

# Cognitive-behavioral Responses to Kitchen Cabinet Interfaces: Implications for Sensor-integrated Materials and Smart Usability Design

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(Received January 6, 2026; accepted February 16, 2026)

**Keywords:** cognitive behavior, kitchen cabinet door, usability, influencing factors

Product usability is linked to how design elements align with human cognitive processes. We investigated the cognitive-behavioral responses to kitchen cabinet interfaces by integrating Norman's three levels of design—instinct, behavior, and reflection—with modern material and sensor technologies. Through three psychophysical experiments using E-Prime software, we examined the effects of cabinet type, handle form, handle position, signifiers, and physical gaps on user perception. The results from Experiment 1 revealed that cabinet type and handle position significantly affect the instinctive classification of units as either drawers or doors. The results of Experiment 2 demonstrated that handle form and signifiers are critical behavioral determinants for perceived opening mechanisms (pull vs press). Furthermore, handle form and signifiers significantly impacted perception latency, with specially shaped handles and physical gaps increasing cognitive load and uncertainty. Reflective usability assessments in Experiment 3 confirmed that alignment with cognitive habits, such as vertical orientations for doors, optimizes accuracy and response speed. Such results underscore the necessity of incorporating smart interfaces, such as piezoelectric sensors and graphene-based touch-sensitive coatings, to provide active feedback and visible affordances. The results provide a reference for the development of a framework for integrating sensor technologies and functional materials, such as piezoelectric thin films, graphene coatings, and organic polymers, into intelligent furniture design to harmonize advanced materials with human behavioral habits to enhance usability.

## 1. Introduction

Norman established the principles of cognitive-behavioral design, providing a theoretical framework for evaluating product usability.<sup>(1)</sup> However, a persistent challenge for designers lies in the integration of product design elements with cognitive processes to optimize user experience. Because design features significantly shape how users perceive and interact with products, it is essential to examine the relationship between user cognition and product design, with an emphasis on the usability of physical interfaces.

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<https://doi.org/10.18494/SAM6167>

Kitchen cabinet doors are designed with primary attention paid to aesthetics and structural integrity, while the ergonomics of opening mechanisms have received limited consideration.<sup>(2)</sup> Although extensive research has been conducted to address door usability,<sup>(3)</sup> the design and functions of cabinet doors have not been extensively researched owing to their distinctive cognitive demands and diverse design configurations.

Norman classified cabinet doors with poorly designed interfaces as Norman doors, which confuse users about whether to push or pull, which are defined as interactions between users and the cabinet doors.<sup>(4)</sup> The interactions are closely related to the concept of affordance, which is a term introduced to describe latent action possibilities between an actor and the environment.<sup>(5)</sup> Norman adapted this concept to product design, emphasizing how products guide human behavior by signaling potential actions.<sup>(6)</sup> In the kitchen, the cabinet door handle is a critical design element as it strongly affects the user's cognitive perception.<sup>(7)</sup> The handle shape affects user behavior<sup>(8)</sup> and alters the user's perceptions of required force, affecting accessibility and usability.<sup>(9)</sup> The spatial relationship between the size and position of cabinet door handles determines perceived availability,<sup>(10)</sup> while metaphorical handle designs modify the user's opening behavior.<sup>(11)</sup>

For cabinet doors, a press mark or similar visual feature acts as a signifier by indicating to the user that pressing at that location will activate the opening mechanism. A signifier in design theory refers to a perceptible cue or marker that communicates where and how an action is performed on an object.<sup>(12)</sup> The term signifier was introduced to complement Gibson's concept of affordance.<sup>(5)</sup> Gaver classified affordances into three types: visible, hidden, and error.<sup>(13)</sup> Hidden affordances are difficult to detect and are often overlooked, leading to cognitive delays, whereas error affordances mislead users into incorrect actions.<sup>(14)</sup> Norman proposed the use of constraints to mitigate these issues. While affordances describe the possible actions an object allows (e.g., a door affords opening), signifiers explicitly indicate or highlight those affordances so that users can recognize them. Without handles, the affordance of opening exists, but it is not obvious. Signifiers make the affordance visible and interpretable, reducing cognitive confusion and guiding correct interaction.<sup>(12)</sup> Conversely, inaccurate or poorly placed signifiers generate cognitive confusion and experimental error.<sup>(15)</sup>

Cabinet door handles are exposed or embedded as a visible affordance or hidden as a hidden affordance. For example, a physical gap between cabinet doors functions as an error affordance; when sufficiently wide, it is mistaken for a concealed handle, prompting an incorrect motor response. Different from conventional doors, the structural orientation of kitchen cabinet doors plays an important role in the cognition of their function. Users perceive translational motion (pulling backward) for drawers and angular motion for doors. On the basis of the principle of visibility, the cabinet door is a primary determinant of this perception, though other design elements also affect perception.

Including the cabinet doors, modern kitchens incorporate organic materials, such as specialized polymers for ergonomic and antimicrobial grips and sensors to adopt smart interfaces for users.<sup>(16)</sup> Inorganic nanomaterials, such as graphene-based coatings, have been employed for touch-sensitive surfaces.<sup>(17)</sup> Functional thin films, including piezoelectric sensors for proximity and touch detection, are also being employed to transform static cabinet doors into interactive smart interfaces that provide active feedback.<sup>(18)</sup>

Drawing on Norman’s three levels of cognitive behavior—instinct, behavior, and reflection—we examined how design elements and sensor-integrated materials affect the usability of kitchen cabinet doors. Experiments were conducted to evaluate the selection of cabinet form (drawer and door), the perceptions of opening modes (pull and press), and the overall ease of use and user satisfaction. The results serve as the basis for the development and selection of sensors and materials for kitchen equipment and for the examination of cognitive-behavioral responses and their application into material and sensor applications, and demonstrate how functional thin films and organic polymers can be integrated into cabinet interfaces to improve usability.

## 2. Methods

### 2.1 Materials

We identified design elements that affect user interaction with kitchen cabinet doors: cabinet type, handle form, handle position, signifiers, and gaps. Cabinet type is classified into two categories: horizontal and vertical. Handle form is defined by presence or absence; when present, handles are further categorized as exposed, embedded, or hidden. Exposed handles include round, short-strip, and long-strip variants; embedded handles consist of short and long embedded forms; hidden handles encompass concealed and specially shaped designs. Handle position refers to the placement of pull handles or signifiers on the cabinet door. For horizontal cabinets, positions include top, center, and right. For vertical cabinets, positions include top, center, right, and top-right, with the left door serving as the reference standard. Signifiers are classified as either present or absent. Gaps are similarly categorized by their presence or absence between cabinet doors (Table 1).

To minimize the effects of external factors, materials were remodeled using 3DMAX, developed by Autodesk, the United States of America, which is widely used for modeling, rendering, and animation. In this study, a double-door base cabinet was employed as the standard unit, with uniform color, material, and background. Specially shaped samples are shown in Fig. 1. The design elements were reflected in the experimental samples.

Table 1  
Specially shaped elements of kitchen cabinet doors.

Design element	Category	Description
Cabinet type	Horizontal	Defines orientation of cabinet doors
	Vertical	
Handle form	Present	When present, handles are classified as below
		Exposed: round, short-strip, long-strip
	Absent	Embedded: short embedded, long embedded
		Hidden: concealed, specially shaped
Handle position	Various cabinet door types	Horizontal cabinets: top, center, right
		Vertical cabinets: top, center, right, top-right (left door as reference standard)
Signifier	Present	Visual cues such as press marks indicating action points
	Absent	
Gap	Present	Refers to the space between cabinet doors, which may affect the perception of affordance
	Absent	

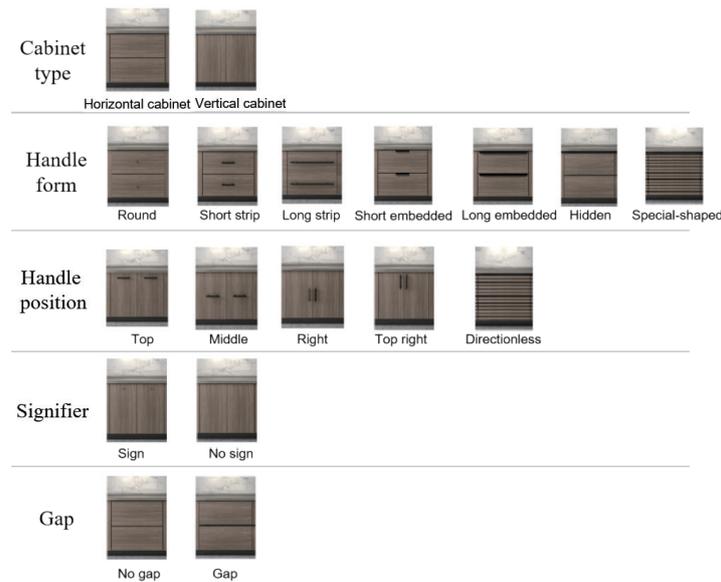


Fig. 1. (Color online) Examples of specially shaped experimental samples.

## 2.2 Experimental tools

E-Prime software was employed to explore behavior, since it is widely used in psychology<sup>(19)</sup> and in design.<sup>(20)</sup> E-Prime is a specialized software designed for creating and running psychological experiments, particularly involving cognitive processes such as perception, attention, memory, and decision-making. E-Prime enables presentation through videos, images, sounds, and text, and offers parameters such as stimulus presentation time, participant reaction time, keystroke accuracy, and character input during testing for subsequent data analysis.<sup>(21)</sup> The experiments in this study were conducted in the Ergonomics Laboratory of Central South University of Forestry and Technology in China. The environments were controlled to ensure consistent temperature and humidity, sound insulation, and shading. E-Prime 2.0 software was run on a 19-inch monitor with a resolution of  $1440 \times 900$  dpi and a refresh rate of 60 Hz.

## 2.3 Experimental process

In Experiment 1, the participants judged whether the kitchen cabinet depicted in each image was a cabinet drawer or door. 59 images numbered from 1 to 59 were presented by the E-Prime 2.0 software. Instructions and the concluding remarks of the participants, reaction time (RT Time), and keystroke response (RESP) were monitored and stored to calculate accuracy. Each image was presented once in a random order. The time for showing images was controlled by the participants. The participants pressed the 'F' key on the keyboard to choose cabinet drawer, and the 'J' key for cabinet door. Following each response, a fixation cross (+) appeared for 500 ms for the participants to focus on the screen center before the next image was displayed.

In Experiment 2, the participants identified the opening mechanism of the cabinet depicted in each image. The procedure was identical to that used in Experiment 1. The key 'F' indicated a pull-open mechanism, whereas 'J' indicated a press-to-open mechanism.

In Experiment 3, the participants evaluated the perceived usability of the cabinets shown in the images. The 59 stimulus images were categorized into drawers and cabinet doors. In the experiment, pressing 'F' indicated that the cabinet appeared easy to use, while pressing 'J' indicated that the cabinet appeared difficult to use or unusable.

## 2.4 Participants

14 undergraduate and 20 graduate students participated in the experiments, with an equal distribution of males and females. The age of the participants ranged from 19 to 34 years old, with an average age of 22.5 years. All were students majoring in design and had familiarity with kitchen cabinet door designs. Before the experiments, the participants were informed and provided consent to take part in the experiment.

## 3. Results

### 3.1 Experiment 1

The participants' perceptions of 59 kitchen cabinet images were analyzed on the basis of the frequency of pressing the "F" key (indicating a "drawer" classification). An analysis of variance (ANOVA) was conducted across five factors: cabinet type, handle form, handle position, signifiers, and gaps. The results indicated that cabinet type ( $F = 79.428, p < 0.001$ ) and handle position ( $F = 11.716, p < 0.001$ ) significantly affected the participants' perceptions. In contrast, handle form ( $F = 0.261, p = 0.951$ ), signifiers ( $F = 0.050, p = 0.826$ ), and gaps ( $F = 0.003, p = 0.986$ ) had no significant effect. Figure 2 illustrates the distribution of keystroke counts across these five factors. In the figure, the green bar presents the range from 25 to 75% of the counts. A horizontal line in the bar presents the median value, and vertical lines with red horizontal bars present the 1.51 quantile regression range. The brown area denotes the perception of horizontal forms as drawers, while the pink area presents the perception of horizontal forms as doors.

The participants predominantly classified horizontal cabinets as drawers, whereas vertical cabinets were perceived as doors. Within the cognitive model of human perception, horizontal forms are strongly associated with drawer functionality. Conversely, while vertical cabinets were primarily perceived as doors, they were occasionally mistaken for drawers. The handle position also played a critical role. When handles were located at the top or center of the cabinet, the participants tended to classify the unit as a drawer. However, when the handle was positioned on the right or upper-right side, the participants recognized it as a cabinet door.

Perceptual inconsistency and uncertainty arose when horizontal cabinets featured right-side handles or when vertical cabinets featured top-centered handles, as these configurations conflict with established cognitive habits. Perception time (keystroke latency) was also analyzed via

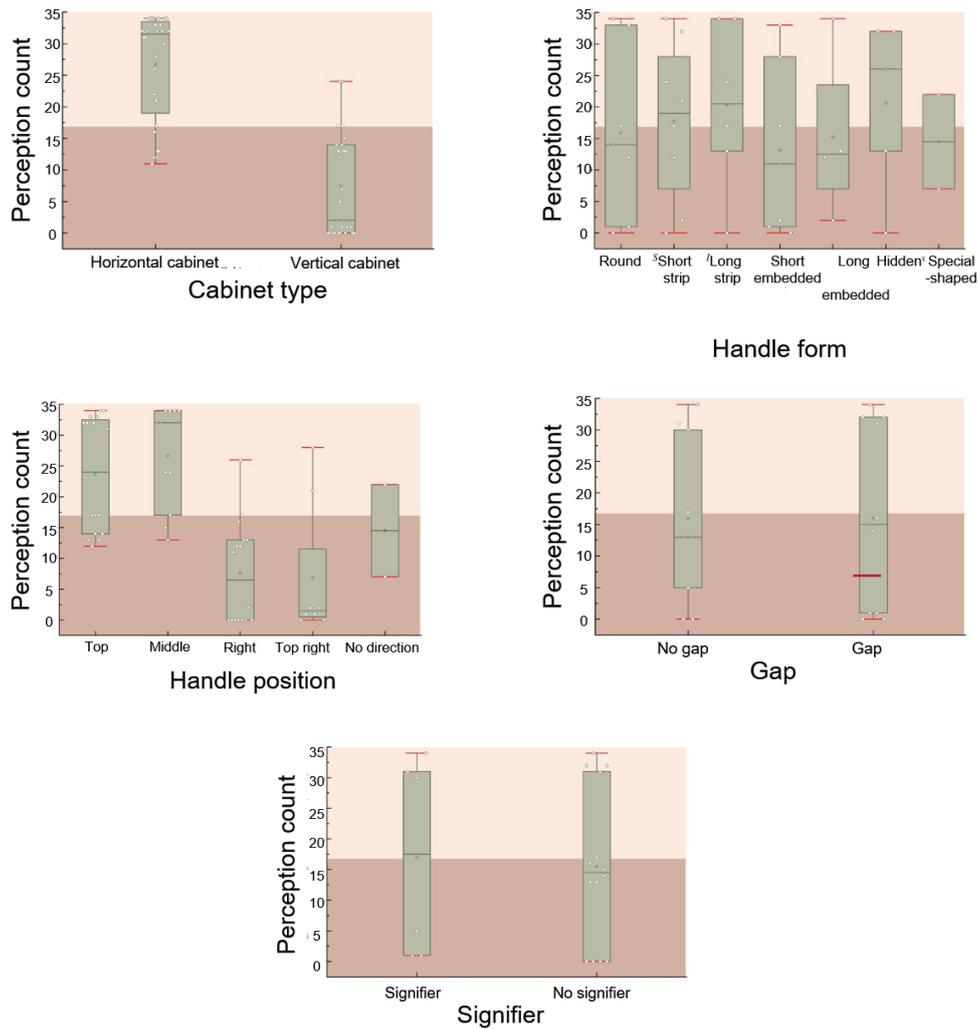


Fig. 2. (Color online) Results of cabinet-type perception counts.

ANOVA. Results showed that handle form ( $F = 3.455$ ,  $p = 0.004$ ) and position ( $F = 5.499$ ,  $p = 0.001$ ) significantly affected response latency. Cabinet type, signifiers, and gaps showed no significant effects. As shown in Fig. 3, perception time increased significantly for specially shaped handles, suggesting that unconventional designs introduce ambiguity. Similarly, nondirectional handle positions increased latency, indicating that a lack of clear positional cues hinders rapid recognition.

The relationship between keystroke count and perception time ( $F = 14.217$ ,  $p = 0.004$ ) revealed that as perceptions became variable, perception time peaked, then decreased as consensus was reached (Fig. 4). This suggests that high perceptual concentration leads to faster decision-making, while inconsistent design cues increase cognitive load and difficulty.

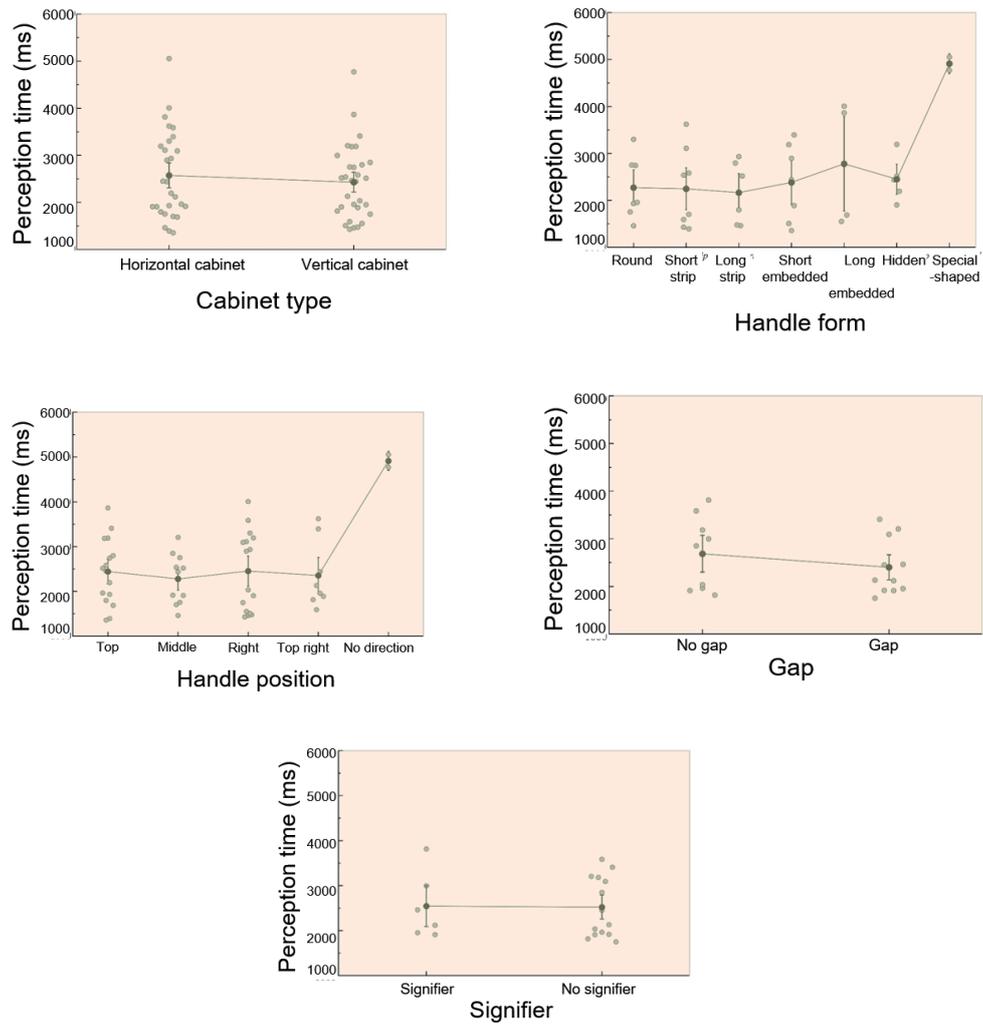


Fig. 3. (Color online) Results of cabinet type perception time. The bar indicates the mean value  $\pm 4.5$  standard error, the filled circle denotes the mean value, and the open circle shows the observed value.

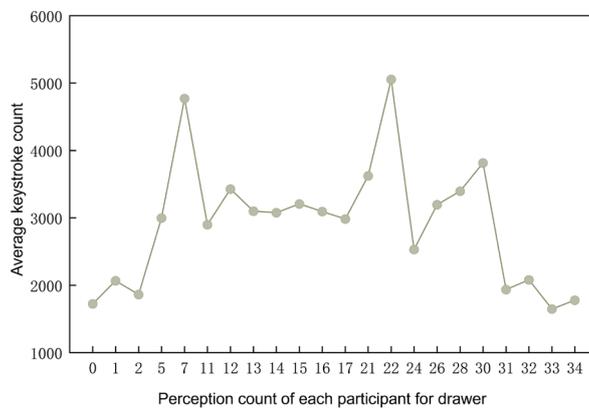


Fig. 4. (Color online) Relationship between keystroke time and perception time of each participant for drawer.

### 3.2 Experiment 2

In Experiment 2, ANOVA was used to analyze the frequency of “F” keystrokes (indicating a pull/push open type). Handle position ( $F = 198.011, p < 0.001$ ), handle form ( $F = 80.446, p < 0.001$ ), and signifiers ( $F = 10.711, p < 0.01$ ) significantly affected perceptions (Fig. 5). Gaps ( $F = 3.763, p < 0.1$ ) showed a marginal effect, while cabinet type and position (overall orientation) were nonsignificant. The presence of a handle was an important determinant of perceived affordance. Units with handles were perceived as a pull type, while those without were seen as a push type. This aligns with the Affordance Theory, where the handle provides a clear visual cue for pulling. Circular and strip handles (both long and short) were consistently identified as pull-

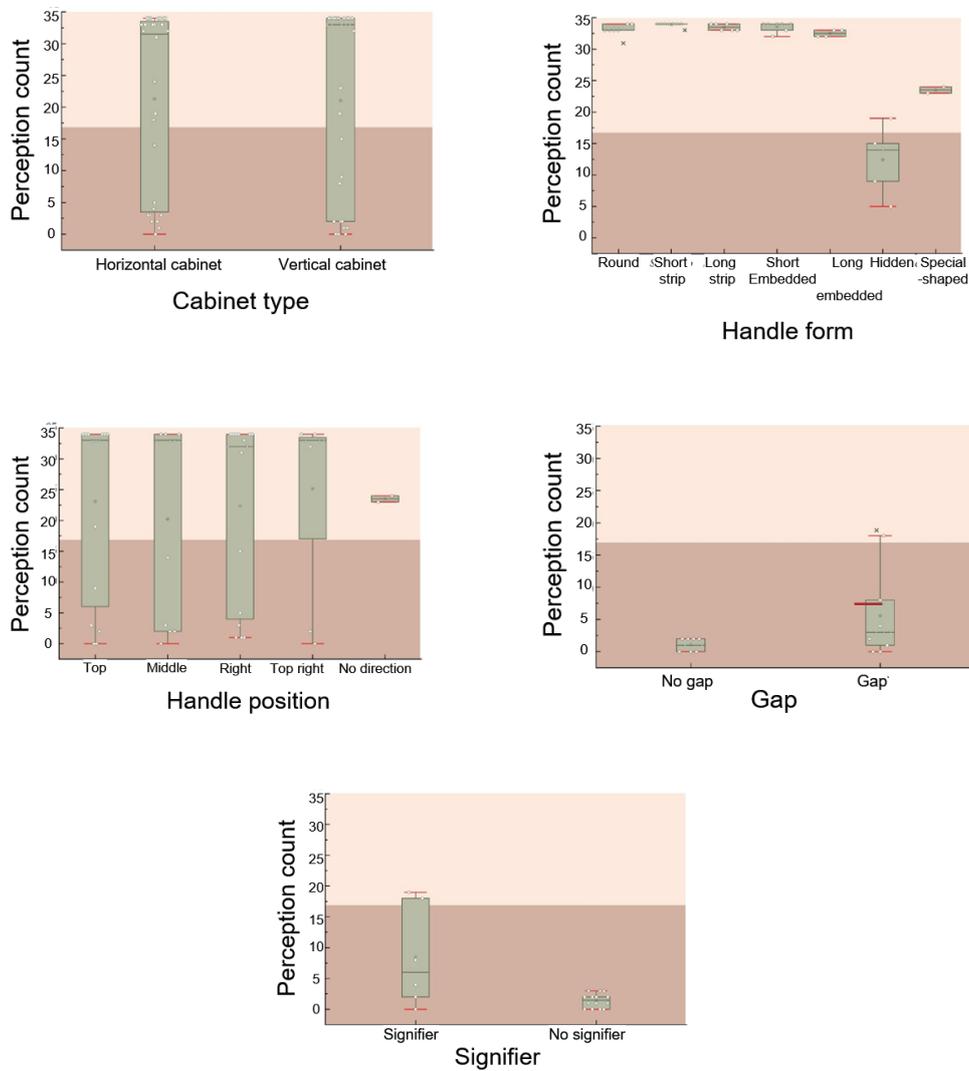


Fig. 5. (Color online) Results of open-type perception counts.

open mechanisms. However, hidden or specially shaped handles caused uncertainty. The inclusion of signifiers successfully guided the participants toward a press-type perception. Without these signifiers, perceptions became inconsistent. Furthermore, the presence of a gap distracted the participants, increasing uncertainty regarding the opening mechanism.

ANOVA results for perception time in Experiment 2 mirrored the above results. The handle form ( $F = 50.409$ ), signifiers ( $F = 29.34$ ), and gaps ( $F = 6.507$ ) all significantly affected processing duration ( $p < 0.05$ ). Figure 6 shows that hidden handles and gaps increased latency due to ambiguity, while signifiers reduced it by providing clarity. Figure 7 confirms that concentrated perception (consensus) correlates with shorter reaction times, whereas conflicting design elements reduce usability.

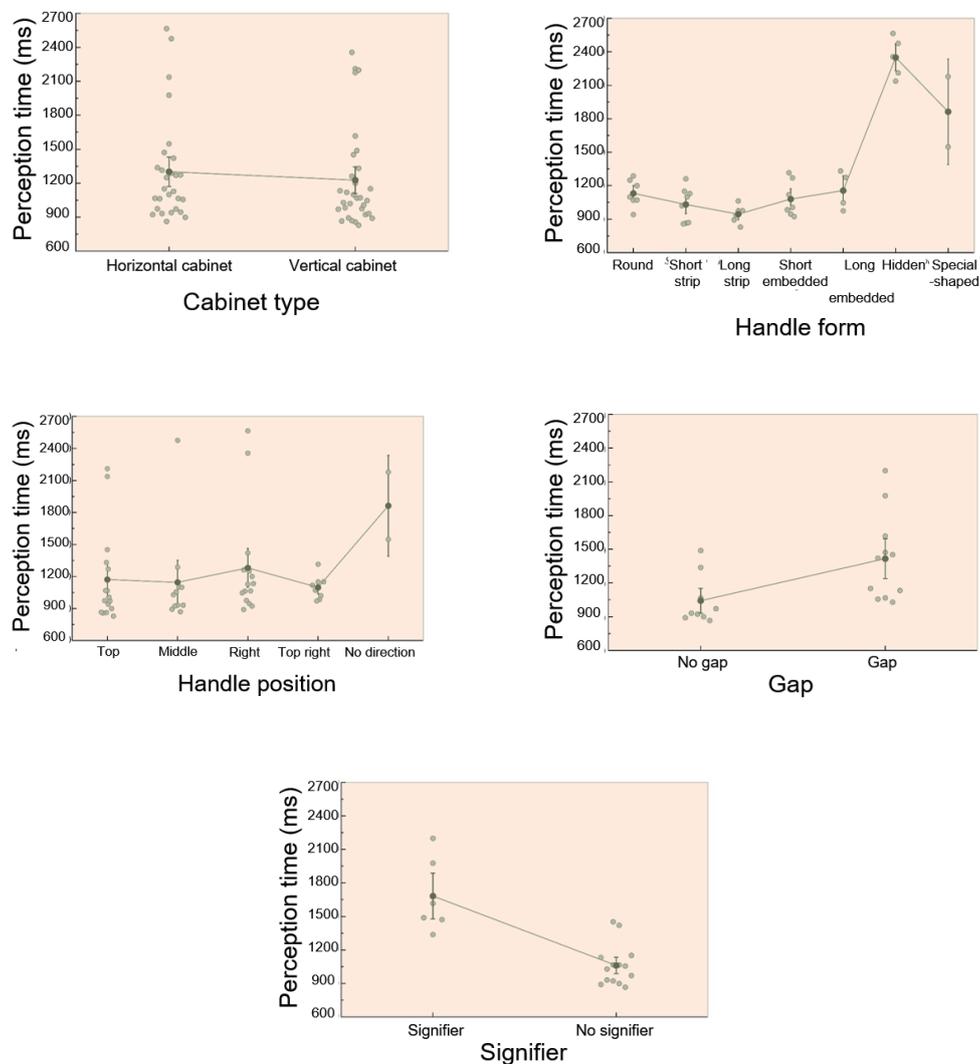


Fig. 6. (Color online) Results of open-type perception time.

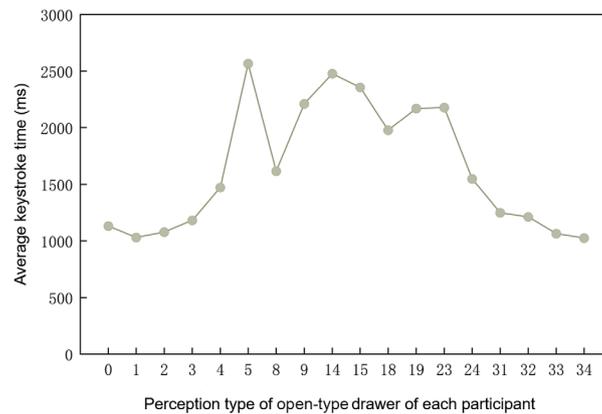


Fig. 7. (Color online) Relationship between keystroke time and perception time of each participant for open type.

### 3.3 Experiment 3

The results of Experiment 3 represented the perceived usability of cabinets and drawers. ANOVA revealed significant effects for both cabinet door perception time ( $F = 8.918, p < 0.01$ ) and drawer perception time ( $F = 9.670, p < 0.01$ ) (Figs. 8 and 9). Consistent with Experiment 1, horizontal cabinet doors were more accurately and quickly identified as drawers, while vertical cabinet doors were more efficiently recognized as doors. Usability perception peaked when the physical design aligned with user habits. While the presence of the door handle did not significantly alter usability, handle perception did. Hidden and specially shaped handles showed lower usability scores than exposed or embedded handles. The handle position and signifiers significantly affected usability perception for both drawers ( $F = 26.813, p < 0.001$ ) and doors ( $F = 13.768, p < 0.001$ ), as well as overall perception time.

## 4. Discussion

### 4.1 Instinctive level: Physical form and immediate perception

The perception of kitchen cabinet door forms is primarily driven by immediate visual cues that elicit rapid cognitive responses. Results from Experiment 1 demonstrate that cabinet type ( $F = 79.428$ ) and handle position ( $F = 11.716$ ) are the most significant factors affecting initial classification. Horizontal cabinets are instinctively associated with drawer functionality, whereas vertical orientations are perceived as doors. This indicates that structural orientation serves as a primary determinant of a user's initial cognitive model. The mapping relationship between cabinet type and handle position further shapes cognitive behavior. Handles located at the top or center lead participants to instinctively perceive the unit as a drawer, while positioning on the right or upper-right side signals a cabinet door. Inconsistencies—such as horizontal units with right-side handles—create perceptual uncertainty and increase cognitive load, as evidenced

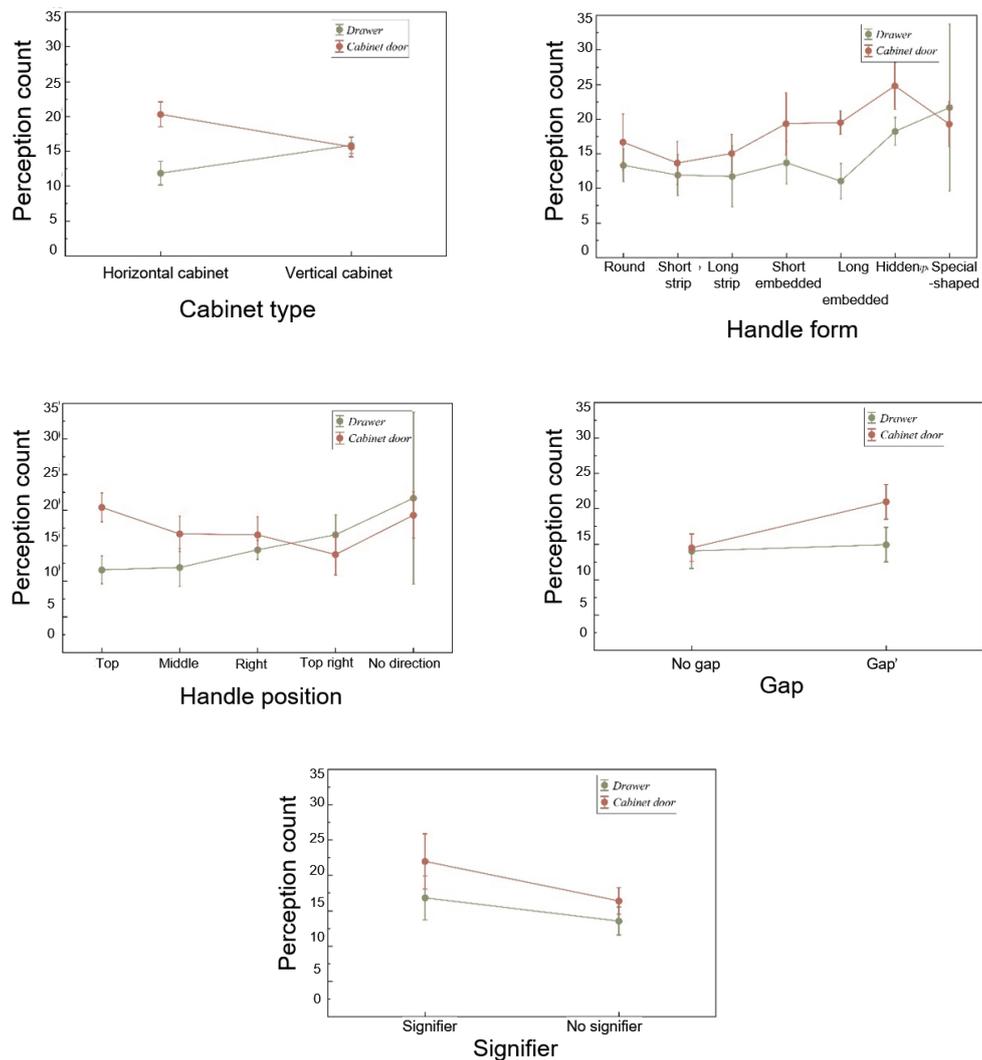


Fig. 8. (Color online) Results of drawer-type perception count.

by longer perception times when consensus is low. To reduce ambiguity and improve usability, designers should prioritize conventional handle placements that align with instinctive habits and avoid specially shaped handles that introduce confusion and delay decision-making.

Beyond visual geometry, the material composition of the interface, particularly organic polymers, plays a critical role in the ergonomic and antimicrobial quality of the grip.<sup>(16)</sup> The results suggest that when handle positions conflict with established cognitive habits, perception time increases. Integrating graphene-based coatings for touch-sensitive surfaces may mitigate this effect by enabling the entire cabinet surface to respond to instinctive contact, regardless of handle placement.<sup>(22)</sup> Such inorganic nanomaterials reduce cognitive load by transforming the cabinet door into a high-sensitivity interactive interface.

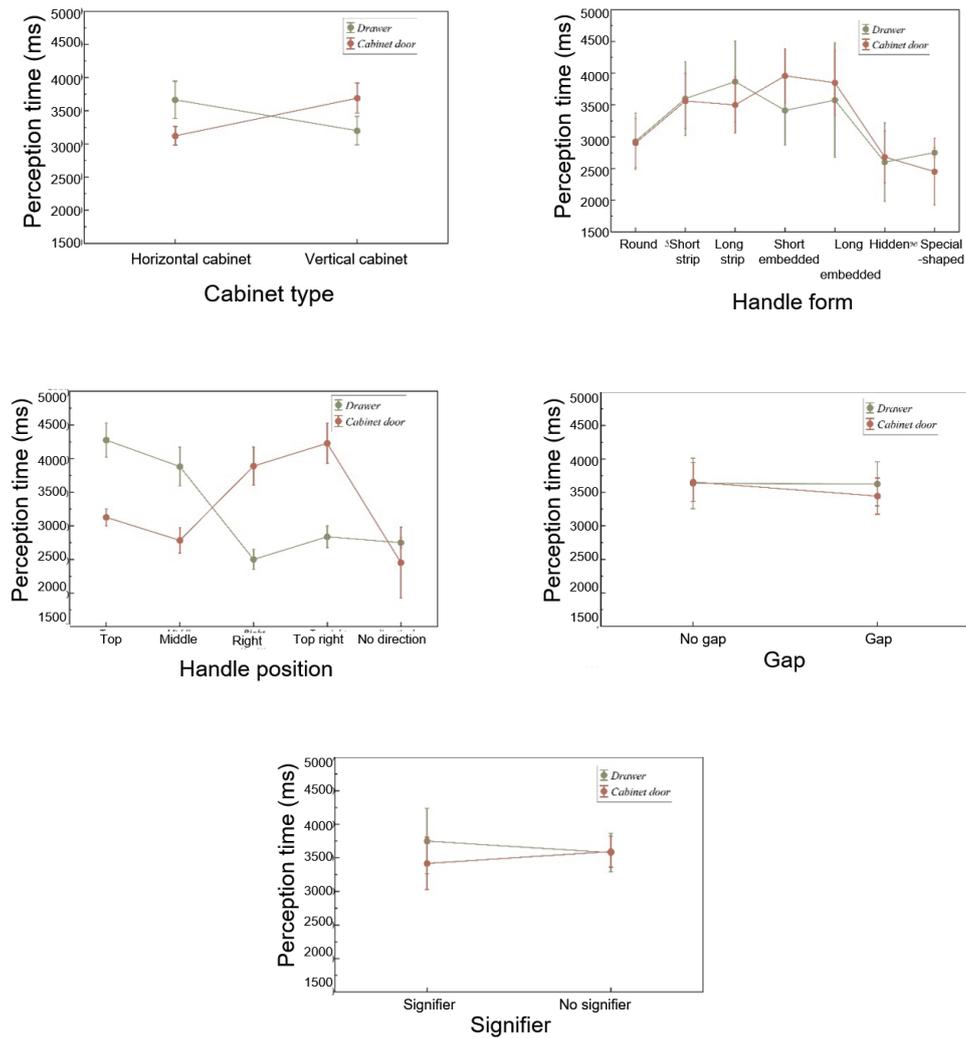


Fig. 9. (Color online) Results of drawer-type perception time.

The integration of such materials represents a shift from reactive to proactive furniture design. The use of organic polymers with high dielectric constants allows for the creation of proximity-sensing halos around cabinet perimeters. Such technological application addresses the instinctive confusion revealed in Experiment 1 by providing visual or haptic cues before a user even touches a misaligned handle. By developing materials printed or coated onto complex 3D surfaces, manufacturers can ensure that the furniture's 'intelligence' is embedded within the material, rather than added as a bulky external sensor.<sup>(18)</sup>

#### 4.2 Behavioral level: Affordance and interaction cues

From the behavioral perspective, user interaction is dictated by the perceived affordance of the interface. Results from Experiment 2 confirm that the presence and form of a handle are

dominant determinants of perceived opening mechanisms ( $F = 80.446$  for handle form). Units with handles provide a visible affordance for pulling, while those without handles are perceived as press- or push-type doors. The visibility of these affordances is critical for usability. Hidden or specially shaped handles disrupt cognitive-behavioral judgments, leading to uncertainty and significantly increased perception time. Conversely, the inclusion of signifiers, such as press marks, effectively guides behavioral intent, reducing perception time and improving cognitive speed. Signifiers act as vital visual markers that clarify latent action possibilities, particularly in designs where traditional handles are absent. Additionally, physical gaps must be managed carefully, as they can function as error affordances, distracting users and increasing uncertainty regarding the opening mechanism. In modern handle-less designs, which rely on push-type interactions, users often experience cognitive delays due to hidden affordances. To address this, functional thin films and piezoelectric sensors can be employed to provide proximity and haptic feedback.<sup>(23)</sup> These sensors transform a static door into an interactive smart interface that delivers active feedback upon approach or touch, thereby reducing the cognitive load identified in Experiment 2. While our results show that signifiers (e.g., press marks) significantly reduce perception time ( $F = 29.34$ ), the integration of proximity sensors in modern kitchen interfaces can further enhance clarity by highlighting the interaction zone before physical contact.

### 4.3 Reflective level: Usability and cognitive habits

At the reflective level, perceived usability and overall satisfaction with kitchen cabinets are significantly affected by long-term cognitive habits and subjective expectations. Results from Experiment 3 indicate that usability perception peaks when physical design aligns seamlessly with established user habits. For example, horizontal cabinets were identified more accurately and quickly as drawers, while vertical cabinets were more efficiently recognized as doors. The reflective evaluation of ease of use is also associated with handle recognizability. Hidden and specially shaped handles received lower usability scores because they conflict with the user's reflective model of how a cabinet should function. While signifiers increase the clarity of perception, their presence does not necessarily enhance subjective usability judgments if the underlying design, such as handle position, is counterintuitive. Beyond conventional design, the integration of intelligent furniture interfaces by using thin-film technology offers opportunities for reflective improvements in usability. By employing organic and inorganic material composites, such as carbon nanotubes for multifunctional smart coatings, designers can create more human-centric interfaces.<sup>(24)</sup> Reflective satisfaction and ease of use are highest when advanced technologies (e.g., tactile polymer grips or invisible interfaces based on graphene touch sensors) function consistently with the user's mental model. A successful smart interface must not only be readable and legible but must also harmonize with deeply ingrained human behavioral habits to truly enhance the user experience.

The development of transparent conductive oxides and flexible piezoelectric thin films offers a solution to the hidden affordance problem identified in Experiment 2.<sup>(22)</sup> These materials enable invisible interfaces that maintain the minimalist aesthetic of modern kitchens while providing the necessary feedback to satisfy the user's reflective need for control. In related

Table 2

Technical mapping of cognitive issues and appropriate sensors and materials to address them.

Cognitive issue	Behavioral impact	Recommended material and sensor	Mechanism and benefit
Hidden affordance (Handle-less design)	Increased cognitive delays and motor response uncertainty.	Piezoelectric sensors and functional thin films.	Transforms static panels into responsive interfaces that provide active haptic feedback upon touch <sup>(16,17)</sup>
Instinctive uncertainty (orientation and handle mismatch)	Conflict with established cognitive habits, increasing perception time.	Graphene-based touch-sensitive coatings.	Enables the entire cabinet surface to act as an interactive zone, reducing the need for precise handle alignment <sup>(22,25)</sup>
Error affordance (physical gaps)	Mistaken for concealed handles, prompting incorrect motor responses.	Proximity sensors and infrared (IR) thin-film arrays.	Detects hand approach and provides visual illumination or signifiers before a user touches the gap <sup>(26,27)</sup>
High recognition latency (specially shaped/hidden handles)	Increased cognitive load and lower usability satisfaction.	Organic polymers and multifunctional smart coatings.	Improves ergonomic grip and provides tactile cues that align with instinctive human contact behaviors <sup>(16,28)</sup>

material development, multimodal surfaces must be prioritized by combining antimicrobial properties with high-sensitivity tactile feedback to ensure the hygiene and cognitive demands of high-use kitchen environments.

To bridge the gap between user behaviors and technical implementation, the cognitive issues identified in the experiments are presented to propose appropriate materials and sensors that can be integrated into kitchen equipment design. The results of this study illustrate how cognitive usability research results can be used for the design of sensor-integrated materials. By mapping behavioral issues to sensor technologies and functional materials, necessary data for material scientists and engineers to develop smart interfaces are provided (Table 2).

## 5. Conclusions

We evaluated the relationship between cabinet design elements and user cognitive-behavioral responses, and revealed that usability is significantly shaped by the visibility and consistency of affordances. The results confirmed that structural orientation, specifically horizontal versus vertical alignment, is the primary driver of instinctive function perception. At the behavioral level, the presence and form of handles serve as dominant cues for opening mechanisms, while signifiers play a crucial role in reducing perception time and guiding correct interaction. Unconventional handle forms and physical gaps act as hidden or error affordances, significantly increasing perception latency and lowering subjective usability scores.

The results also highlighted opportunities for integrating smart technologies to mitigate cognitive confusion caused by handle-less or aesthetically complex designs. Functional thin films and piezoelectric sensors for proximity detection can transform static panels into responsive, user-centric interfaces. In addition, the use of organic polymers and inorganic

graphene coatings provides a pathway for creating antimicrobial, touch-sensitive surfaces that align with instinctive human contact behaviors. Future developments in smart cabinetry must incorporate sensor-integrated materials to deliver the visible affordances and signifiers necessary for seamless interaction. The results of this study offer a basis for further research into how intelligent furniture can be more effectively adapted to ingrained human cognitive habits. According to the results, it is required to validate the performance of sensor-integrated coatings and thin films in cabinets to advance both usability design and sensor applications.

### Acknowledgments

This research was supported by the Hunan Provincial Philosophy and Social Science Foundation Project (22YBA116) and the Key Scientific Research Projects of the Hunan Province Department of Education (25A0252).

### References

- 1 D. Norman: The design of everyday things (Basic books, New York, 2013) p. 76. <https://ia902800.us.archive.org/3/items/thedesignofeverydaythingsbydonnorman/The%20Design%20of%20Everyday%20Things%20by%20Don%20Norman.pdf>.
- 2 J.-Y. Son, Y.-H. Bae, Y.-C. Kim, R.-S. Oh, W.-H. Hong, and J.-H. Choi: Sustainability **12** (2020) 8453. <https://doi.org/10.3390/su12208453>
- 3 X. Qu, D. Zhang, G. Lu, and Z. Guo: IEEE Trans. Syst. Man Cybern. Syst **47** (2017) 2870. <https://doi.org/10.1109/TSMC.2016.2531675>
- 4 W. W. Zhang, M. H. Liu, and W. Wang: Zhuang Shi **5** (2022) 46. <https://doi.org/10.16272/j.cnki.cn11-1392/j.2022.05.025>.
- 5 J. J. Gibson: The Ecological Approach to Visual Perception (Psychology Press, New York, 2014) p. 127. <https://doi.org/10.4324/9781315740218>
- 6 R. Robert: Technol. Cult. **31** (1990) 554. <https://doi.org/10.2307/3106094>
- 7 J. Maraney: [https://www.decorhandles.co.za/blogs/news/the-science-behind-ergonomic-door-handle-design?srsltid=AfmBOopGaU\\_VOwkjloEh5F9hg1N9kWHBP517OIjc5K\\_wzthXu0swq4Nn](https://www.decorhandles.co.za/blogs/news/the-science-behind-ergonomic-door-handle-design?srsltid=AfmBOopGaU_VOwkjloEh5F9hg1N9kWHBP517OIjc5K_wzthXu0swq4Nn) (accessed December 2025).
- 8 S. Fragoso, R. R. Rebs, and D. L. Barth: Proc. 2012 Int. Work. Conf. Adv. Visual Interfaces Technol. affordances (AVI, 1991) 50–57. <https://doi.org/10.1145/2254556.2254569>
- 9 L. C. Paschoarelli, R. Santos, and P. Bruno: Work **41** (2012) 4825. <https://doi.org/10.3233/WOR-2012-0771-4825>
- 10 H.-C. You and K. Chen: Des. Stud. **28** (2007) 23. <https://doi.org/10.1016/j.destud.2006.07.002>
- 11 Y. Huang and N. Kang: Proc. 2017 Int. Conf. Biom. and Kansei Eng. (ICBAKE, 2017) 42–48. <https://doi.org/10.1109/ICBAKE.2017.8090640>
- 12 D. A. Norman: Interactions **15** (2008) 18. <https://doi.org/10.1145/1409040.1409044>
- 13 W. W. Gaver: Proc. 1992 ACM Conf. Computer-supported cooperative work (CSCW, 1992) 17–24. <https://doi.org/10.1145/143457.371596>
- 14 J. Lu and L. Cheng: IPBS **47** (2013) 142. <https://doi.org/10.1007/s12124-012-9202-2>
- 15 X. Qu, D. Zhan, G. Lu, and Z. Guo: IEEE Trans. Syst. Man Cybern. Syst. **47** (2017) 2870. <https://doi.org/10.1109/TSMC.2016.2531675>
- 16 M. A. Al Faruque, M. Syduzzaman, J. Sarkar, K. Bilisik, and M. Naebe: Nanomaterials **11** (2021) 2414. <https://doi.org/10.3390/nano11092414>
- 17 V. V. Pillai, B. Ramasubramanian, O. Sequerth, S. Pilla, T. Wang, A. K. Mohanty, P. Govindaraj, S. M. Alhassan, N. Salim, P. Kingshott, F. K. Fuss, S. Ramakrishna, and N. Hameed: Appl. Mater. Today **42** (2025) 102574. <https://doi.org/10.1016/j.apmt.2024.102574>
- 18 T. Xu, L. Jin, Y. Ao, J. Zhang, Y. Sun, S. Wang, Y. Qu, L. Huang, T. Yang, W. Deng, and W. Yang: Nat. Commun. **15** (2024) 10876. <https://doi.org/10.1038/s41467-024-55177-y>
- 19 Psychology Software Tools: <https://support.pstnet.com/hc/en-us/articles/360026123314-INFO-E-Prime-for-Beginners-30574> (accessed December 2025).

- 20 M. Yang and G. L. Liu: *J. Beijing Inst. Fash. Technol. (Nat. Sci. Ed.)* **35** (2015) 14. <https://doi.org/10.16454/j.cnki.issn.1001-0564.2015.01.003>
- 21 C. Shaw and F. Nickpour: *ADR* **2** (2024) 37. <https://doi.org/10.1016/j.ijadr.2024.07.003>
- 22 S. He, Y. Ma, G. Maulik, M. Jellicoe, A. Nag, W. Powell, S. Deng, J. Fang, and Y. Wu: *Sens. Actuators Phys.* **372** (2024) 115363. <https://doi.org/10.1016/j.sna.2024.115363>.
- 23 Z. Li, B. Mi, X. Ma, P. Liu, F. Ma, K. Zhang, X. Chen, and W. Li: *Chem. Eng. J.* **477** (2023) 140729. <https://doi.org/10.1016/j.ccej.2023.147029>
- 24 N. N. Joshi, J. Narayan, and R. Narayan: *Mater. Adv.* **5** (2024) 9160. <https://doi.org/10.1039/D3MA00636K>
- 25 H. Liu, S. Bao, and X. Wang: *Micromachines* **13** (2022) 184. <https://doi.org/10.3390/mi13020184>
- 26 P. Muralt, R. G. Polcawich, and S. Trolier-McKinstry: *MRS Bull.* **34** (2009) 658. <https://doi.org/10.1557/mrs2009.177>
- 27 M. W. M. Tan, H. Wang, D. Gao, P. Huang, and P. S. Lee: *Chem. Soc. Rev.* **53** (2024) 3485. <https://doi.org/10.1039/D3CS01017A>
- 28 A. Kantaros, T. Ganetsos, Z. Kanetaki, C. Stergiou, E. Pallis, and M. Papoutsidakis: *Processes* **13** (2025) 2492. <https://doi.org/10.3390/pr13082492>