1. INTRODUCTION

Seated work is an essential part of a person’s productive activities. Many workers perform work at visual display terminals (VDT) in the office, and students are also seated as they read and write in schools or libraries. A workstation, consisting of a chair and a desk, is necessary for these sedentary tasks. Many ergonomic studies have dealt with the design of workstations [1, 2], and studies on chairs are especially abundant [3, 4]. In the market, most chairs have various functions from basic adjustment mechanisms, such as seat height adjustment [Note 1], to unique adjustment mechanisms, such as swinging mechanisms [Note 2]. On the other hand, the design of a desk, which is another component of a workstation, is often primitive, with most desks having a flat and fixed-height top board, although sit/stand desks [Note 3] have recently appeared. This is because the main purpose of the desk is to support an object. Moreover, desks or counters are often built into buildings and have less flexibility in design. However, there is an important design philosophy that considers the various preferences of users in order to achieve a “harmonious value creation in an inclusive society,” which is the main theme of KEER2020 [5]. From this point of view, we focused on the design of a flat/sloped writing desk that considers users’ individual preferences for desk heights because it is hypothesized that a tilted board can offset the difference in desk heights.

The design values of desks can be studied in two ways: one is with focus on the height [6-8] and the other is focused on the slope of the top board [9-12]. In both studies, evaluation indices for calculating the design values are generally based on subjective evaluations, physiological indices (such as muscle activities), and task performances.

These standard methods can deliver the best conditions for the average user, but they cannot examine how other users feel about these conditions. In addition, the height and tilted angle of the top board should not be considered separately, however, there are few studies that investigates the combination of these two [11]. Therefore, this study investigated the combination of top board height and tilted angle. The aim of this study was to propose the design value of a flat/sloped writing desk that accepts individual preferences of desk heights. We performed two experiments in this study: a pilot experiment that evaluated the effects of a tilted board, while the other was an analysis of a desk that combines a tilted angle with height. The experiments were conducted with the approval of the Research Ethics Committee of Shinshu University (No. 150), and informed consent was obtained from all participants.
2. METHOD

2.1 Design value

1) Desk heights

In this study, we used seat-to-table height (Sashaku) as the fundamental design criteria for desk heights because Sashaku can explain desk heights, regardless of seat height. According to Noro [13], Sashaku is a Japanese term that refers to the distance between the desk (work surface) and the seat pan (1).

\[
Sashaku = DH - SH
\]  

Here, DH and SH mean desk edge’s height and seat height, respectively.

2) Tilted angle of top board

The tilt angle of the top board was defined as the angle on the sagittal plane between the top board’s slope and horizontal face. The origin was defined at the edge on the human side of the board. A general flat board has an angle of 0°, and this is increased by tilting.

2.2 Pilot experiment

The purpose of this pilot experiment was to confirm the fundamental effect of the tilted board on subjective and objective responses. We prepared an experimental desk with an adjustable top board and carried out a physio-psychological evaluation for usability. Sixteen Japanese university students (Table 1(a)) performed a single-digit calculation task for 90 seconds on a 0°, 10°, or 20° tilted desk. A tilted angle was presented in random order after practicing a task on a flat desk. The height of the seat and the desk’s front edge were fixed at 400 mm and 700 mm, respectively. The measurements consisted of the performance of the calculation task, electromyography (MP150, BIOPAC Systems, Inc., USA, subjects: Trapezius, Flexor digitorum superficialis, and Extensor digitorum), acceleration of writing hand (MVP-RF8, MicroStone Corporation, Japan), center of pressure (COP) on the seat (Carg-4motion, N-wave Co. Ltd, Japan), subjective usability, and profiling of mood states [14]. Subjective usability was evaluated using the semantic differential (SD) method (nine paired terms, seven grade scale). The experimental scene is shown in Figure 1.

To investigate the effects of the tilted angle, we performed a one-way ANOVA (factor: tilted angle) for each measurement. Statistical analysis was performed using a statistical software (BellCurve for Excel, Social Survey Research Information Co., Ltd., Japan), and the significance level was defined as 5%. In this study, the results that were easy to explain are shown in particular. They are the performance of calculation, electromyography of the trapezius, COP, and three paired terms about subjective usability.

Table 1: Participants’ self-reported heights (Unit: mm)

|                | Male     | Female   | Average | Standard deviation |
|----------------|----------|----------|---------|--------------------|
| (a) Pilot Experiment |          |          |         |                    |
| Male           | 1680     | 1690     | 1700    | 1710               |
| Female         | 1570     | 1590     | 1600    | 1610               |
| Average        | 1671     |          |         | 98                 |
| (b) Experiment of combination with tilted angle and Sashaku |          |          |         |                    |
| Male           | 1740     | 1700     | 1710    | 1720               |
| Female         | 1620     | 1570     | 1580    | 1590               |
| Average        | 1657     |          |         | 81                 |

**Figure 1**: Experimental equipment for pilot experiment

2.3 Experiment of combination with tilted angle and Sashaku

We conducted further experiment that investigated combination with tilted angle and Sashaku in order to propose design value of flat/sloped writing desk from a subjective evaluation. An experimental desk with an adjustable tilt and desk front edge height was prepared. A matrix comprising five angles (0°, 10°, 20°, 30°, and 40°) and five heights of Sashaku (250, 300, 350, 400, 450 mm) were set as the experimental conditions. Additionally, a stool with a height of 400 mm was used. The experimental equipment and conditions are shown in Figure 2. Two kinds of tasks (reading and writing) were performed by the participants in each experimental condition. In the reading task, the participants silently read a Japanese sentence with 208 characters, while the writing task involved participants writing a word with 8 kanji three times. Both tasks were performed on a vertical A4 size paper. After performing each task, participants rated the subjective usability from the following seven grades (-3: extremely bad, -2: bad, -1: slightly bad, 0: neither, +1: slightly good, +2: good, +3: extremely good). Sixteen Japanese students (Table 1(b)) were recruited, but one participant, whose measured data was defective, was excluded from the analysis. The experimental procedure
was as follows: First, we presented one of the five conditions of Sashaku and introduced all tilted angles in a random order. Next, it was repeated on the other Sashaku, which was also presented in a random order. In each experimental condition, the participants performed the reading task first and the writing task later.

In the analysis step, 2-way ANOVA (factor: tilted angle and Sashaku) was used for the value of subjective usability for each task in order to investigate the effects of tilted angle, Sashaku, and an interaction. The analysis environment and significance level were the same as in the pilot experiment.

3. RESULTS AND DISCUSSIONS

3.1 Pilot experiment

The measured results are shown in Figure 3. Since participants’ calculation abilities varied widely, the calculated numbers were standardized by the number of practice tasks performed (Figure 3(a)). The main effect of tilted angles was not significant; however, the mean values under tilted conditions were slightly larger than flat. The muscular active mass of the trapezius was not very different among each tilted condition (Figure 3(b)). On the other hand, the main effect of the tilted angle was significant (\(p < .01\)) on the result of COP (Figure 3(c)), and COP transitioned backward on the tilted condition compared with the flat condition. As reported in the previous studies [9,10], tilted desk may erect the trunk and reduce muscle activities on back and neck. The findings support our results that tilted board around 10° made the trunk upright and COP shifted backward. Additionally, the main effect of subjective visibility was significant (\(p < .01\)), and erect posture caused by tilted board may improve visibility. Significant main effects were not observed on writability and comfort (Figure 3(d)), while the 10° tilted condition was evaluated as the best on their three paired terms. Therefore, it was suggested that the 10° tilted board had good subjective usability and the slightly tilted desk did not worsen usability compared to the flat desk, while calculating for both the performance and physiological response.

However, we could not explain usability using other measurements because their values varied widely. It is a future endeavor to standardize experimental tasks and measurement values. Nevertheless, the results showed that a 10° or 20° tilted board is unlikely to disturb usability, while examining the combination with tilted angle and Sashaku.

3.2 Experiment of combination with tilted angle and Sashaku

The evaluated mean values for each condition are shown in Table 2, and the results of the 2-way ANOVA are shown in Table 3. Interactions were not significant, and the only the main effects of both the tilted angle and Sashaku were significant (\(p < .01\)). Here, we defined the personal acceptable region as conditions that had evaluations that were above “Neither.” The results showed that the acceptable region was wider on the reading task than on the writing task. Based on the mean values, the best condition was 30° for the tilted angle and 300 mm for the reading, and 10° and 300 mm for the writing task. Focusing on the results of the writing task, the acceptable region of Sashaku on the flat condition was...
between 300 mm and 350 mm, but at 10°, it was between 250 mm and 400 mm. This result supported our hypothesis that working in an elevated position becomes possible by using a tilted board. In other words, a slightly tilted desk can assume a higher range of Sashaku than a flat condition.

### 3.3 Design value of tilted desk

In the previous section, we focused on the mean values of the evaluations to explain the overall effect of the combination of tilted angle and Sashaku; however, it is important in the design phase to consider the users’ body size or their own minimum gratification level. Thus, we investigated the design value of the tilted angle and Sashaku in two ways. Additionally, in this paper, we calculated the design value based only on the results of the writing task because the acceptable region was more critical for writing than reading in Section 3.2.

First, we standardized desk height by the participant’s individual height and tried to calculate the relationship between subjective usability and standardized Sashaku (2).

\[
\text{Standardized Sashaku} = \frac{\text{Sashaku}}{\text{individual height}}
\]  

(2)

We plotted the raw evaluated scores and standardized Sashaku for each tilted angle, as seen in Figure 4. Then, we fitted a quadratic curve for these and calculated the adjusted coefficient of determination \( R^2 \) as part of the regression analysis because it was hypothesized that neither too high nor too low was suitable for Sashaku.

As a result, the values of \( R^2 \) were low for every tilted angle condition, and the quadratic curve could not represent the relationship between the evaluation score and standardized Sashaku. For the flat condition, the evaluated scores were low in the high Sashaku region (> approximately 0.26), but the scores varied widely in the region where Sashaku is under approximately 0.26. The hypothesis that neither too high nor too low was suitable for Sashaku was not supported by the results (Figure 4 (a)). We believe that this was mainly due to the large individual differences in the subjective evaluation. The participants in this study were university students who had already grown up enough, and it was thought that they already had set individual preferences for the desk heights. In other words, if they have used height-fixed desks, short people are used to work at high desks, and vice versa for tall people.

In another tilted condition, there was a tendency that so steep boards are not preferred; however, large individual differences were observed on evaluated scores similar to the 0° condition. Therefore, we decided that it was difficult

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**Table 2**: Mean value of subjective usability (N=15, painted cells: not better than "Neither")

| (a) Reading task | 0° | 10° | 20° | 30° | 40° |
|------------------|----|-----|-----|-----|-----|
| 250 mm           | -0.53 | 0.00 | 0.20 | 0.60 | 0.33 |
| 300 mm           | 0.20 | 0.93 | 1.07 | 1.47 | 0.67 |
| 350 mm           | 0.07 | 1.27 | 1.27 | 0.80 | 0.67 |
| 400 mm           | -0.40 | 0.67 | 0.87 | 0.60 | 0.60 |
| 450 mm           | -1.73 | -0.53 | -0.60 | -0.13 | -0.27 |

| (b) Writing task | 0° | 10° | 20° | 30° | 40° |
|------------------|----|-----|-----|-----|-----|
| 250 mm           | -0.53 | 0.00 | -1.13 | -1.07 | -1.33 |
| 300 mm           | 0.40 | 1.13 | 0.93 | 0.13 | -0.93 |
| 350 mm           | 0.33 | 1.07 | 0.67 | 0.53 | -0.33 |
| 400 mm           | -0.13 | 0.60 | 0.80 | -0.33 | -1.33 |
| 450 mm           | -1.60 | -0.73 | -0.67 | -1.40 | -1.73 |

**Table 3**: Results of 2-way ANOVA (N=15, n.s.: not significant, *: p<.05, **: p<.01)

|          | Reading task | Writing task |
|----------|--------------|--------------|
| Sashaku  | < 0.001 **   | < 0.001 **   |
| Tilted angle | 0.010 **     | < 0.001 **   |
| Interaction | 0.703 n.s.  | 0.106 n.s.   |

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**Figure 4**: Relationship between subjective usability and standardized Sashaku on the writing task (points: raw evaluated score, lines: fitted quadratic curve, N=15×5, \( R^2 \): adjusted coefficient of determination)
to propose design values for a flat/sloped writing desk based on raw evaluated scores and standardized Sashaku.

Next, we tried to calculate design values in another manner by considering the users’ own minimum gratification level. We defined evaluation scores greater than zero point (i.e. better than “Neither”), which means non-negative impression, as the participants’ own minimum acceptable level. We then counted numbers of participants with their own minimum acceptable level (PWAL) on each condition. Here, we believe that conditions with a higher percentage of PWAL suggest having a more acceptable range for various users. Moreover, we provided curves on the percentages of PWAL and proposed design values for the flat/sloped writing desk. The calculated percentages or numbers of PWAL on each Sashaku are shown in Figure 5. Since plots appear in a convex shape, that is, the results supported our hypothesis that neither too high nor too low is suitable for Sashaku, we placed a quadratic curve for plots on each tilted angle as part of the regression analysis. Most of the R² values were high (0.784–0.995), except for the 40° tilt condition (0.310). Thus, it was believed that these curves, except for the 40° tilted condition, can explain the percentage of PWAL well. On each curve, the vertex’s coordinates (x, y) were the most acceptable Sashaku (x) and its percentage of PWAL (y). For example, the most acceptable Sashaku is 339 mm and its percentage of PWAL is 91.7% on the writing task when using a 10° tilted board. The most acceptable tilted angle was 10°, followed by 20°.

Then, we proposed the design value of the flat/sloped writing desk when various users performed the writing work. The best condition was 10° tilted and 339 mm Sashaku, as seen in Figure 5; however, providing ranges for the design value is also important to address various situations. Therefore, we calculated the recommended ranges of Sashaku by substituting each acceptable percentage (i.e., percentage of PWAL) for y on the formulas in Figure 5. A low acceptable percentage gives a wide range of Sashaku, while a high percentage provides a narrow range. Table 4 shows the recommended range of Sashaku at acceptable percentages. On the writing task, a 10° tilted condition offers the widest range compared to the others. A 10° tilted board and 319–359 mm Sashaku will satisfy 90% of users, while 278–401 mm board will address the concerns of 75% of users. Specifically, 10% and 25% of users will not be gratified, respectively. However, the wider range of Sashaku will be advantageous when users use an adjustable chair and a fixed desk. Users can utilize various chairs (e.g., adjustable and wheelchairs) and a one-size-desk that can be used by everyone.
In Figure 6, we provide design examples when the desk’s height was fixed at 700 mm. The advantage of our proposal is that the designer can cater to an acceptable level of user diversity (i.e., a range of \textit{Sashaku}), angle of tilted board, and working task.

However, the proposal was calculated based on participants whose heights ranged from 1,520 mm to 1,790 mm (mean, 1,657 mm; standard deviation, 81 mm). Thus, the proposal should be given only in situations where similar users participate. The wider range of \textit{Sashaku} will especially be an advantage for users of various heights, such as children and elders. Investigating them in a similar way is one of the future tasks.

4. CONCLUSION

In this study, we hypothesized that working in an elevated position would be comfortable when using a tilted board. We also investigated the effect of a tilted board, in order to propose design values for flat/sloped writing desks that are acceptable to individuals’ preferences regarding desk heights. Based on the results, we arrived at the following conclusions:

1. It was suggested that a 10° tilted board had good subjective usability, and a slightly tilted desk did not worsen usability.
2. Tilted angle and \textit{Sashaku} affected usability independently, and interactions were not observed on both the reading and writing tasks.
3. We investigated the relationship between \textit{Sashaku} standardized by individual height and subjective usability; however, no clear correspondence between these was observed.
4. We calculated the acceptable percentage, which was the ratio of participants with their own minimum acceptable level for each condition. As a result, it is believed that \textit{Sashaku} can explain the acceptable percentage well with quadratic curves, except for the 40° tilted condition.
5. We proposed the recommended ranges of \textit{Sashaku} on flat and tilted conditions based on the quadratic curves. The advantage of our proposal is that the designer can select an acceptable level of user diversity, that is, they can consider and weigh the acceptable percentage against the range of \textit{Sashaku}. Additionally, it is also worth noting that the proposal can be used for the situation when the desk’s height is fixed as \textit{Sashaku} is calculated.

Meanwhile, there are some aspects that need further investigations. We could not explain the usability of the tilted board by using certain measurements, such as electromyography and hand movements because their values varied widely. It is also imperative to standardize the experimental tasks and measurement values. Additionally, the proposed design values were calculated based on participants whose heights ranged from 1,520 mm and 1,790 mm (mean: 1,657 mm, standard deviation: 81 mm). Thus, the proposal can be considered only in situations where there are similar users. A wider range of \textit{Sashaku} will especially be advantageous for users with different heights. Investigation with participants who have more diverse height ranges is effective for expanding the scope of this study.

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NOTES

1. For example, such as OKAMURA’s \textit{CG-E chair} (https://www.okamura.co.jp/product/seating/cg-e/) and IKEA’s \textit{FLINTAN} (https://www.ikea.com/jp/js/p/flintan-office-chair-vissle-black-00336842/) are typical type of office
chairs with simple height-adjustment function.
2. KOKUYO’s ing (https://www.kokuyo-furniture.co.jp/products/office/ing/) has unique seat swinging function and HermanMiller’s aeron chair (https://www.hermanmiller.com/ja_jp/products/seating/office-chairs/aeron-chairs/) has additional adjustable features such as tilt tension of backrest and lumbar height.
3. IKEA’s SKARSTA (https://www.ikea.com/us/en/p/skarsta-desk-sit-stand-white-s95324818/) and OKAMURA’s Swift (https://www.okamura.co.jp/product/desk_table/swift/sp/index.html) are example of sit/stand desk.

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