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Ergonomic Recommendations for Range of Control Panel Angle of Touchscreen Kitchen Appliances

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Abstract: Control panels for kitchen appliances have been designed in various forms and with different design parameter values. Among these design parameters, the panel angle is one of the most important factors influencing the usability and user preference. However, few studies have been conducted regarding the panel angle effects in the context of kitchen appliances. There are only a few safety-oriented regulations or guidelines for kitchen appliance design. Therefore, in this study, the effect of the control panel angle of touchscreen kitchen appliances on their usability was empirically investigated for providing appropriate ergonomic recommendations. A total of six panel angles, namely, 0°, 15°, 30°, 45°, 60°, and 90°, were employed in the experiment in consideration of the design parameter values used in existing slide-in/freestanding ranges. Three usability evaluation measures, namely, visibility, physical comfort, and preference, were employed. For each of the six panel angles, 20 participants performed temperature/power-level setting tasks and then subjectively rated the panel angle in terms of the three measures. The following major findings were obtained: (1) the control panel angle affected the scores of all three measures; and (2) when considering visibility, physical comfort, and preference comprehensively, the panel angle ranges 15°–42° and 15°–19° were recommended as the appropriate and optimal ranges, respectively. The findings of this study may be helpful in the ergonomic design of touchscreen panels for kitchen appliances, which can improve the usability of these panels and reduce human errors and response time in emergencies.

Keywords: control panel angle; kitchen appliances; touchscreen panel; usability evaluation; ergonomic design

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Citation: Son, M.; Beck, D. Ergonomic Recommendations for Range of Control Panel Angle of Touchscreen Kitchen Appliances. *Appl. Sci.* **2022**, *12*, 7913. https://doi.org/10.3390/app12157913

Academic Editors: Alessandro Naddeo and Rosaria Califano

Received: 15 June 2022
Accepted: 5 August 2022
Published: 7 August 2022

1. Introduction

Control panels (hereafter referred to as panels) used in modern kitchen appliances such as ovens, cooktops, and induction ranges have been designed in various forms and with different design parameter values. For example, electric induction range panels have been designed with various angles (0°, 15°, 60°, 90°, etc.) for different brands, such as GE, Bosch, KitchenAid, Frigidaire, Café, Samsung, and LG. In addition, there are several control types for panels, such as knobs (various shapes), touchscreens, and a combination of both. Recently, with the development of touchscreen interface technology, touchscreen panels are being widely used in kitchen appliances. In particular, touchscreen interfaces are being used for most ovens and induction ranges. The design parameter values of these panels can affect usability when operating kitchen appliances; in particular, the panel angle is one of the most important factors influencing not only usability, which includes visibility and physical comfort, but also user preference [1–6].

Several studies have been conducted on the usability of panels (especially panel angles) in the context of digital devices such as smart phones or tablets [1–9]. In addition, when it comes to the user's comfort/discomfort, many studies have been carried out regarding reachability and usability [10,11], range of rest postures of upper limbs [12–16], and methods for measuring and objectifying the comfort rating [10,17–19]. However, few studies have examined the usability of panels in the context of kitchen appliances. Very few regulations or design guidelines [20–22] focus on safety while using kitchen appliances. In the ergonomics literature [23,24], studies on compatibility (spatial/movement compatibility, etc.) and human error related to panels have been conducted in detail; however, no guides for panel-related design variables such as the panel angle have explicitly been mentioned.

The touchscreen panels of modern kitchen appliances usually have panel angles close to 0° or 90° (e.g., those of Bosch, KitchenAid, Frigidaire, Café, and Dacor electric induction ranges), which are mainly determined based on aesthetic factors and ease of mechanical design rather than usability. The following problems may occur if usability is not sufficiently considered in determining the panel angle. First, users are highly likely to be in uncomfortable and awkward postures when operating improperly designed panels, which may cause physical discomfort in their necks, waists, and fingers/wrists. They may even develop musculoskeletal disorders upon repeated and prolonged use of poorly designed panels [2,5,25–41]. Second, because the panel angle directly affects the viewing angle at which the user looks at the panel, it may be difficult for users to check the cooking temperature, time, and other options easily when the panel angle is not appropriate. In addition, inappropriate panel angles may cause users to stand in unnecessarily awkward positions, such as bending the neck, waist, and knee. Third, there is a possibility that the aforementioned physical factors (physical discomfort and low visibility) negatively affect the cognitive performance of the users, resulting in a longer response time or human error. Multiple studies have examined the effects of a physical workload on the performance of concurrent mental tasks in different contexts. Barker and Nussbaum [42] found that physical workload and fatigue decreased the cognitive task performance of registered nurses.

Moreover, Lorist et al. [43] found that fatigue-inducing muscle contractions decreased the reaction task performance of users. Kerr et al. [44] showed that postural balance maintenance adversely affected the performance of spatial memory tasks. Unlike most home appliances, user mistakes and inappropriate operation of kitchen appliances can lead to safety accidents, such as fires [45]; hence, it is essential to design panels that have good usability and minimize user errors and response times in case of emergencies.

Therefore, the current study aimed to provide ergonomic recommendations for the panel angle ranges of touchscreen kitchen appliances by empirically investigating the effects of the panel angle on usability evaluation. A total of six panel angles, namely, 0°, 15°, 30°, 45°, 60°, and 90°, were employed while considering various design parameter values that were adopted and implemented in existing slide-in/freestanding ranges. For the usability evaluation, the subjective ratings of visibility, physical comfort, and preference were utilized, similar to many previous studies that have dealt with the usability of touchscreen products [1–6].

2. Materials and Methods

2.1. Study Design and Experimental Variables

For this study, an experimental environment similar to that of an actual kitchen was established, and a laboratory experiment was performed. Given that the installation height of existing slide-in/freestanding ranges, such as Samsung, LG, Whirlpool, Bosch, and Miele, was in the range of approximately 800–900 mm, the panel height (H) was set to an average value of 850 mm. To accomplish the purpose of the experiment, a touchscreen panel mockup with an adjustable panel angle was used rather than a finished product. The horizontal distance (D) between the product and user, which was set to 200 mm, was determined based on the average distance between the product and users when they operated the kitchen appliance in the pilot test. The experimental apparatus used in this study is shown in Figure 1.

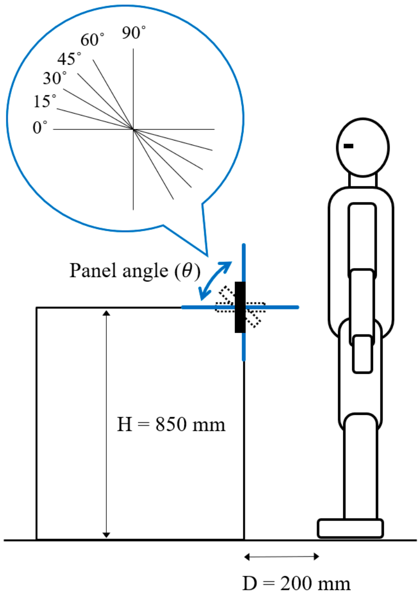


Figure 1. Experimental apparatus.

The panel angle of the touchscreen panel was the independent variable in the study and had six levels (0°, 15°, 30°, 45°, 60°, and 90°). The touchscreen panel mockup was designed to be similar to actual touchscreen panels, which are widely used in kitchen appliances (Figure 2). It had straight-line range sliders that could operate two burners (left/right), and its power level was displayed in red. To set the power level, the 'Burner selection button' needed to be pressed (Figure 2); thereafter, the desired power level was chosen by selecting any value between "LO" to "HI" or by using the range slider with the drag-and-drop action.

Figure 2. Touchscreen panel mockup.

Three measures, namely visibility, physical comfort, and preference, which have been the mainly considered measures in previous studies [1–6] dealing with the usability of touch interface-based products, were considered as the dependent variables in this study. The description of each measure and the questions asked to the participants for each measure are provided in Table 1. For each of the three measures, the participants answered the question using a 7-point Likert scale [46,47] that had the endpoints "Strongly disagree" (1) and "Strongly agree" (7), and the midpoint "Neutral" (4).

Table 1. Three subjective rating measures.

Measure	Description	Question
Visibility	A measure of the degree of ease with which the user could visually check the power levels while manipulating the panels	"How much do you agree with the statement that it was easy to see the power levels when manipulating the panels?"
Physical comfort	A measure of the overall sum of the subjective feelings of comfort/discomfort on individual body parts while manipulating the control panels	"How much do you agree with the statement that it was comfortable to use the panel?"
Preference	A measure of the subjective liking or disliking of the control panels	"How much do you agree with the statement that it was preferred to use the panel?"

2.2. Participants

Twenty participants (7 males and 13 females) in their 20 s to 40 s participated in the experiment. All participants were Americans with more than one year of experience using slide-in/freestanding ranges with a touchscreen panel. The ages and heights of the participants are summarized in Table 2. These participants did not suffer from any musculoskeletal or neurological disorders. Each signed an informed consent form before participation, and the experiment was carried out in accordance with the Declaration of Helsinki.

Table 2. Participant demographic information.

	Sex	Mean	SD	Min	Max
Age (years)	Male (n = 7)	36.0	5.45	29	43
	Female (n = 13)	31.8	7.20	22	47
	Total (n = 20)	33.3	6.81	22	47
Height (cm)	Male (n = 7)	185	3.87	180	192
	Female (n = 13)	167	7.22	155	178
	Total (n = 20)	173	10.6	155	192

2.3. Procedures

The experiment was conducted as follows. Each participant stood 200 mm away from the panel. The experimental task involved setting one of the nine power levels given by the experimenter (from "LO" to "HI" in Figure 2). Before the experimental task, the participants underwent an introduction/training session to familiarize themselves. Each participant performed the experimental trial four times (twice for the left-side burner and twice for the right-side burner) in a row for each panel angle. After finishing the experimental trials for each of the six panel angles, the participants rated their visibility, physical comfort, and preference on a 7-point Likert scale. The presentation order of the six panel angles was randomized for each participant. The participants were video-recorded from several angles (frontal and side views) using a Sony camcorder (HDR-PJ675) while they performed the experimental tasks to identify their uncomfortable/awkward postures during panel operation. Specifically, for each of the six panel angle conditions, each participant's degree of neck flexion and wrist extension was determined through an examination of the recorded video clips.

2.4. Data Analyses

A one-way repeated-measures ANOVA was conducted to test the effect of the independent variable (panel angle) on each dependent variable (visibility, physical comfort, and preference). Mauchly's test was performed to assess the sphericity of the data for each ANOVA. In cases where the sphericity was violated, the degrees of freedom were corrected; the Greenhouse–Geisser correction was used when the Greenhouse–Geisser estimate of sphericity (e) was less than 0.75; otherwise, the Huynh–Feldt correction was used [48,49].

In the case of statistically significant ANOVA results, post hoc multiple comparisons with Bonferroni corrections were conducted to determine which pairs of panel angles significantly differed in the mean value. All statistical tests were conducted using IBM SPSS Statistics 23.0 and were based on an alpha level of 0.05.

3. Results

The ANOVA results showed that the panel angle significantly affected all three dependent measures: visibility: F (5, 95) = 34.4, $p < 0.001$, $\eta_p^2 = 0.64$; physical comfort: F (2.94, 55.8) = 19.5, $p < 0.001$, $\eta_p^2 = 0.51$; and preference: F (5, 95) = 24.1, $p < 0.001$, $\eta_p^2 = 0.56$. The mean and standard deviation of each panel angle for each dependent measure are shown in Figures 3–5 with asterisks indicating statistical significance in the post hoc multiple comparisons with Bonferroni corrections. In all figures, asterisks indicate significance in the pairwise comparisons, and the error bars represent one standard error above and below the mean.

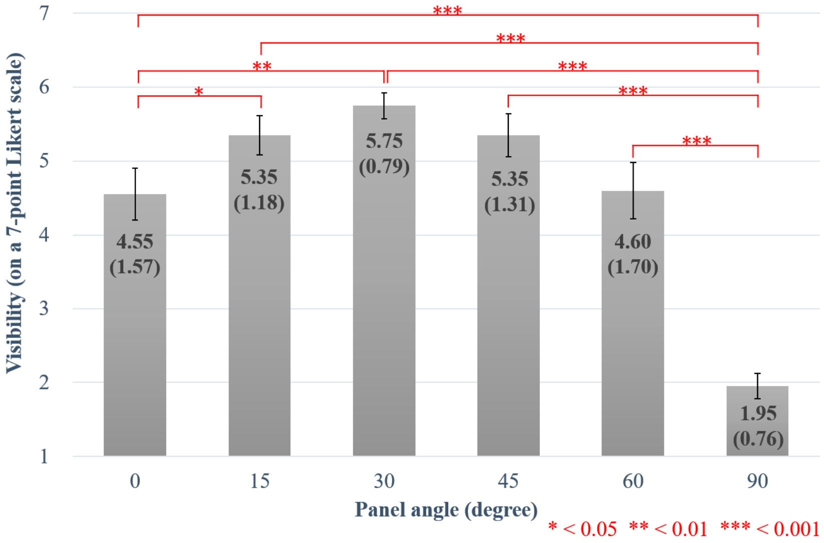


Figure 3. Visibility ratings with the results of post hoc multiple comparisons.

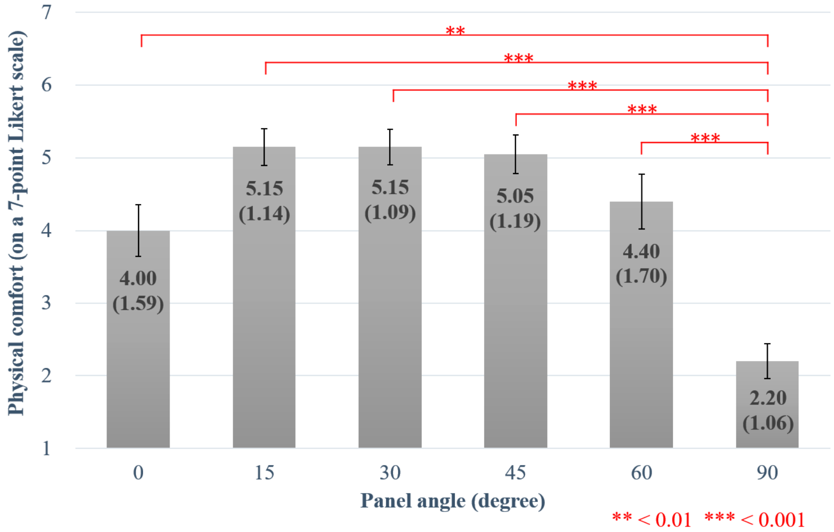


Figure 4. Physical comfort ratings with the results of post hoc multiple comparisons.

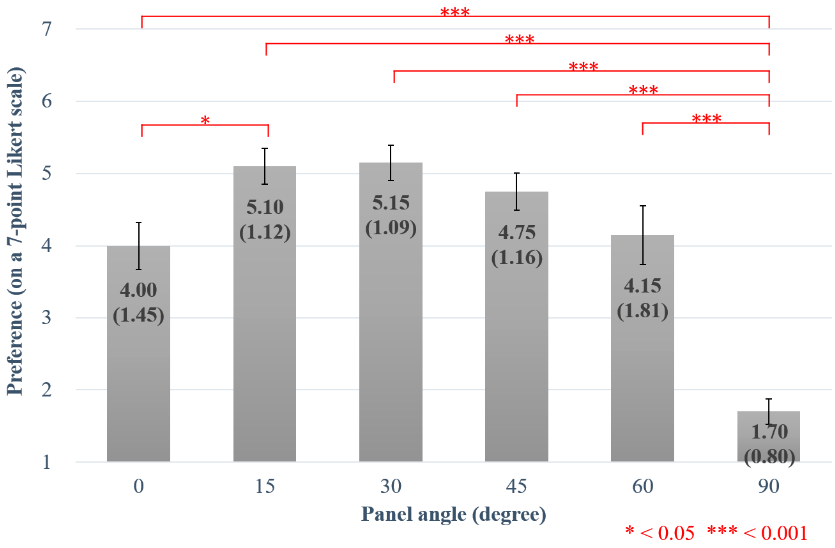


Figure 5. Preference ratings with the results of post hoc multiple comparisons.

3.1. Visibility

The panel angles of 0° to 60° showed scores higher than 4 ("Neutral") on the seven-point scale; in particular, 15° to 45° angles showed high scores between 5 ("Slightly agree") and 6 ("Agree"). Meanwhile, those of 90° showed a score lower than 2 ("Disagree"). Overall, the distribution of the mean visibility scores showed an inverted U-shape. The panel angle of 0° had a significantly smaller mean than those of 15° and 30°, and that of 90° had a smaller mean than those of all other angles.

3.2. Physical Comfort

As for physical comfort, the distribution of the mean scores showed an inverted U-shape, similar to that of the visibility ratings. The panel angles of 0° to 60° showed scores higher than 4 ("Neutral"); in particular, 15° to 45° angles showed scores higher than 5 ("Slightly agree"). Conversely, the panel angle of 90° received low evaluations close to 2 ("Disagree"), showing a significantly smaller mean than the other angles.

3.3. Preference

The panel angles of 0° to 60° showed scores higher than 4 ("Neutral"); in particular, those of 15° to 45° showed high scores close to 5 ("Slightly agree"). Meanwhile, the panel angle of 90° showed a score lower than 2 ("Disagree"). Similar to the other two measures, the distribution of the mean preference scores showed an inverted U-shape. The panel angle of 0° had a significantly smaller mean than that of 15°, and that of 90° had a smaller mean than all other angles.

4. Discussion

Our study aimed to empirically investigate the ergonomic panel angle range of touch-screen kitchen appliances. Subjective ratings of visibility, physical comfort, and preference were performed while changing the panel angle to achieve this objective. A total of six panel angles (0°, 15°, 30°, 45°, 60°, and 90°) were considered, and a seven-point Likert scale was used for the subjective ratings of the three measures.

Data analyses revealed that the panel angle significantly affected the visibility, physical comfort, and preference ratings. Across all three measures, the mean score distribution showed an inverted U-shape as the panel angle increased. The panel angles of 0° to 60° showed scores higher than 4 ("Neutral"); in particular, those of 15° to 45° showed scores higher than or close to 5 ("Slightly agree"). Conversely, in the case of the panel angle of 90°, it showed a low score of close to 2 ("Disagree").

The observed effect of the panel angle on the visibility ratings can be attributed to the difference in angle between the line of sight of the user and the panel according to the changes in the panel angle. Such a difference appeared to determine the task difficulty for the user in checking the power levels displayed on the panel. As the touchscreen panel required the user to stare at the panel throughout the operation, visibility was considered one of the most important usability measures. It should be noted that the touchscreen panel served as both a control and a display. According to the existing literature, the best visibility/legibility is guaranteed when the display/panel is perpendicular to the line of sight of the user [2,4,6,50,51]. According to a guideline for the display tilt angle [47], when the angle (α) between the line of sight of the user and the display/panel was 90° ($\alpha_{optimal}$), within the range of 70°–110° ($\alpha_{optimal} \pm 20°$), within the range of 60°–120° ($\alpha_{optimal} \pm 30°$), within the range of 50°–130° ($\alpha_{optimal} \pm 40°$), or out of the range of 50°–130°, the level of visibility was described as "very good", "good", "moderate", "bad", or "very bad", respectively. Based on the eye heights recorded in the anthropometric reference data for US adults [52], the optimal panel angles that supported perpendicular viewing angles for the 5th percentile female (142.1 cm) and the 95th percentile male (175.3 cm) were calculated to be 19° ($\alpha_{optimal}\,[5\text{th }\%ile\ female] = 90 - \tan^{-1}\left[\frac{1421-850}{200}\right]$) and 12° ($\alpha_{optimal}[95\text{th }\%ile\ male] = 90 - \tan^{-1}\left[\frac{1753-850}{200}\right]$), respectively. Accordingly, the panel angles that ensured a "moderate" level of visibility were determined to be 0° to 49° (19° ± 30°) for the 5th percentile female and 0° to 42° (12° ± 30°) for the 95th percentile male, respectively (the case wherein the panel angle was smaller than 0° was excluded). Therefore, according to the design for extreme individuals, which is one of the principles in the application of anthropometric data [23,53,54], a panel angle range to ensure a "moderate" level of visibility for 95 percent of the population (the range from the 5th percentile female to the 95th percentile male) was 0° to 42°. A panel angle range to ensure a "very good" level of visibility for 95 percent of the population was 12° to 19°. These theoretically calculated results were almost in line with our experimental results, which indicate that the panel angles of 0° to 60° showed higher visibility scores than 4 ("Neutral"), and those of 15° to 45° showed high visibility scores between 5 ("Slightly agree") and 6 ("Agree").

The observed panel angle effects on the physical comfort ratings could be explained by the difference in the postures of the participants while changing the panel angle. When each user operated the panel, the wrist extension or neck/waist bending angles were determined according to the panel angle. If each joint angle is outside the comfortable range of motion (ROM) of the corresponding joint, discomfort may occur [1,2,5,33,34]. A post-examination of the video recording data revealed that the degree of wrist extension increased as the panel angle increased, and the average wrist-extension angle was approximately 40° when the panel angle was 60°. Considering that the wrist extension ROM for the 5th percentile of US adults is approximately 41° [55], users with a small ROM were expected to feel uncomfortable when the panel angle exceeded 60°. Therefore, considering the aforementioned results, it can be recommended that a panel angle should be designed to be within 60°. This recommendation agrees with our experimental results which indicated that the panel angles of 0 to 60° showed physical comfort scores higher than 4 ("Neutral").

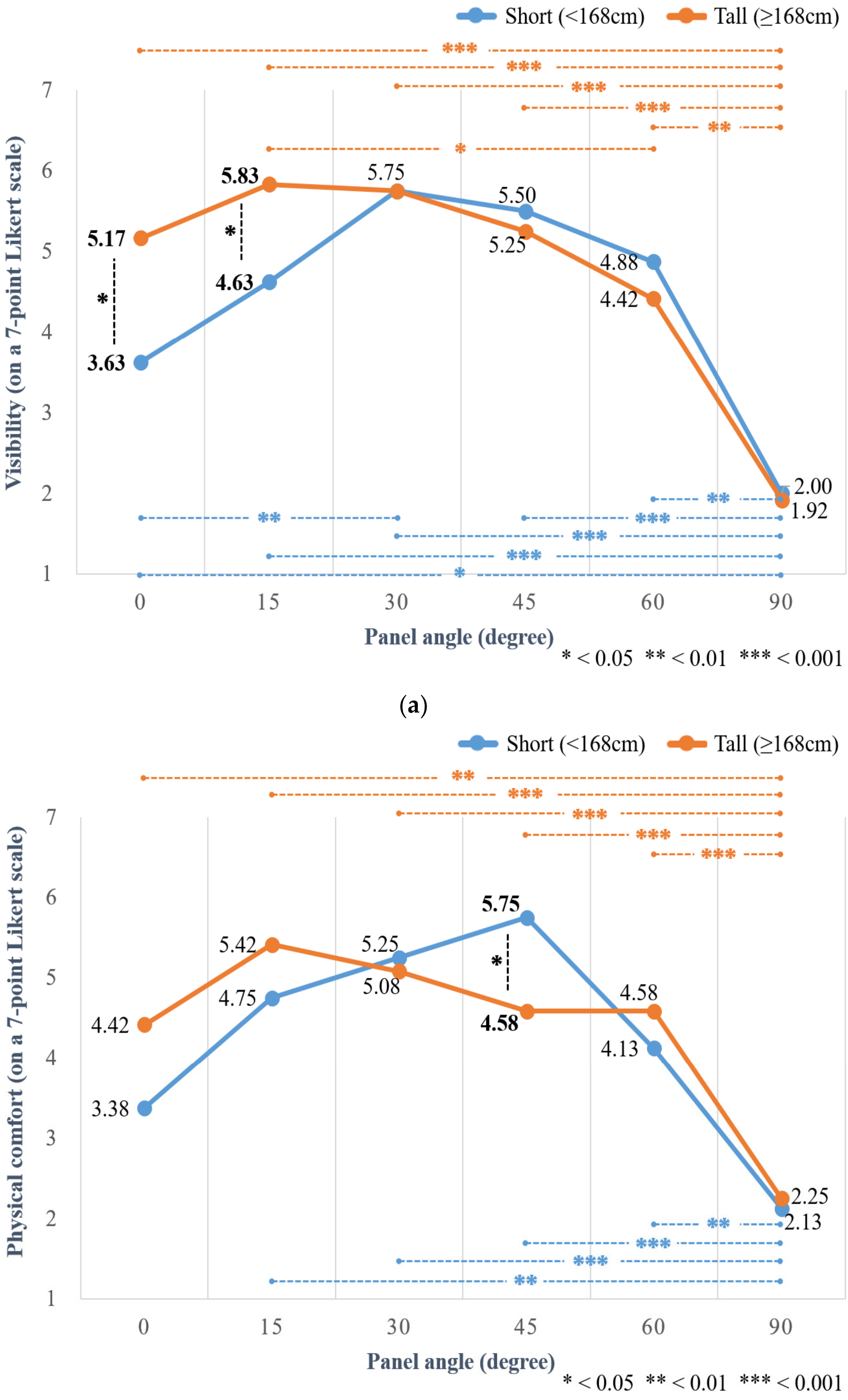
Besides wrist extension, neck flexion seemed to affect physical comfort during panel operation. In most cases, the panel is installed at a height of 800–900 mm from the ground. Thus, it inevitably involves neck flexion when the user operates the panel. The mechanistic basis for the relationship between the head flexion angle and neck pain arises from the increase in the gravitational moment of the head mass during flexed postures [56–58]. This requires greater activation of the neck extensor muscles than a neutral posture does [5,33,59,60]. Indeed, a post-examination of the video-recorded data revealed that neck flexion was observed in all users during the panel operation, and the shortest (155 cm) and tallest (192 cm) participants showed neck flexion angles of 40° and 50°, respectively. For all participants, the degree of neck flexion was largest when the panel angle was 0°, although there was not much difference in this degree when other panel angles were used (the difference was within 5° on average); there was little difference in neck flexion for the panel angles from 15° to 90°. The relatively large neck flexion at the panel angle of 0° was interpreted as an attempt by the user to obtain a better viewing angle. In the context of operating the panel installed at a height of 800–900 mm from the ground, it was assumed that the neck flexion angle was more affected by the height of the user than the panel angle.

Considering that the neck flexion ROM for the 5th percentile of US adults is approximately 40° [55], users who are very tall and have low flexibility may find it cumbersome when operating a panel with a gentle slope (particularly when the panel angle is 0°). Therefore, it is recommended to avoid designing panels with such gentle slopes. This finding is congruent with the results of other studies [2,5,34] conducted to assess usability during tablet use. They revealed that the fatigue levels of the neck, back, and waist reached the highest point when the tablet was placed at 0°. Therefore, they proposed that tablet users should avoid placing their tablets flat on the table (0°) to decrease the load on their neck muscles. Collectively, a panel angle range of 15° to 60° could be suggested in terms of good physical comfort, considering both wrist extension and neck flexion. This range is broadly consistent with our experimental results in which the panel angles of 0° to 60° showed physical comfort scores higher than 4 ("Neutral"), and those of 15° to 45° showed physical comfort scores higher than 5 ("Slightly agree").

The observed effects of the panel angle on the preference of the user can be largely explained in terms of visibility and physical comfort. As mentioned earlier, the viewing angle of the user and their posture during the control panel operation changed as the panel angle changed from 0° to 90°. It was inferred that the changes in visibility and physical comfort could be responsible for their preference. The mean score distribution of preference showed very similar patterns to those of visibility and physical comfort (Figures 3–5); the panel angles of 0° to 60° showed scores higher than 4 ("Neutral"), and those of 15° to 45° showed high scores close to 5 ("Slightly agree"). These findings suggested that visibility and physical comfort directly influenced user preferences. Indeed, the correlations between preference and visibility were positive and statistically significant ($r = 0.84$, $p < 0.001$). In addition, a positive correlation was found between preference and physical comfort ($r = 0.86$, $p < 0.001$).

Summarizing the aforementioned results, in terms of visibility, the appropriate panel angle range was 0° to 42° (optimal range: 12°–19°) based on the existing literature and 0° to 60° (optimal range: 15°–45°) based on our experiment. In terms of physical comfort, the appropriate panel angle range was 15° to 60° based on the literature and 0° to 60° (optimal range: 15°–45°) based on our experiment. In terms of preference, the appropriate panel angle range was 0° to 60° (optimal range: 15°–45°) based on the experiment. Taken altogether, the current study results showed a recommended range of 15° to 42° with respect to the horizontal, with the optimal range being 15° to 19°.

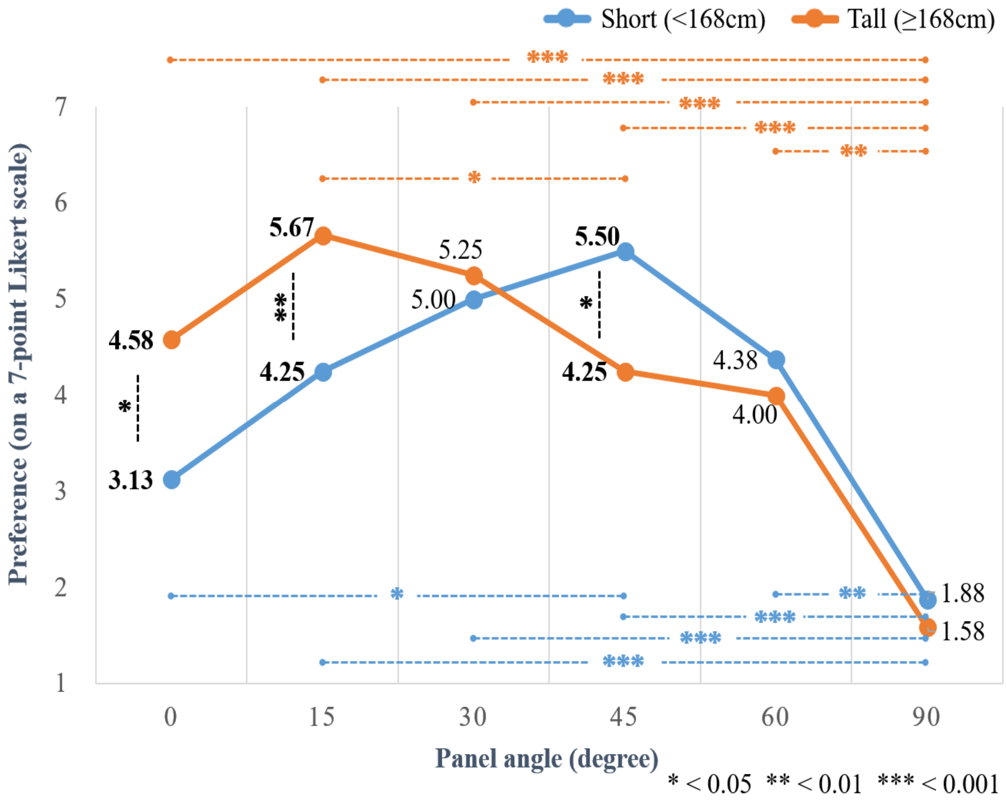
Interestingly, the distribution of the subjective rating scores showed slightly different trends depending on the height of the participant across all three measures (visibility, physical comfort, and preference). Accordingly, the participants of this study were divided into a "tall" group with twelve people and a "short" group with eight people based on the average height of US adults, which is 168 cm [61], and a two-way mixed ANOVA was performed to determine whether there was an interaction effect between the panel angle and height group. The ANOVA results showed that the interaction effect was statistically significant for all three measures: visibility: $F(5, 90) = 3.41$, $p < 0.01$; physical comfort: $F(5, 14) = 3.38$, $p < 0.05$; and preference: $F(5, 90) = 4.82$, $p < 0.01$. For each of these three measures, the simple main effects for the group and angle were also statistically significant. For each dependent variable, the mean of each panel angle is shown in Figure 6a–c, with asterisks indicating statistical significance in post hoc multiple comparisons with Bonferroni corrections. In all figures, asterisks indicate significance in pairwise comparisons.



(**a**)

(**b**)

Figure 6. *Cont.*



(**c**)

Figure 6. Interaction effects between panel angle and participant height on (**a**) visibility, (**b**) physical comfort, and (**c**) preference. The blue and orange asterisks indicate significant angle effects for the "short" and "tall" groups, respectively, and the black asterisks indicate significant height effects for each panel angle.

The overall trends for the three measures showed that the "tall" group showed scores higher than 4 ("Neutral") when the panel angle was from 0° to 60° and that the "short" group showed scores higher than 4 ("Neutral") when the panel angle was from 15° to 60°. Furthermore, the overall mean score distribution of the three measures for both height groups showed an inverted U-shape; the center of the arc for the "tall" group was located to the left relative to that for the "short" group. To put this in perspective, when the panel had a gentle slope, such as 0° or 15°, participants in the "tall" group showed significantly higher visibility and preference scores than those of the "short" group (Figure 6a,c). Meanwhile, when the panel angle was 45°, participants in the "short" group showed significantly higher physical comfort and preference scores than those of the "tall" group (Figure 6b,c).

A possible interpretation of these findings is that when the panel angle was changed, the visibility and physical comfort the participants experienced during the experimental task changed according to their height. Regarding visibility, as mentioned earlier, the viewing angle of the panel changed based on the eye height of the participant. Accordingly, it can be seen that the panel with a gentle slope was more advantageous for the "tall" group than the "short" group. These results concurred with those of Schultz et al. [4]. They conducted a workstation analysis that showed that the optimal viewing angle for touchscreen displays installed at a height of 980 mm was found to be 55° from the horizontal for the 2.5th percentile of Japanese females (146 cm) and 30° for the 97.5th percentile of US males (191 cm).

To understand the difference in these results in terms of physical comfort, it is necessary to consider the relative position of the panel according to the height of the participant. In other words, although panel operation was performed at the same height of 850 mm for all participants, the relative position of the panel (compared to the body of the participant) differed according to the height of the participant. Accordingly, it can be inferred that the degree of wrist extension according to the height of the participant was different for the same panel angles. Indeed, a post-examination of the video recording data showed that for a participant who was 195 cm, the panel height was located around his thighs, and for a participant who was 155 cm, the panel height was around her waist.

Further, the degree of wrist extension for the "tall" group was larger than that for the "short" group when the panel angle was 45°. The observed results wherein the "tall" group exhibited a smaller physical comfort score than that exhibited by the "short" group at a panel angle of 45° (Figure 6b) could be explained by the aforementioned results. When the panel angle was gentle, such as within 30°, it appeared that neither the "tall" nor "short" groups felt much discomfort because the degree of wrist flexion was not large. When the panel angle was steeper than 60°, it can be seen that the physical comfort scores for both the "tall" and "short" groups decreased equally as the wrist angle was outside the comfortable ROM for both groups. As for neck flexion, a post-examination of the video recording data revealed that the neck flexion of the "tall" group was slightly larger than that of the "short" group. However, as there was no difference in the physical comfort scores between the groups at angles other than 45°, it could be inferred from this study that neck flexion did not have a sufficiently strong effect to cause a significant difference between groups.

5. Conclusions

Overall, the current study empirically elucidated the effects of the panel angle on the ratings of visibility, physical comfort, and preference. The results of the present study revealed the significant effects of the panel angle on the ratings of the three measures, suggesting that while designing a panel, usability factors such as visibility and physical comfort, as well as aesthetic factors and ease of mechanical design should be considered. Summarizing the results, it can be concluded that a panel angle of 15° to 42° (optimal range of 15° to 19°) from the horizontal is recommended for touchscreen panels.

The current study has some practical and theoretical implications. First, the appropriate panel angle range presented in this study was determined based on visibility and physical comfort; thus, these results are expected to contribute to ensuring comfortable visibility and minimizing physical discomfort for users when using the panel. Further, it is expected to help prevent musculoskeletal disorders caused by prolonged and repetitive use. Second, as mentioned in the Introduction section, mistakes of the user and their improper operation of kitchen appliances can lead to safety accidents such as fires. Therefore, the recommended range of the panel angle presented in this study is expected to contribute to minimizing human error and the response time of the user in case of an emergency. Third, from the analysis and study results, it can be concluded that an ergonomically excellent panel angle should be presented in an appropriate range rather than being defined by one specific value. In other words, providing an adjustable range appears more advantageous in accommodating many users than simply providing a single optimal value based on the "one-size-fits-all" approach. This is in complete agreement with the "designing for adjustable range" principle [23,54], which suggests that designers should design certain dimensions of equipment or facilities such that they can be adjusted according to individual users. Based on the differences in body size according to gender, age, and country, it is recommended to provide a panel with an adjustable range or to design a panel angle differently according to each target user.

Some limitations of the current study are acknowledged, along with future research ideas. First, the appropriate range of panel angles presented in this study was derived from a context wherein a panel was operated at a close distance in front of kitchen appliances; thus, our findings do not apply to other contexts. If other contexts, such as one involving checking the cooking temperature/time in a kitchen space of 2–3 m, are considered together, the appropriate range may differ. Second, this study considered only subjective rating scores for visibility, physical comfort, and preference as dependent variables. In future studies, in addition to the subjective rating measures, task performance measures such as task completion time, response time, and error rate should be studied as dependent variables to further enhance our understanding of the effects of the panel angle on response times and errors of the user. In addition, electromyography, motion capture analysis, and the Borg CR10 scale may be considered when evaluating physical comfort. Lastly, the touchscreen panel considered in this study can be further classified into several types, such as those with a round (circular) or straight-line range slider. In addition, there is a traditional control type that utilizes knobs. Given that there may be differences in operation posture, grip, and viewing angle depending on these control types, future studies need to investigate other control types to understand the interaction effects between the panel angle and control type on users.

Author Contributions: Conceptualization, M.S.; methodology, M.S.; formal analysis, M.S. and D.B.; investigation, M.S. and D.B.; resources, M.S.; data curation, M.S. and D.B.; writing—original draft preparation, M.S.; writing—review and editing, D.B.; visualization, M.S.; supervision, D.B.; project administration, M.S.; funding acquisition, D.B. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by Incheon National University Research Grant in 2021.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Samsung Electronics Co., Ltd., especially Jung-Min Kim, for their assistance with the experiments.

Conflicts of Interest: The authors declare no conflict of interest.

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