Quality and User Experience (2024) 9:3
https://doi.org/10.1007/s41233-024-00067-w

RESEARCH ARTICLE

Visibility Control for Supporting Workers using Blind-based Partitioning Devices

Rikiya Fukushima[1] · Kazuyuki Fujita[2] · Kodai Ito[3] · Yuichi Itoh[3]

Received: 13 February 2023

Abstract
Open-plan offices encourage communication among office workers, but they also create distractions stemming from the movement, glances, and nearby conversations of co-workers. Partitions are often employed to mitigate these distractions, yet they struggle with achieving equilibrium between privacy and situational awareness. In this study, we propose a system of visibility control utilizing a blind-based partitioning device whose slat angles can be individually controlled. To demonstrate our system's efficacy, we implemented a prototype of the device consisting of 48 controllable slats with servo motors, allowing visibility control of the front and both sides of the worker's desk. Our accuracy test of the visibility control revealed that visibility from the user's view can be controlled with an error of 6.4%. Subsequently, we conducted a user study that asked participants to design the shape of the partition under specific conditions of task and co-worker location. The results show that users want to change the partition shape according to the conditions and that using the device improves the subjective sense of task performance, comfort, concentration, and visual privacy in the video-summarizing tasks, but slightly reduces subjective comfort and concentration in the conversation tasks. These findings demonstrate a solid need for our system and established the usage guidelines.

Keywords Human-computer interaction (HCI) · Spatial transformation · Open-plan workspaces · Transform partition

Introduction

The popularity of open-plan offices has surged in recent times due to the perceived benefits of fostering communication among employees and cost-effectiveness in comparison to traditional private office spaces [1, 6, 29].

However, the constant visual and auditory distractions, such as colleagues' movements and nearby conversations, can negatively impact worker productivity and well-being [2, 5, 6, 13, 18, 23, 24, 27]. Thus, creating workspaces with appropriate openness has been a critical issue for efficient knowledge work [9].

To regulate the openness of a workspace, various interactive partitioning systems have been proposed using wheeled robots [16, 19, 20], shape memory alloys [7], or augmented reality (AR) content [17]. However, little has been examined on exactly controlling the visibility from both inside and outside of a worker's workspace. Several studies have explored accurate visibility control glass panels by varying the transparency of LCD-based panels [4, 22], but they remain limited in that they simultaneously block sound between them, possibly discouraging conversation.

Therefore, in this study, we focus on blinds for visibility control and propose a blind-based partitioning system whose slat angles are individually controllable. The view of the environment through the blinds changes depending on the slat angle and the viewer's position. If we can develop a blind-based partition and control the angle of the slats individually, we can change the visibility of workers and the way others see them, in addition to supporting conversation. This system also offers different environments depending

✉ Yuichi Itoh
itoh@it.aoyama.ac.jp

Rikiya Fukushima
fukushima.rikiya@ist.osaka-u.ac.jp

Kazuyuki Fujita
k-fujita@riec.tohoku.ac.jp

Kodai Ito
kodai.ito@it.aoyama.ac.jp

[1] Osaka University, Suita, Japan

[2] Tohoku University, Sendai, Japan

[3] Aoyama Gakuin University, Sagamihara, Japan

Published online: 12 August 2024

on the situation, such as conversations with co-workers or preventing distractions from them. Creating such a partitioning system will contribute to realizing an intelligent environment that adaptively changes the workspace according to the user's state and situation and influences the user's work performance accordingly, thereby improving the user experience at work.

We first describe the details of implementing a blind-based partition device, as shown in Fig. 1, to control visibility for supporting workers. Second, we experiment to quantitatively evaluate the degree to which the prototype can control the visibility of the environment. Finally, we conduct a design study to derive guidelines for the successful use of this system.

Related work

Modern office layouts and work styles

Many recent offices have adopted an open-plan layout owing to its cost-effectiveness, as it allows for a reduction in the overall footprint of the workspace in comparison to traditional closed-off offices [29]. Furthermore, open-plan offices possess the benefit of facilitating observation and communication among employees [1, 6]. However, certain drawbacks have also been identified, such as the potential for disruption of worker concentration due to ambient noise and visual distractions [2, 6, 13, 18, 23, 24]. Additionally, open-plan offices may not provide adequate privacy for employees [5, 27]. These factors can lead to increased dissatisfaction and stress among workers, resulting in decreased productivity. Furthermore, the high density of individuals in open-plan offices can contribute to the transmission of viruses and bacteria, exacerbating the risk of illness among employees [21].

One potential strategy to address the shortcomings of open-plan offices is the implementation of an innovative work style known as activity-based working (ABW), which was first proposed by a company [14]. ABW provides workers with access to a variety of spaces with different configurations—including open-plan and closed-off layouts—that they can choose based on the task at hand, which has been shown to improve worker comfort and productivity [3, 8, 12, 25]. However, this approach typically necessitates a larger physical space than traditional offices. Furthermore, a study has indicated that employees tend not to frequently move around their workspaces and prefer to remain in a single location [11]. Therefore, we posit that a more cost- and space-efficient solution to the drawbacks of open-plan offices would be to tailor each worker's fixed workspace to their specific activities rather than adopting the ABW approach. As such, we focus on controlling the partition visibility.

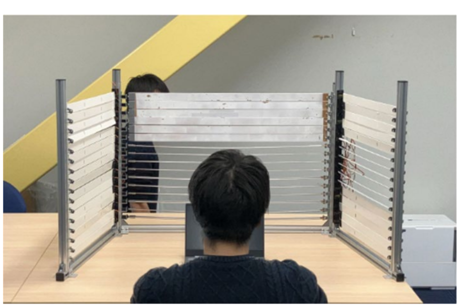


Fig. 1 Example of using a blind-based partition device

Permeability-variable partitions

Partitioning is a prevalent method of achieving sound and visual privacy in open-plan offices, but it also results in a diminished awareness of one's surroundings. To reconcile this trade-off, various proposals have been put forward in the field of human-computer interaction for partitions with adjustable permeability to the environment, either in a physical or virtual capacity [9]. For instance, Takeuchi introduced the concept of "weightless walls," which enables virtual auditory partitioning by enabling users to hear only the sound within the walls via noise-cancelling headphones [28]. Lee et al. investigated the use of augmented reality (AR) partitioning, where each user can perceive virtual partitions through the use of an optical see-through head-mounted display, which affords the advantage of arbitrary control over the shape of the partition and does not compromise the overall view of the space [17]. However, these approaches necessitate the use of a device, which may interfere with natural social behavior.

Additionally, research has been conducted on controlling the permeability or position of physical walls or partitions. "Squama" and "Window Wall" are partitions constructed with multiple dimmable glass panels, the transparency of which can be individually adjusted by applying voltage [4, 22]. These systems provide precise visibility control between users separated by them, but also uniformly block sound transmission, potentially hindering conversation.

Lee et al. developed wheeled robotic partitions whose position could be controlled and found, through a user study, that its approach behavior to the user induces a high user preference [16]. Onishi et al. proposed a similar robotic partitioning system that supported height adjustment and multiple-partition cooperation [19, 20]. These systems enable the creation of a wide range of workplace configurations but may be somewhat cumbersome for the singular purpose of controlling interactivity. We therefore focus on the utilization of blinds, which afford easy control of visibility (and audibility). As an analogous effort to our own, Coelho and Maes proposed Shutters, a curtain composed of louvers whose openness could be individually controlled by a shape memory alloy [7]. This system enables flexible control of the physical partition permeability but does not specifically target the visibility of workers in an office setting. In this study, we aim to support workers by strictly regulating the visibility of blind partitions based on a worker's viewpoint by adjusting the slat angle individually.

Proposed system

Overview

We focus on blinds because they provide a view of the environment that can be changed according to the angle of the slats and the user's viewpoint position. Therefore, controlling the angle of the slats individually can adjust the visibility of workers and the way others see them in addition to promoting ease of conversation. It also offers various setup configurations depending on the situation, such as stimulating conversation with co-workers, preventing distractions from their movement and gazes, and allowing workers to feel a sense of openness. Note that our primary concern is controlling visibility; controlling audibility is outside the scope of this study. In the following, we describe the system design, prototype implementation, and performance evaluation.

System design and implementation

We focus on the simplest setting; the design of a partition device that can be used by a single worker on their desk. In a study conducted by Shiraishi et al., a sufficient personal workspace was defined as measuring 70 cm in depth and 100 cm in width [26]. Thus, we designed our prototype to accommodate an area of 70×100 cm with a height of 70 cm. The prototype was configured with three blind walls, one in front and one on each side, to enclose a personal workspace.

We implemented the prototype system as shown in Fig. 2; it is comprised of three blind-like partitions on the front, left, and right sides. To conform to the aforementioned requirements for a sufficient personal space, the width of the front partition is 100 cm, while the width of the left and right partitions is 70 cm. The height of the partitions is 70 cm. Each partition consists of 16 slats attached to a servo motor (Miuzei MS18 micro servo) fixed to a support pole, as shown in Fig. 3. The angles of the servo motor axis can be controlled from 0° to 180° by means of pulse-width modulation (PWM) control. The other side of the slat is connected to the post by a rotating plate and, as the angle of the servomotor changes, the slat angle also changes from 0° to 180°. The servo motors are controlled by a microcontroller (Arduino Mega 2560) and an application written in C#. The angle of the slats can be controlled via serial communication from a PC or other device.

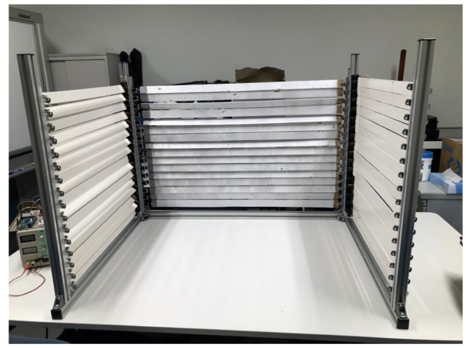


Fig. 2 Appearance of blind-based partition device

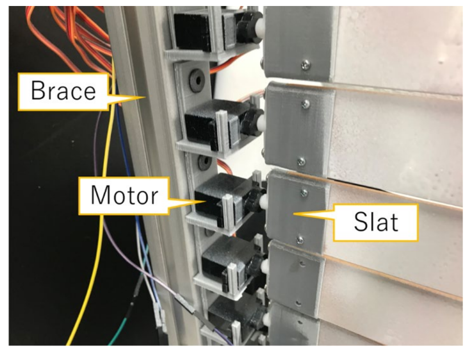


Fig. 3 Motors of blind-based partition device

Slat angle calculation

Within our system, users are able to manipulate visibility through the individual adjustment of each slat's angle. We defined visibility of the surroundings as the proportion of the opposing environment that is discernible through the partition when viewed in the direction of the partition. This section outlines the method for calculating the slat angle to regulate visibility of the environment. First, the system calculates the slat angle that maximizes the environment's visibility. It is maximized when each slat faces the user's viewpoint direction. We represent the user's viewpoint position by the distance d from the partition and the height H from the underside. As shown in Fig. 4, the angle at which one slat S_n faces in the direction of the user's viewpoint position is denoted by φ_{S_n} based on the upward direction of the partition. Expressing this φ_{S_n} using the height H of the user's viewpoint position, the distance d of the user's viewpoint position from the partition, and the height h_{S_n} of the position of the slat S_n, we obtain Eq. 1.

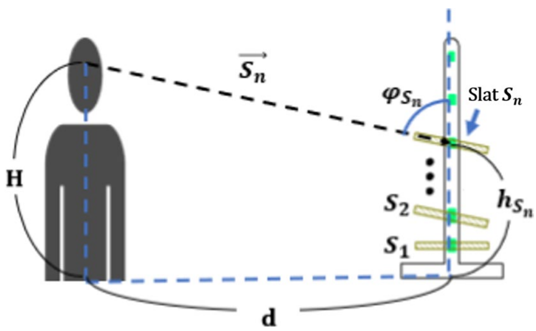


Fig. 4 Location of slat and viewpoint

$$\varphi_{S_n} = \tan^{-1}\frac{d}{H - h_{S_n}} \tag{1}$$

Then, the system calculates how the slats can be tilted from this φ_{S_n} angle to control the visibility of the environment. First, we consider the extent to which a single slat controls visibility. As shown in Fig. 5, when the width of the slats and the spacing between slats is L, the area where a single slat can control visibility is length L with the slat position as the midpoint. Note that the area of length L from the user's viewpoint is $L \sin \varphi_{S_n}$ when converted to an edge perpendicular to their line-of-sight vector $\mathbf{S_n}$. Here, we define *visibility* as α, which is the percentage of the area controlled by the slats that has an unobstructed view to the other side. As shown in Fig. 6, the area where the slats block the view is $L \sin \lambda$ on the side perpendicular to the user's line-of-sight vector $\mathbf{S_n}$ when the slat angle is inclined λ degrees from the user's viewpoint direction. However, we calculate it approximating L^2 as sufficiently small compared to d^2. Within the area of length $L \sin \varphi_{S_n}$ where slat S_n controls visibility, the length of the area blocked by the slat is $L \sin \lambda$. Therefore, the visibility α within the area controlled by a single slat is expressed as in Eq. 2 and λ is expressed as in Eq. 3.

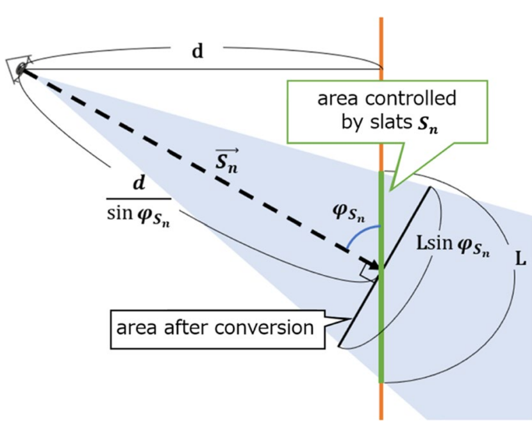


Fig. 5 Range where the slat controls visibility

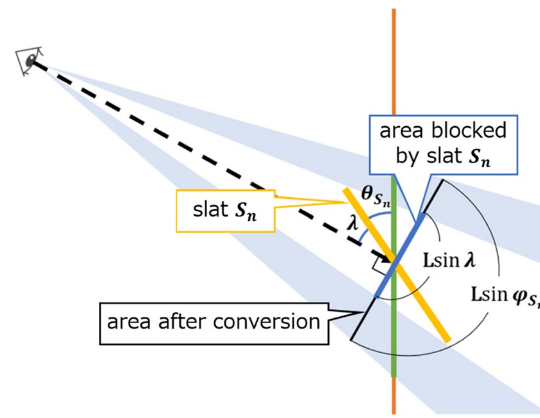


Fig. 6 Visibility control by changing the angle of the slat

$$\alpha = 1 - \frac{\sin \lambda}{\sin \varphi_{S_n}} \tag{2}$$

$$\lambda = \sin^{-1}\{(1-\alpha)\sin \varphi_{S_n}\} \tag{3}$$

Finally, the angle θ_{S_n} of slat S_n to obtain a certain environmental visibility α can be expressed using φ_{S_n} as in Eq. 4.

$$\begin{aligned}\theta_{S_n} &= \varphi_{S_n} \pm \lambda \\ &= \varphi_{S_n} \pm \sin^{-1}\{(1-\alpha)\sin \varphi_{S_n}\} \\ &= \tan^{-1}\frac{d}{h - h_{S_n}} \pm \sin^{-1}\frac{d(1-\alpha)}{\sqrt{(h-h_{S_n})^2 + d^2}}\end{aligned} \tag{4}$$

Using the angles thus obtained, we perform the following experiment.

Performance evaluation

To experimentally assess the precision of visibility control with our proposed system, we digitally assessed the target visibility as viewed through the prototype partition device with adjusted slat angles. In this experiment, we utilized images captured by a camera installed at the user's vantage point as opposed to the actual user's field of view.

Initially, we established the target values for environmental visibility and set the slat angles calculated by our formula in Sect. 3.3. Subsequently, we captured the slats portion of the partition from the front direction, as shown in Fig. 7. The camera was oriented towards a target point at a height of 45 cm on the opposite side of the partition. We then computed the percentage of pixels in the captured image that were unobstructed by the slats and defined it as an actual measure of the visibility of the environment. An example of the captured images is presented in Fig. 8. For this measurement, we prepared five

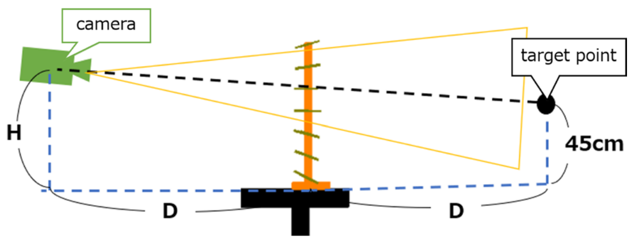


Fig. 7 Arrangement of experimental environment

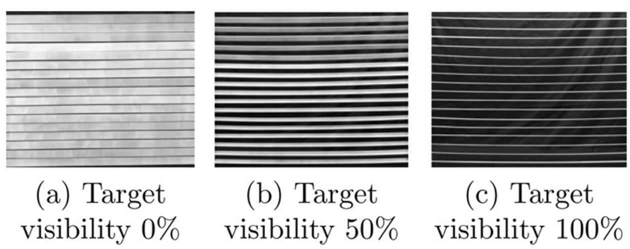


Fig. 8 Images taken in the experiment

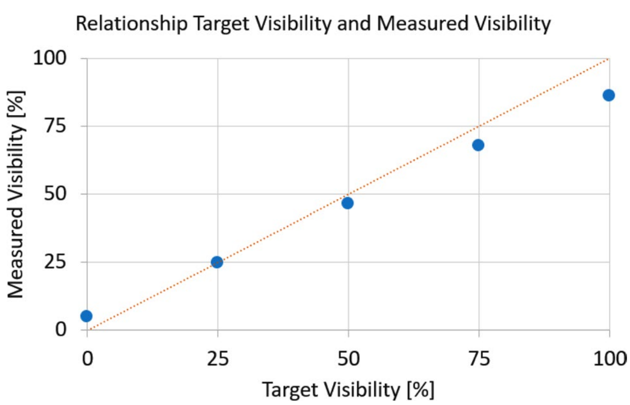


Fig. 9 Results of the experiment

conditions of camera height H: 30, 45, 60, 75, and 90 cm; two conditions of the camera to partition distance D: 60 and 90 cm; and the target values for environmental visibility: 0, 25, 50, 75 and 100%. Finally, we evaluated the visibility accuracy of the environmental control by calculating the error between the target and measured values under these different conditions.

The results of the experiment are illustrated in Fig. 9. The mean error between the target and measured values of the environmental visibility was 6.4% (SD = 4.9). How much such error affects the user's performance and subjective preference is examined in the user studies described in the following section.

Design study

Purpose

We conducted a design study using the implemented blind-based partition device to derive guidelines for the successful use of this system. There are three main objectives of this experiment. The first is to determine the existence of a need for workers to alter the configuration of partitions in various scenarios. The second is to identify the desired configuration of partitions in each scenario when a need for alteration is present, thereby determining the appropriate configuration to automatically implement. The last is to ascertain the efficacy of blind-based partitions as a system for modifying partition configurations.

Experimental design

To determine the experimental design, we examined the factors potentially affecting office workers. Sanders et al.'s study showed that the impact of external stimuli on work performance depends on the task type [25]. In addition, Sundstrom et al.'s study showed that how others see the workers affects their performance and satisfaction with the workspace [27]. Furthermore, to clarify the effectiveness of the device, the task should also be performed without the device in place.

Therefore, we set the independent variable based on three factors: the task type (*Video summarizing* and *Conversation*), the co-worker location (*Standing diagonally behind*, *Sitting in front*, and *No co-worker*), and the use of the device (*With device* and *Without device*). We chose two tasks to perform at the desk, *Video summarizing* and *Conversation*, referring to the previous study [17] and our preliminary experimental results. The details of the tasks are shown in Table 1.

The three conditions for co-worker location, as shown in Fig. 10, were decided by referring to Lee et al.'s interaction model of what tends to occur around desks in offices [15]. In the experiment, the experimenter played the role of the co-worker. In condition *Standing diagonally behind*, the experimenter stands diagonally back to the right, as shown in Fig. 10a. This condition replicates a situation in which a co-worker visits the workspace or a co-worker walks behind the workspace. In condition *Sitting in front*, the experimenter sits on the opposite side of the front partition, as shown in Fig. 10b. This condition replicates a situation in which a co-worker is sitting with the worker directly across the partition. In condition *No co-worker*, the experimenter leaves the room, as shown in Fig. 10c. Note that we eliminated one impossible condition that

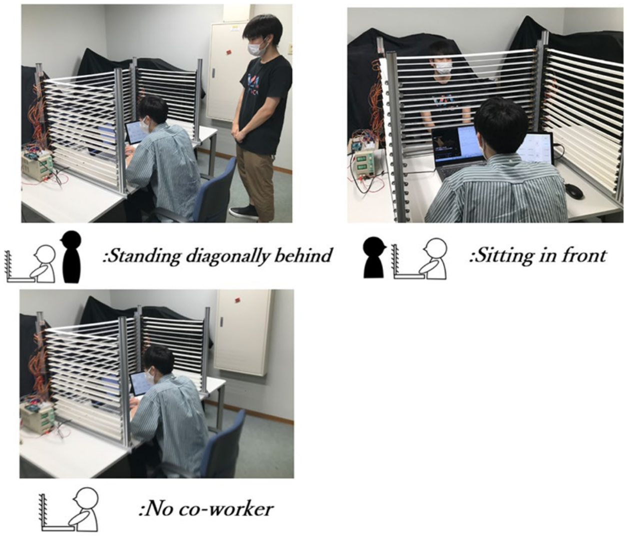


Fig. 10 Conditions for the position of the co-worker

combines *Conversation* task and *No co-worker*, resulting in five combinations of task type × co-worker location tested in total.

Participants and setup

We recruited thirty university students (mean age 21.5 years, 18 males, 12 females). The study was conducted individually with each participant. The participants were seated in a room measuring approximately 3.5 × 4.0 m, equipped with a blind-based partition device, as shown in Fig. 11a. The participants were able to adjust the angle of each slat of the device through an application on a 12.3-inch tablet PC (Microsoft Surface). Additionally, the participants were able to switch to frequently observed shapes from preliminary experiments with the push of a button on the application.

Procedure

Before the onset of the experiment, we provided the participants with an overview of the experiment and explained how to operate our device. We then asked them to perform several tasks under multiple conditions in the work environment shown in Fig. 11. In *With device* conditions, we additionally promoted them to an optimal partition shape. To control the shape of the partitions, participants selected one of the three types of visibility shown in Fig. 8 for each of the three partitions (or their top and bottom halves, as needed) by manipulating a control panel on a tablet device (Microsoft Surface, 12.3 inches). At the beginning of each task under these conditions, all partition shapes were returned to their closed state. We then asked the participants to perform tasks while designing the shape of the partition under these conditions. During this time, we recorded a video of what partition shapes the participants designed for each condition. Following each condition, we asked the participants to complete a questionnaire regarding their task performance and partition design, as shown in Table 2. Finally, upon completion of all conditions, the participants were asked to complete a post-experiment questionnaire, as shown in Table 3. These questionnaires were adapted from Shiraishi et al.'s study [26].

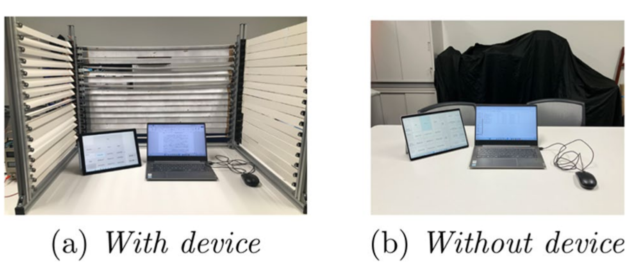


Fig. 11 Experimental environment

Results and discussion

Overview

The design study resulted in a total of 150 (5 conditions x 30 participants) partition shapes. We classified them according to the characteristics of the partition shapes based on our observation of the recorded video. Figure 12 shows the patterns of shapes that were frequently observed in the overall conditions and their percentages. Figure 13 shows the shapes and percentages of partitions that were designed frequently in each condition. Figure 14 shows the mean visibility of the observed partition shape per condition (in (a) the front partition, (b) the right partition, and (c) the left partition, respectively). To observe the statistical differences, we conducted Holm's multiple comparisons. Figure 15 shows the answers for each condition to Q1, Q2, Q3, and Q4 of the

Table 1 Task content conditions

Task	Details
Video summarizing	This task is to watch a short news video and summarize it in words. The length of the video is about 2 min and the summary must be at least 50 words. Participants are free to re-watch, pause, and rewind the videos
Conversation	This is a conversation task with a co-worker. During this task, the co-worker continues to talk to the participant about an appropriate topic. The conversation should last approximately 3 min. During the task, the experimenter continues to talk to the participants about appropriate topics

Table 2 Every-trial questionnaire

No	Questions
Q1	How well did you perform the task? (7-point Likert scale)
Q2	Was the environment in which you performed the task comfortable? (7-point Likert scale)
Q3	Was it easy to concentrate on the task in the environment where you performed the task? (7-point Likert scale)
Q4	Did the environment where you performed the task maintain your visual privacy? (7-point Likert scale)
Q5	For what purpose did you change to the current partition shape? (asked only in *With device* conditions)

Table 3 Post-experiment questionnaire

No	Questions
Q1-1	Did using the partition device improve your working environment? (7-point Likert scale)
Q1-2	Please tell us why you answered as above in Q1-1
Q2-1	Would you like to continue using partitioning devices? (7-point Likert scale)
Q2-2	Please tell us why you answered as above in Q2-1
Q3	If you had complete freedom to change the shape of the partition, how would you change it? Please let us know if there is anything we can do to improve the device
Q4	If you were to use this device, in what situation and how would you use it?

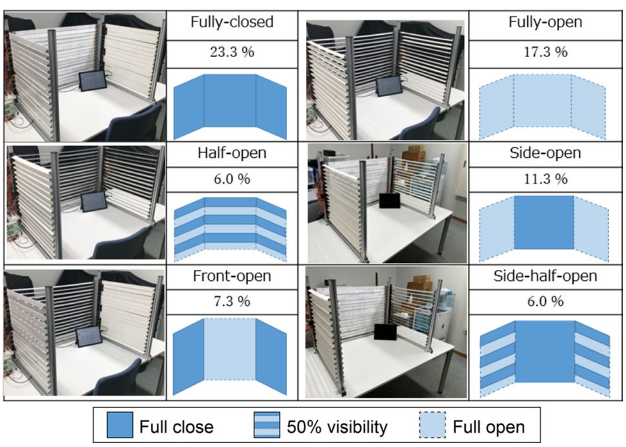


Fig. 12 Frequently observed partition shapes

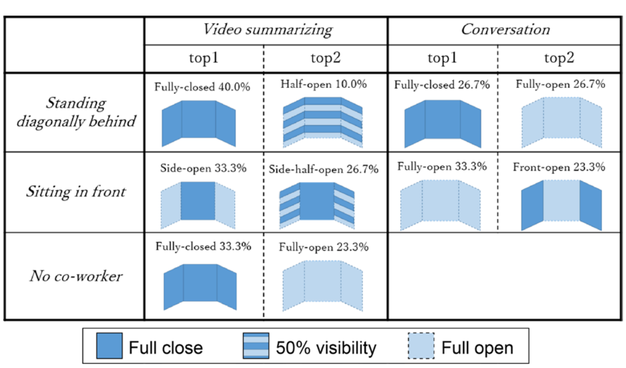


Fig. 13 Frequency of observed partition shapes for each condition

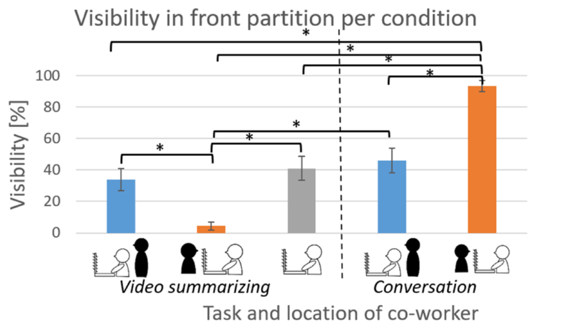
every-trial questionnaire in Table 2. We compared the condition *With device* with the condition *Without device* by means of a paired t-test. Based on these results and the open-ended portion of the questionnaire, we discuss the objectives we set at the beginning of this section.

Obtained partition shapes and visibility

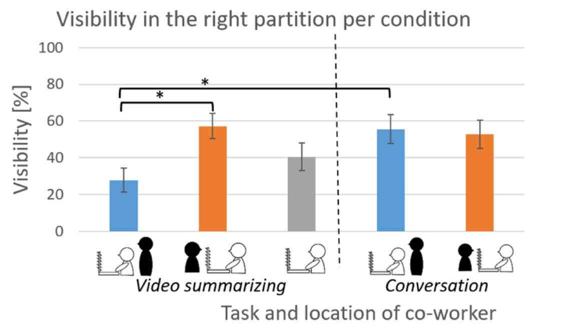
As shown in Fig. 12, the obtained partition shapes were diverse; even the "fully-closed" shape, which obtained the highest percentage, accounted for 23.3% of the total. This shows a strong individual difference of the participants in their preferred partition shapes. Only a minority of participants configured different visibility for the top and bottom halves of each partition. This may be because the conditions we prepared were rather simple, so participants did not feel a particular need to change the visibility locally. Further investigation is needed to determine the benefit of being able to control the slats individually.

As shown in Fig. 13, the prevalent shapes varied across conditions, suggesting that the participants exhibited a preference for distinct partition shapes in each condition. This result shows that the workers' needs for partition shapes vary depending on the tasks and co-worker locations, which indicates that there is a solid demand for partitions with changeable visibility.

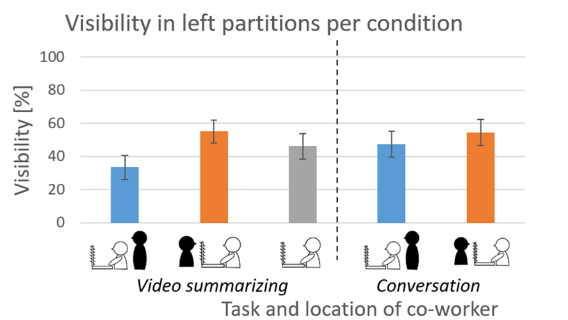
As shown in Fig. 14a, the obtained visibility in the front partition was the lowest in the *Video summarizing* × *Sitting in front* condition, which was significantly lower than in the other conditions ($p < .05$). Regarding the purpose of the partition design as asked in the every-trial questionnaire shown in Table 2, 86.7% of the participants in this condition



(a) Visibility in front partition per condition



(b) Visibility in right partition per condition



(c) Visibility in left partition per condition

Fig. 14 Visibility in partitions per condition

responded "to keep the co-worker out of sight" or "to cut off the co-worker's line of sight." This indicates that our system should lower visibility in the front partition to avoid eye contact with co-workers when performing personal tasks.

By contrast, the obtained visibility in the front partition was the highest in the *Conversation* × *Sitting in front* condition. In this condition, 90.0% of the participants stated the partition was designed "to see the co-worker" or "to talk with the co-worker easily." This also indicates that the participants consider eye contact with co-workers important during conversation, so the system could be controlled to increase the visibility in the front partition by recognizing the task type.

As shown in Fig. 14b, the obtained mean visibility in the right partition was the lowest in the *Video summarizing* × *Standing diagonally behind* condition of the five conditions. This is primarily because the co-worker was standing diagonally to the right side; the visibility of the right partition may have been lowered so as not to be seen by the co-worker and to increase visual privacy. By contrast, in the *Conversation* task, the obtained visibility was significantly higher than the *Video summarizing* task under the *Standing diagonally behind* condition ($p < .05$). This could be to make it easier to talk with the co-worker.

As shown in Fig. 14c, there was no significant difference ($p > .05$) between each pair of the five conditions in the obtained visibility, but the overall tendency seemed to be similar to the right side (Fig. 14c). This could be because the participants tried to make the partition shape symmetrical.

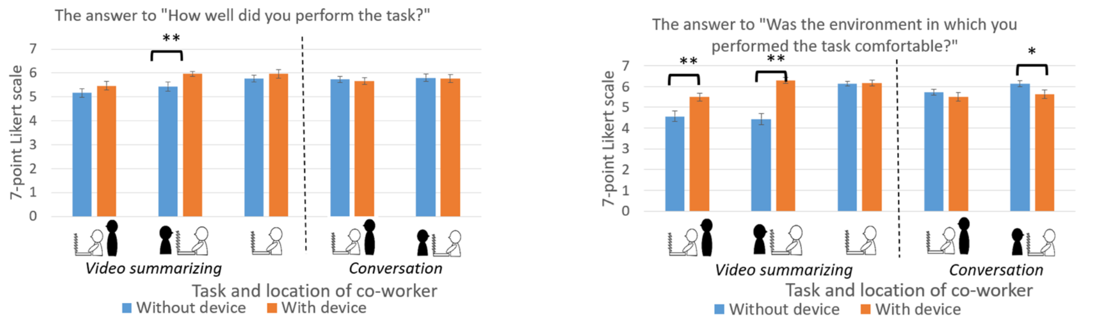
The results above show that there is a certain trend in the shape of the partition required for the task and the co-worker location, although there is some variation depending on the participants' preferences, and these experimental results can be used as guidelines for our future improvements towards full automatic control of the partition shape.

Subjective measures

Regarding the subjective task performance question in the every-trial questionnaire, as shown in Fig. 15a, the mean score for all conditions was 5.77 (SD = 0.87) and 5.58 (SD = 0.89) in *With device* and *Without device*, respectively. The score *With device* was significantly higher than *Without device* in the *Video summarizing* × *Sitting in front* condition ($p < .01$). Since the *Video summarizing* was a front-facing task, increasing the visual privacy using the partitions would have contributed to the participants' subjective task performance.

Regarding the subjective comfort and concentration question in the every-trial questionnaire, we obtained a similar tendency; as shown in Fig. 15b and c, the obtained scores *With device* were significantly higher than *Without device* in the *Video summarizing* × *Standing diagonally behind* and *Video summarizing* × *Sitting in front* conditions ($p < .01$), while it was lower than *Without device* in the *Conversation* × *Sitting in front* condition ($p < .05$). In the *Video summarizing* task, the partition device increased the subjective comfort and concentration because it kept the co-worker out of view, but in the *Conversation* task, the participants may have felt uncomfortable and distracted having a conversation across the partition device.

Regarding the subjective visual privacy asked in the every-trial questionnaire, as shown in Fig. 15d, the scores *With device* were significantly higher than *Without device* in the *Video summarizing* × *Standing diagonally behind* ($p < .01$), *Video summarizing* × *Sitting in front* ($p < .01$), and *Conversation* × *Standing diagonally behind* condition ($p < .05$). This was probably because the partition device made it difficult to



(a) Answers to Q1 of the every-trial questionnaire (b) Answers to Q2 of the every-trial questionnaire

(c) Answers to Q3 of the every-trial questionnaire (d) Answers to Q4 of the every-trial questionnaire

Fig. 15 Results of the every-trial questionnaire

be seen from the surroundings and visual privacy was easier to maintain.

Thus, we found that the subjective measures were improved by the use of our partition device in many conditions of the *Video summarizing* task. However, we also found that, in the *Conversation* task, the subjective comfort and ease of concentration were slightly reduced. In the post-experiment questionnaire shown in Fig. 3, there were several comments supporting this result, such as “When talking over the partition, I was aware of the presence of the slats even when the partition was completely open.” and “I would like to create a state in which the partition is completely absent in some situations.”

The responses to the questions “Did using the partition device improve your working environment?” and “Would you like to continue using partitioning devices?” in the post-experiment questionnaire (as shown in Fig. 3) were rated with an average of 5.8 pts (SD = 1.0) and 5.6 pts (SD = 0.95), respectively, both of which were much higher than the neutral score of 4. These results indicate that the device improved the subjective work environment and was generally preferred by the participants.

General discussion

Application examples

Based on the results of the user study, we propose several application examples that automatically change the shape of our device, as shown in Fig. 16.

The user study showed that workers’ workspace demands vary depending on the task type, especially between personal tasks and conversational tasks. Thus, an application can control the slat angles according to the user’s current task, estimated from the active applications on the user’s own devices such as PCs and smartphones (Fig. 16a). Similarly, when a certain duration of continuous working time is detected on the user’s device, the system can encourage the user to take a break by changing the partition into an open state (Fig. 16b). We also found that bystander location affects the user’s demanded partition shapes and the demands also vary by the combination of task type and bystander location. Therefore, we propose

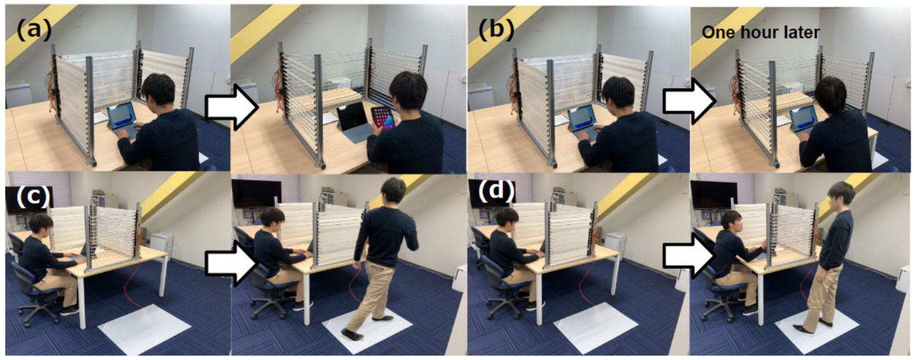


Fig. 16 Application examples of visibility control depending on **a** task type, **b** working duration, **c** necessity for visual privacy, and **d** necessity of communication

an application that can detect the presence and location of bystanders using a pressure-sensitive sheet on the floor (Fig. 16c and d). For example, if a person passes nearby when the user is performing a personal task, the visibility of the partition can be reduced so that the user and task are hidden (Fig. 16c). However, if the person stands by the user for more than a certain duration (the person's intention could be more accurately inferred by using the idea of proxemics [10]), the system assumes that the person wants to talk to the user and opens a partition on that person's side (Fig. 16d).

Note that the system should allow the user to manually set the shape of the partition or learn the user's partition individual preferences, as our user study shows a strong diversity in the users' demanded partition shapes for each condition. For manual control of the partition shape, we need to develop user interfaces in the future, such as switching shapes by calling presets from the user's smartphone or manipulating individual slats by hand gestures.

Limitations and future work

Our user study succeeded in deriving several guidelines for controlling the partition shapes of our system, but we still face several limitations. First, the user study was a laboratory study with a limited number of participants and conditions tested. We still have many other factors regarding actual use in office spaces, such as the space size, number of co-workers, task duration, and worker attributes; future work will conduct another user study covering a wider range of conditions and scenarios with a larger and more diverse participants. Regarding the measurements, our user study relied on the subjective evaluation of the worker using the device; thus, we also plan to obtain quantitative metrics such as objective task performance, eye-tracking data, and the user's physiological responses in our follow-up study.

Second, we would also like to examine the long-term effect and external validity of our system by conducting an in-the-wild user study using actual office spaces; this will gain a more robust understanding of how our system performs in diverse and dynamic environments. Regarding the suitable location of our system, many participants commented that it provided a place to work alone with other people around. We thus believe that our system can be applied to places other than offices, including homes and cafes, and conducting user studies in these places can be part of our future work.

Third, the user study revealed that our system was sometimes perceived as interfering with conversation, even when in a fully open state. Thus, as obtained in the post-experiment questionnaire, we will consider an improved mechanism in which the slats can be fully removed from the partition, e.g., by sliding on a rail.

Fourth, our analysis in the user study focused mainly on simple shapes of the partition (e.g., fully open and fully closed) and the calculated visibility value, whereas our system can make more complex shapes by controlling each slat individually. We believe our system has the potential to separately control the visibility of the workers and the way others see them since the visibility of the environment through the blinds changes depending on the viewpoints for a specific slat angle. Therefore, in the future, we will pursue new effects of the system by verifying the difference in appearance through the partition from multiple positions.

Finally, this study is only concerned with controlling visibility, not audibility. The current system does not have a substantial ability to block sound, but it may be possible to manipulatively reflect sound by considering the size/shape of the partition and the materials and angles of the slats. In addition, since the sound generated by the servo motors is potentially distracting to surrounding workers, we could attempt to make it quieter. By working on these, we hope to create a system that can control visibility and audibility independently.

Conclusion

In this paper, we proposed and examined visibility control for supporting workers using a blind-based partition device whose slat angles can be individually controlled.

We implemented a prototype of the device and our performance test showed that the device controls the visibility of the user's view with an error of 6.4%.

We then conducted a design study that asked participants to design their preferred partition shapes while performing specific tasks under specific conditions of co-worker location. The results showed that workers demanded to change the partition shapes according to the tasks and the co-worker location. More specifically, they tended to reduce the visibility of the partition when securing their visual privacy and increase it when interacting with the outside. The subjective evaluation also revealed that using this device improved the subjective sense of task performance, comfort, concentration, and visual privacy in the video-summarizing tasks, but slightly reduced the subjective comfort and concentration in the conversation tasks. We derived guidelines from these results for future improvements towards full automatic control of the partition shape. We hope that these guidelines will be one of the elements in creating intelligent work environments that significantly enrich the worker experience.

Acknowledgements This work was partially supported by JSPS KAKENHI Grant Number JP24H00745.

Declarations

Conflict of interest The authors declare that there are no Conflict of interest.

Consent to participate All human participants involved in the studies described in this publication provided explicit written consent to participate in the studies of their free will.

Consent for publication All human participants involved in the studies described in this publication provided explicit written consent to allow publication of the analysed study data.

References

1. Allen TJ, Gerstberger PG (1973) A field experiment to improve communications in a product engineering department: the nonterritorial office. Human Fact 15(5):487–498
2. Altmann EM, Trafton JG, Hambrick DZ (2014) Momentary interruptions can derail the train of thought. J Exp Psychol: Gen 143(1):215
3. Arundell L, Sudholz B, Teychenne M et al (2018) The impact of activity based working (ABW) on workplace activity, eating behaviours, productivity, and satisfaction. Int J Environ Res Public Health 15(5):1005
4. Bader P, Voit A, Le HV et al (2019) Windowwall: towards adaptive buildings with interactive windows as ubiquitous displays. ACM Trans Comput-Human Interact (TOCHI) 26(2):1–42
5. Banbury SP, Berry DC (2005) Office noise and employee concentration: identifying causes of disruption and potential improvements. Ergonomics 48(1):25–37
6. Bernstein ES, Turban S (2018) The impact of the 'open' workspace on human collaboration. Philos Trans Royal Soc B: Biol Sci 373(1753):20170239
7. Coelho M, Maes P (2009) Shutters: A permeable surface for environmental control and communication. In: Proceedings of the 3rd International Conference on Tangible and Embedded Interaction, pp 13–18
8. Engelen L, Chau J, Young S et al (2019) Is activity-based working impacting health, work performance and perceptions? a systematic review. Build Res Inf 47(4):468–479
9. Fujita K, Takashima K, Itoh Y et al (2023) Human-workspace interaction: prior research efforts and future challenges for supporting knowledge workers. Qual User Exp 8(1):7. https://doi.org/10.1007/s41233-023-00060-9
10. Grønbæk JE, Korsgaard H, Petersen MG, et al (2017) Proxemic transitions: designing shape-changing furniture for informal meetings. In: Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, pp 7029–7041
11. Hoendervanger JG, De Been I, van Yperen N et al (2016) Flexibility in use: flexibility in use: switching behaviour and satisfaction in activity-based work environments. J Corp Real Estate 18(1):48–62
12. Inamizu N (2019) The impact on individuals and organizations of the choice of work environment to match their activities: activity based working/office and creativity (special feature: changing workplaces, changing work styles). Jpn J Labor Res 61(8):52–62
13. Kim J, de Dear R (2013) Workspace satisfaction: the privacy-communication trade-off in open-plan offices. J Environ Psychol 36:18–26
14. Lanks B (2014) Cozy in your cubicle? an office design alternative may improve efficiency. Bloomberg Businessweek, available at: URL:https://wwwbloombergcom/view/articles/2017-06-07/a-mathematician-ssecret-we-re-not-all-geniuses
15. Lee B, Lee M, Zhang P, et al (2019a) An empirical study of how socio-spatial formations are influenced by interior elements and displays in an office context. In: Proceedings of the ACM on Human-Computer Interaction
16. Lee H, Kim Y, Kim Ms (2013) Come on in!: A strategic way to intend approachability to a space by using motions of a robotic partition. In: 2013 IEEE RO-MAN, IEEE, pp 441–446
17. Lee H, Je S, Kim R et al (2019) Partitioning open-plan workspaces via augmented reality. Pers Ubiquitous Comput 26(6):1–16
18. Mark G, Gonzalez VM, Harris J (2005) No task left behind? Examining the nature of fragmented work. In: Proceedings of the SIGCHI conference on Human factors in computing systems, pp 321–330
19. Onishi Y, Takashima K, Fujita K, et al (2021) Self-actuated stretchable partitions for dynamically creating secure workplaces. In: Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems, pp 1–6
20. Onishi Y, Takashima K, Higashiyama S, et al (2022) Waddlewalls: room-scale interactive partitioning system using a swarm

of robotic partitions. In: Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22), pp 1–15
21. Pejtersen JH, Feveile H, Christensen KB et al (2011) Sickness absence associated with shared and open-plan offices-a national cross sectional questionnaire survey. Scand J Work, Environ Health 37(5):376–382
22. Rekimoto J (2012) Squama: modular visibility control of walls and windows for programmable physical architectures. In: Proceedings of the International Working Conference on Advanced Visual Interfaces, pp 168–171
23. Sander EJ (2021) Open-plan office noise increases stress and worsens mood: We've measured the effects. The Conversation
24. Sander ELJ, Marques C, Birt J et al (2021) Open-plan office noise is stressful: multimodal stress detection in a simulated work environment. J Manag Organ 27(6):1021–1037
25. Sanders GS, Baron RS (1975) The motivating effects of distraction on task performance. J Personal Soc Psychol 32(6):956
26. Shiraishi M, Sugiyama K (1993) The effect of low partitions on workers in offices: focusing on opposing layouts. Stud Design 95:25–30. https://doi.org/10.11247/jssdj.1993.25_1 (https://www.jstage.jst.go.jp/article/jssdj/1993/95/1993_KJ00007026172/_article/-char/ja/)
27. Sundstrom E, Burt RE, Kamp D (1980) Privacy at work: architectural correlates of job satisfaction and job performance. Acad Manag J 23(1):101–117
28. Takeuchi Y (2010) Weightless walls and the future office. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp 619–628
29. Vischer J (1999) Will this open space work? Harv Bus Rev 77:28–40