https://ati-scale.org/>

- Bachynskyi, M., Palmas, G., Oulasvirta, A., Weinkauff, T., & Steed, A. (2015). Performance and ergonomics of touch surfaces: A comparative study using biomechanical simulation. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15). ACM.
- Bergstrom-Lehtovirta, J., et al. (2018). I really did that: Sense of agency with touchpad, keyboard, and on-skin interaction. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. ACM.
- Brooke, J. (1996). *SUS: A "quick and dirty" usability scale*. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & I. L. McClelland (Eds.), *Usability evaluation in industry* (pp. 189–194). Taylor & Francis.
- Burmistrov, I., Zlokazova, T., Izmalkova, A., & Leonova, A. (2015). Flat design vs traditional design: Comparative experimental study. In Human-Computer Interaction – INTERACT 2015 (LNCS 9297, pp. 106–114). Springer.
- Cornelio Martinez, P. I., et al. (2017). Agency in mid-air interfaces. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. ACM.
- Cornelio, P., et al. (2022). The sense of agency in emerging technologies for human-computer integration: A review. *Frontiers in Neuroscience*.
- de Korte, E. M., de Kraker, H., Bongers, P. M., & van Lingem, P. (2008). Effects of a feedback signal in a computer mouse on movement behaviour, muscle load, productivity, comfort and user friendliness. *Ergonomics*, 51(11), 1757–1775.
- Euro NCAP. (2025, November 26). *Euro NCAP announces 2026 protocol changes to tackle modern driving risks*. <https://www.euroncap.com/en/press-media/press-releases/euro-ncap-announces-2026-protocol-changes-to-tackle-modern-driving-risks/>
- Evangelou, G., et al. (2021). I feel it in my fingers! Sense of agency with mid-air haptics. In 2021 IEEE World Haptics Conference (WHC). IEEE.
- Hoggan, E., Brewster, S. A., & Johnston, J. (2008). Investigating the effectiveness of tactile feedback for mobile touchscreens. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '08). ACM.
- Huang, H., & Hou, G. (2025). The impact of usage experience and input modality on trust experience and cognitive load in older adults. *Frontiers in Computer Science*, 7, 1659594.
- Kay, M., Rector, K., Consolvo, S., Greenstein, B., Wobbrock, J. O., Watson, N. F., & Kientz, J. A. (2013). PVT-Touch: Adapting a Reaction Time Test for Touchscreen Devices. *PervasiveHealth '13*, 248–251.
- Mathur, P., & Moallem, A. (2022). Tesla Model 3: Impact of vertical segmentation on visual search time. *Usability and User Experience*, 39, 1–9.
- Murakami, T., & Kitazaki, M. (2024). Effects of transformation patterns in virtual embodiment on sense of body transformation, sense of body ownership, and sense of agency. *Transactions of the Virtual Reality Society of Japan*, 29(1), 39–47.
- Oulasvirta, A., Kim, S., & Lee, B. (2018). Neuromechanics of a Button Press. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–13.
- Radwin, R. G., & Jeng, O.-J. (1997). Activation force and travel effects on overexertion in repetitive key tapping. *Human Factors*, 39(1), 130–140.
- Ramnath, R., et al. (2020). Interacting with Android Auto and Apple CarPlay (TRL report).
- Vikström, F. D. (2022, October 18). Physical buttons outperform touchscreens in new cars, test finds. *Vi Bilägare*.
- Xia, C. (2023). Research on user interface design of home appliances based on behavioural logic. *SHS Web of Conferences*, 152, 05003.