Age and Gender Differences in the Pseudo-Haptic Effect on Computer Mouse Operation in a Desktop Environment

Yuki Ban, *Member, IEEE*, and Yusuke Ujitoko, *Member, IEEE*

Abstract—Pseudo-haptics is a method that can provide a haptic sensation without requiring a physical haptic device. The effect of pseudo-haptics is known to depend on the individual, but it is unclear which factors cause individual differences. As the first study establishing a calibration method for these differences in future research, we examined the differences in the pseudo-haptic effect on mouse cursor operation in a desktop environment depending on the age and gender of the user. We conducted an online experiment and collected data from more than 400 participants. The participants performed a task of lifting a virtual object with a mouse pointer. We found that the effect of pseudo-haptics was greater in younger or male participants than in older or female participants. We also found that the effect of pseudo-haptics, which varied with age and gender, can be explained by habituation to the mouse in daily life and the accuracy of detecting the pointer position using vision or proprioception. Specifically, the pseudo-haptic effect was higher for those who used the mouse more frequently and had higher accuracy in identifying the pointer position using proprioception or vision. The results of the present study not only indicate the factors that cause age and gender differences but also provide hints for calibrating these differences.

Index Terms—Haptics, Pseudo-haptics, Individual difference

1 Introduction

With the development of virtual reality and human-computer interaction systems, attention to the presentation of haptic information has been increasing rapidly, not only in research fields but also in society. Familiar examples include the presentation of vibrations on smartphones, touchscreens, game controllers, and head-mounted displays. However, owing to the limited availability of inexpensive, compact, and easy-to-use actuators, commercially available products do not have a common mechanism for presenting haptic information, such as weight, force, or compliance. Although various attempts have been made in the research field, it has not yet been possible to present complex and varied haptic impressions using only inexpensive, small-sized, and lightweight devices.

Recently, the cross-modal effect has attracted attention as a new methodology for presenting sensory information [1]. The cross-modal effect is an illusory phenomenon in which the perception of one sensory stimulus changes due to the influence of other sensory stimuli received at the same time. There are various findings on the cross-modal effect related to haptic perception, and strong illusions can be observed between vision and haptic perception [2].

Among such visuo-haptic cross-modal interactions, pseudo-haptics has attracted particular attention in the fields of virtual reality (VR) and human-computer interaction [3], [4]. Users feel haptic sensations with pseudo-haptics by observing the difference in the movement of their body and the corresponding visual feedback. For example, when a virtual dumbbell moves faster than a real one that the user moves, it makes users perceive the dumbbell as lighter [5]. Previous studies have shown that this phenomenon can be used to present haptic impressions such as weight [6] and force [7]. By using pseudo-haptics, haptic sensations can be presented without a device that physically reproduces haptic sensations. In addition, by combining this phenomenon with a haptic device, it is possible to present haptic information with a resolution and intensity that exceed the physical limits of the device [8]. The development of displays that utilize pseudo-haptics is expected to help the spread of haptic content in the real world, which has not been as widespread as visual and auditory content owing to the size, complexity, and cost of stimulus presentation devices.

However, we empirically know that the effects of pseudo-haptics vary among individuals. In other words, even when the same visual stimuli are presented, the perceived intensity of the haptic sensations differs among participants [9]. In previous studies, the effects of visual stimuli were evaluated by averaging the effects among experimental participants without considering the variation in the effects among individuals. Therefore, it was not clear which participant factors affected individual differences in the pseudo-haptic effect. To establish pseudo-haptics as a robust haptic presentation technology, it is necessary to clarify the characteristics of individuals that affect the illusion effect and to develop a method to control individual differences.

The purpose of this study is to identify how user's age and gender affect the effectiveness of pseudo-haptics to realize a method to compensate for these individual differ-

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ences in future studies. In this paper, the effectiveness of pseudo-haptics means the magnitude of modulated haptic perception when the same visual stimulus is presented. In the field of optical illusions, it has been reported that the effectiveness of illusions changes with age. Specifically, the effectiveness of illusions increases or decreases with age depending on the illusion mechanism [10]. In addition, it has been reported that there are some optical illusions, such as the Poggendorff illusion, in which the magnitude of the illusion is larger for females than for males [11], [12].Furthermore, it has been reported that females become less accustomed to the Müller-Lyer illusion than males when the illusion is presented repeatedly and that the illusion effect persists [13]. The occurrence of cross-modal effects has also been reported to vary depending on the age, gender, and culture of the experiencer [14]. Since pseudo-haptics is an illusory phenomenon, especially the vision-related cross-modal illusion, and is considered to be somewhat related to optical illusions, we hypothesized that the illusory effect of pseudo-haptics may be affected by individual characteristics, such as age and gender.

In this study, as a first step to identify the factors that cause individual differences in the effectiveness of pseudo-haptics, we focused on the pseudo-haptic effect that modulates illusional weight perception during lifting of a virtual object with a computer mouse on a desktop PC environment. We collected data from various age and gender groups and investigated the changes in the illusion effect depending on these characteristics.

In addition, since pseudo-haptics is an illusional phenomenon in which haptic perception is modulated by visually presented information, we hypothesized that the accuracy of detecting the mouse pointer position using proprioception or vision would affect the effect of pseudo-haptics and designed a task to test this hypothesis.

2 Related Works

2.1 Individual differences in sensory illusion

Many researchers have conducted various studies on individual differences in the effectiveness of sensory illusions.

Binet was the first to classify optical illusions based on the changes of their effect with development. He classified various illusions into innate and acquired illusions [15]. In the former, the magnitude of the illusion gradually decreased with age, whereas in the latter, the illusion appeared late and its magnitude increased gradually. Many studies have reported on the relationship between age and the effectiveness of various optical illusions. For example, most studies have reported a linear decrease in the effectiveness of the Müller-Lyer and Delbouef illusions with age [10], [16]. However, some studies have shown that the illusions increase with age in the group of 5 to 9 years of age [17]. The effectiveness of the Ponzo and horizontal–vertical illusions has been reported to increase until a certain age and then remain constant or decrease with age [18], [19]. The general developmental tendency of the Ponzo illusion is a gradual increase from 4 to 7 years of age, followed by a decrease. Although the age at which the illusion reaches its maximum varies from 7 to 13 years, depending on the study, all studies agree that the illusion reaches its maximum at a certain age. Regarding the horizontal-vertical illusion, most studies reported that the effectiveness of illusion gradually increased from the age of 5, reached its maximum at 9 or 10, and then decreased [19], although some studies reported that the effectiveness of the illusion reaches its maximum in adulthood [17]. For the Ebbinghaus illusion, it has been reported that the illusion effect does not occur in children between 4 and 6 years of age, and that no alteration in size perception occurs [20].

Research on gender differences in the effectiveness of optical illusions has also been conducted. Shaqiri et al. conducted a large-scale study with more than 800 participants and reported that the effectiveness of the Ponzo illusion was larger in females than in males [21]. In their experiment, no significant differences between males and females were found for Ebbinghaus, Müller-Lyer, Ponzo-Hallway, and Tilt illusions. Declerck et al. conducted an experiment with the Poggendorff illusion and reported that the percentage of perceptual error due to the illusion was significantly larger in females than in males [11]. Moreover, for the horizontal-vertical illusion, Fraisse et al. confirmed that females have stronger illusions than males under the condition of no time limit in the visual presentation of the figures [19]. However, the effects of gender on visual perception are complex, and there is no comprehensive study of gender differences in optical illusions, although there have been attempts to explain gender differences based on differences in brain activity when viewing illusory figures [22].

It has been reported that not only age and gender but also the cultural environment in which a person grew up can affect the effectiveness of an optical illusion. Bremner et al. used the Ebbinghaus illusion to reveal cross-cultural differences in illusion effects in childhood and adolescence [23]. They compared the effectiveness of the Ebbinghaus illusion between urban dwellers and people with little or no exposure to urban or Western artifacts and reported that urban dwellers had a stronger illusion effect.

2.2 Age, gender, and cultural differences in the cross-modal illusion

Age, gender, and cultural differences have been shown to affect the effectiveness of cross-modal illusions, although the number of reports is not as large as in the case of optical illusions. In the McGurk effect, which is a cross-modal effect between visual and auditory perception, it has been reported that the effectiveness of illusion is greater in adults than in children, and lip-reading ability has been cited as one of the factors causing this difference [24]. It has been suggested that observers with low lip-reading ability use phonetic cues rather than visual cues, thus reducing the occurrence of the McGurk effect. Moreover, it has been reported that the illusory effect is relatively weaker among Japanese-speaking adults and children than among English-speaking adults and children [25], [26], suggesting that the cultural difference in the illusory effect is related to the difference in the stopping position of the gaze on the speaker in Japanese and English-speaking countries [27].

In addition, the size-weight illusion, a cross-modal effect between visual and haptic sensations, has been reported to be larger in adults than in children [28]. By contrast, Nyssen

& Bourdon reported that the effectiveness of the size-weight illusion did not differ according to sex or education level [29].

Individual differences in the interaction between aroma and taste have also been investigated. Bertelsen et al. hypothesized that the interaction between aroma and taste varies among individuals and investigated the influence of individual differences (gender, age, and "sweet liker status") on the effect of aroma on sweetness intensity among young adults [14]. The results of the study showed that females were more susceptible to the sweetness-enhancing effect of vanilla aroma than males. The researchers clustered participants according to their sweet liker status based on their preference for the samples and found that although sweet taste ratings were found to vary with the sweet liker status, aroma enhanced the sweetness ratings similarly across clusters.

As described above, it has been reported that age, gender, and cultural differences affect sensory illusions. However, although pseudo-haptics is a cross-modal illusion, such individual differences have not been investigated.

2.3 Pseudo-haptics

Recently, considerable research has focused on pseudo-haptics, which expresses tactile sensations using only cross-modal effects. Pseudo-haptics refers to the tactile feel that occurs when the movement of a virtual pointer on a screen differs from that of a physical body. When a user believes that the pointer moves according to the movement of their body, changes in the movement of the pointer are regarded as changes in the haptic sense, such as the force on the hands, and evoke a pseudo-haptic sensation.

There are mainly three types of input used for generating pseudo-haptics: amount of movement of the user's actions; the force needed to press down on a surface, such as a touch screen; and the duration of clicking a mouse or touching a screen [4]. There are mainly three types of output: the movement or rotation of a virtual body part or pointer, the surface deformation of a virtual object, and the color or size of the pointer. In this study, we focus on pseudo-haptic feedback, where the amount of movement of the user's hand is used as an input, and the movement of a pointer is used as an output. The ratio of the amount of input movement (Control) and output movement (Display) is called the CD ratio, and we can modify various tactile perceptions by controlling this ratio. This type of pseudo-haptics is reportedly able to present weight [6], compliance [30], [31], kinetic/static friction [30], [32], and roughness of object surface texture [33], [34]. If the CD ratio is smaller than 1.0, the output motion is smaller than the actual input motion, and the user perceives increased weight or resistance with this ratio. In this paper, a large effectiveness of pseudo-haptics means a large change in haptic perception when the same visual stimulus is presented. For example, when presented with a CD ratio of 0.8, users with large effectiveness of pseudo-haptics perceive the virtual object to be very heavy, while users with small effectiveness perceive almost no change in weight.

Situations where this type of pseudo-haptics can be generated include mouse operation in a desktop computer environment, touch screen, and gesture input by the user's hand movements. Some studies have confirmed that the same effects, such as manipulation of weight perception, can be obtained by manipulating the same CD ratio even in different situations [3], [5].

As an example of the application of this type of pseudo-haptics, a presentation of an object's weight has been proposed for computer games where the user interacts with a virtual environment (VE). These proposals are often implemented using hand gestures, but they can also be applied to PC games where users interact with VE through mouse operations [35], [36]. Some researchers proposed applying pseudo-haptics with mouse operation to the desktop user interfaces. Mensvoort et al. created a design tool for mouse-operated pseudo-haptics and published it online as "PowerCursor" [37]. They proposed improving the usability of the UI using pseudo-haptic feedback, which attracts or repels the mouse cursor to a button or pull-down menu. Applications to learning tools for understanding cause-and-effect relationships between concepts or events have also been proposed. For example, Kashihara et al. confirmed that pseudo-haptic feedback for manipulating a concept map representing knowledge learned from an instructional text could promote awareness of important concepts and relationships embedded in the text [38]. Presenting a heavy feel to the nodes representing concepts could indicate an important concept. Additionally, by making the nodes repel or attract each other, relationships among the nodes can be suggested [39]. Thus, presenting pseudo-haptic feedback is expected to promote understanding of the corresponding concepts and relationships.

2.4 Mechanism of pseudo-haptics

It is important to survey the proposed mechanisms of pseudo-haptics because individual differences can be explained by them. Several theories have been proposed to explain the mechanism of pseudo-haptics.

2.4.1 The maximum likelihood estimation

One theory is that this phenomenon is based on the maximum likelihood estimation (MLE) framework [40] proposed by Ernst et al. This theory explains that sensory information is integrated based on its reliability (likelihood) for people to estimate the properties of physical objects. They have shown that the perception of spatial properties based on vision and proprioception can be explained as a MLE that integrates information from both sensory modalities to maximize the accuracy of the final spatial perception [40]. They examined the perception of the width of an object picked with two fingers, while there was a gap between the visual and proprioceptive information. They confirmed that the perceived width of the object was almost identical to the maximum likelihood estimate calculated from the perceptual distribution when judged only by vision or only by proprioception. It has also been reported that the contribution of visual information to the width perception of an object is reduced when noise is added to the image to reduce the accuracy of vision or when the viewpoint is changed [40], [41].

Based on these findings, it can be hypothesized that people with a lower accuracy of proprioception are more

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strongly affected by visual stimuli in pseudo-haptics, and the effectiveness of the illusion may be stronger. Furthermore, it can be hypothesized that people with a higher accuracy of vision are more strongly affected by visual stimuli in pseudo-haptics. In fact, it has been reported that it is important to hide the actual body movements of the user or keep the user's awareness away from actual body movements by keeping them away from the visual presentation to generate a strong pseudo-haptic effect [3], [42]. These reports could also support the importance of reducing the sensory accuracy of one's own body position in improving the effect of pseudo-haptics.

2.4.2 The forward dynamics calculations and the inverse dynamics calculations

Unlike MLE, which adequately describes spatial perception, there is an attempt to explain the mechanism of pseudo-haptics using forward dynamics calculations (FDC) and inverse dynamics calculations (IDC) that consider the relationship between motion and force. FDC is the process of estimating the motion information of an object from the information of the applied force. For example, it has been suggested that when a person moves their arm, the trajectory of the hand is predicted by forward dynamics calculations based on the motor commands to the muscles [43], [44]. It has been found that the prediction of hand trajectory by forward dynamics calculation may be involved in pseudo-haptics [45]. Honda et al. constructed an experimental system in which a virtual object displayed on a monitor was moved by manipulating a manipulandum. They reported that when the visual feedback of the position of the virtual object was delayed by 400 ms, the virtual object's weight was perceived to be heavier than when the feedback was not delayed. They hypothesized that this phenomenon was due to a prediction error in the hand position caused by the delay. To test this hypothesis, they compared the perceived weight of a virtual object in a condition in which the object was continuously exposed to delayed visual feedback and in a condition in which the object was continuously exposed to non-delayed visual feedback. They found that the perceived weight was lighter in the former condition, in which the prediction error was expected to be smaller. Conversely, IDC estimates the force applied to an object from the object's motion. Takamura and Gomi investigated the strength of kinetic resistance while varying the visual movement of the cursor on the screen and the periodic movement of the stylus pen [46]. They confirmed that the strength of motor resistance associated with cursor delay correlated with the acceleration in the direction of cursor movement. This result suggests that their participants used IDC with visual motion information as input to form an internal model of the dynamics of the spring-damper system.

Based on these findings, it is expected that the effect of pseudo-haptics will become stronger when the prediction error of motion caused by visual feedback is clearly perceived. To perceive the motion prediction error clearly, it is necessary to have a high accuracy of the sense of motion and of one's own body position.

Summarily, the mechanism of pseudo-haptics is explained by MLE, which is concerned with the perception of spatial characteristics, and FDC/IDC, which focuses on the relationship between motion and force. The accuracy of the user's proprioception may affect the effectiveness of pseudo-haptics in some way, although there are differences depending on the evidence of the mechanism of pseudo-haptics. We designed tasks to measure the accuracy of detecting the mouse pointer using proprioception and vision and investigated the relationship between the results of these tasks and the effectiveness of pseudo-haptics.

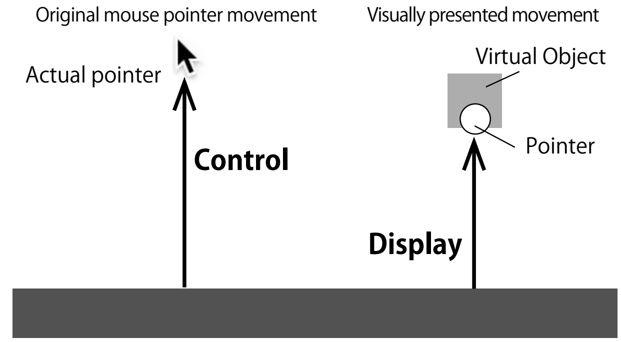

Fig. 1. Illustration of the control/display ratio (CD ratio). During dragging, the actual movement of the pointer (control; shown on the left side) multiplied by the CD ratio is the movement of the visually presented pointer (display; shown on the right side). When the virtual object was not dragged by the visually presented pointer, the actual pointer and visually presented pointer movements were the same.

3 Examining the Effects of Age, Gender, and Other Factors on the Pseudo-Haptic Effect

3.1 Experimental design

We conducted an online experiment using crowdsourcing to collect data on the effects of pseudo-haptics from a large number of participants of different ages and genders. Although it is possible that there are differences in the magnitude of the pseudo-haptic effect among racial groups, in this study, we focused on Japanese people as the first stage of data collection. Thus, we used Lancers [47], one of the largest crowdsourcing sites in Japan.

We chose a mouse pointer manipulation in a desktop environment as it is a common pseudo-haptic effect that can be performed online. While various studies have been conducted on the effects of pseudo-haptics in mouse manipulation [33], we focused on weight perception of lifting a virtual object with a pointer and designed the task accordingly.

Several studies have reported gender and age differences in weight perception in real space. Ross et al. investigated the effects of gender and handedness on weight discrimination when lifting a box by hand [48]. They reported that males performed better with their dominant hand and females performed better with their non-dominant hand, with no overall advantage by gender. Maguinness et al. examined the effect of aging on the ability to discriminate the object's weight from the other's lifting action [49]. Their experiment revealed that older adults were less sensitive than younger adults in discriminating the weight of a lifted box. They discussed that the sensitivity to subtle visual weight cues was reduced due to age-related visual and motor dysfunction and that the elderly needed more salient visual cues to interpret the actions of others accurately. Since we estimate weight from visual cues in pseudo-haptics, if the sensitivity to visual cues decreases with age, as in the results of Maguinness et al. [49], the pseudo-haptic effects may be less likely to occur in the elderly than in the young.

The implementation of pseudo-haptics that changes weight perception follows a previous study [50]. Specifically, when a virtual object is lifted by the pointer, the apparent amount of movement of the pointer (display, shown on the right side in Fig. 1) is equal to the original amount of movement of the mouse pointer (control, shown on the left side in Fig. 1) multiplied by a certain gain (control/display ratio; CD ratio). Participants rated the perceptual intensity of weight. We called this task a "pseudo-haptic rating task."

We considered that not only the age and gender of the participants but also the familiarity with mouse operation and the localization accuracy of the pointer with proprioception and vision could affect the illusion effect. We tested the following three hypotheses in this experiment. H1-A and B are hypotheses related to age and H2 is related to gender;

- **H1-A:** It has been reported that older adults have lower pointing motor accuracy than younger adults in the absence of visual feedback [51], indicating that they rely more on visual than proprioceptive information [52], [53]. Thus, we hypothesized that if the weight perception presented by pseudo-haptics is induced based on the MLE framework, the pseudo-haptic effect is stronger in the elderly, whose proprioception accuracy is low, and the contribution of visual information to motion is larger than in younger adults.
- **H1-B:** It has been reported that motion prediction accuracy is lower in the elderly than in young adults [54]. Therefore, we hypothesized that if the pseudo-haptics of weight are based on the framework of FDC/IDC, the effect of pseudo-haptics would be greater in young adults, whose motor prediction accuracy is higher than that of older adults.
- **H2:** Some studies revealed that the difference in accuracy between males and females in motion prediction is slight or insignificant [55], and different results have been reported which of the genders is more accurate in proprioception depending on experimental design and other factors [56], [57]. Therefore, we hypothesized that there would be no gender difference in the effectiveness of pseudo-haptic weight.

Therefore, in addition to the pseudo-haptic rating task, we conducted a "haptic pointing task" and "visual pointing task," as described in Section 3.3 and 3.4 and a questionnaire survey on the frequency of mouse use in daily life after the completion of all tasks. We designed these tasks based on the works of Haaland et al. and Block et al. comparing the effects of proprioceptive and visual information on arm-aiming movements between young and elderly adults [52], [53]. To examine the influence of proprioceptive information on the pointing task, they set up a condition where the target position was displayed but the hand position was not fed back. They also set up a condition where the hand position was displayed but the target position was not fed back to examine the influence of visual information on pointing.

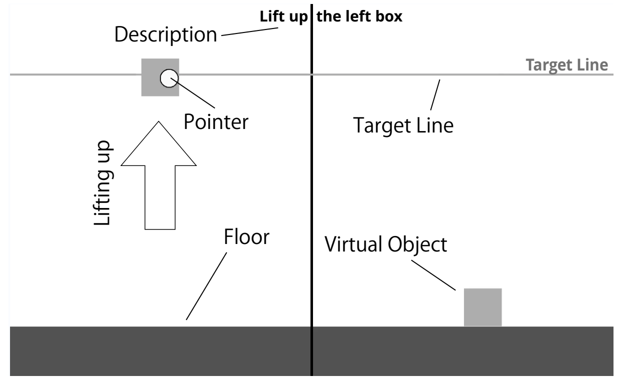

Fig. 2. Pseudo-haptic rating task. The participants lifted two virtual objects from the floor to the target line by dragging. Of the two objects, one corresponds to a standard stimulus (CD ratio = 1.0) and the other corresponds to a comparison stimulus (CD ratio = 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, or 1.3).

We designed the " haptic pointing task " and the " visual pointing task " by arranging their experiments so that they could be conducted in the mouse manipulation in the online experiment.

Since this experiment was conducted online, an instructional manipulation check was introduced to check whether the experimental participants were seriously engaged in the task. The maximum duration of the experiment was 35 min per person.

3.2 Pseudo-haptic rating task

Fig. 2 shows the experimental screen of the pseudo-haptic rating task. In this study, the entire data collection was in Japanese, so that the task descriptions in the experimental screens were also in Japanese (they are translated into English in the figures). The participant manipulated the white circle pointer using the mouse. The actual mouse pointer was not displayed in this task. On the task screen, the floor surface, two virtual objects, and a target line for the height to which the virtual objects were to be lifted were displayed. The participant dragged the left and right virtual objects up to the target line, as instructed on the experimental screen. Because this experiment was conducted using crowdsourcing, the size of the monitors used by the participants was not standardized. However, the experimental screen was displayed in full screen mode to prevent the screen size from being changed during the experiment. The distance from the floor to the target line in Fig. 2 was set to 385 px, and the diameter of the white circle pointer was set to 28 px.

When the white circle pointer was not dragging the virtual objects, the pointer moved at the same speed as the actual mouse pointer (which was hidden). However, when the virtual object was dragged by the white circle pointer, the pointer and virtual object moved according to the CD ratio. In other words, when the CD ratio was greater than 1.0, the virtual object moved faster than the actual mouse pointer, and the object should be perceived as lighter based on previous findings of pseudo-haptics. By contrast, when the CD ratio was smaller than 1.0, the virtual object moved slower than the actual mouse pointer and should have been perceived as heavy. The manipulation of the pointer displacement according to the CD ratio was

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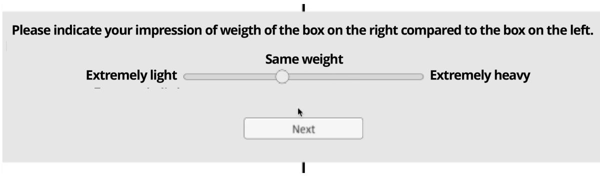

Fig. 3. Weight evaluation by visual analog scale. Because the initial position of the slider's knobs may bias the responses, the knob was not displayed until the participant clicked on the slider.

performed only for vertical mouse movements. Participants were instructed to move the mouse in a straight vertical direction when lifting the virtual box. When the participant stopped dragging the virtual object with the pointer, the virtual object fell to the floor. The acceleration during the fall was set to be constant (30 px/s^2) regardless of the CD ratio setting. The repulsion coefficient of the floor was set to zero to eliminate the effect of repulsion on weight perception.

One of the two virtual objects had a CD ratio of 1.0 as a standard stimulus.The other virtual object had a CD ratio of 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, or 1.3 as a comparison stimulus. After the participants lifted the two virtual objects, they were asked to rate the weight of the second lifted virtual object on a scale of 0 (extremely light) to 100 (extremely heavy), compared with the first lifted object, using the visual analog scale method [58] (Fig. 3). The participants were asked to answer the weight of the second virtual object, as compared to the weight of the first lifted virtual object being 50. This response method was based on a previous study where participants were asked to respond to their impression of the weight of a virtual object that was changed by visual stimuli [59]. Therefore, when the virtual object of the comparison stimulus was perceived as heavier/lighter than the standard stimulus (CD ratio: 1.0), the rated value was expected to be larger/smaller.

To eliminate the effects of order, we alternated which of the two virtual objects was lifted first. The participants lifted the two virtual objects, compared them, and answered the impression of weight. They performed six trials for each CD ratio of the comparison stimulus. Therefore, each participant performed 42 trials in total during the experiment (7 CD ratios, $\times$, 6 trials). The order of the CD ratios presented was counterbalanced among participants.

3.3 Haptic pointing task

To verify the accuracy of the sense of body position, that is, proprioception, we designed a "haptic pointing task" in mouse manipulation. This task was designed to verify the pointing accuracy of each participant when manipulating the mouse pointer in the experiment. As described in Section 2, the effectiveness of pseudo-haptics may be affected by the accuracy of the participant's proprioception. In the ordinary pseudo-haptic situation, the participant's own body motion is hidden by the visual stimulus presentation. Thus, in this study, the accuracy of the body motion in the visually hidden state, that is, the pointing ability in the visually hidden state, was defined as the accuracy of proprioception in the mouse pointer operation.

In this task, participants moved the pointer from the bottom to the top of the screen to the target line by mouse operation, while the pointer was not visible. At the start of the task trial, the pointer was visible, as shown in Fig.4, and it disappeared upon crossing the start line. The participants were instructed to move the hidden pointer by mouse operation and to left click at the position where they considered the target line had been displayed. The appearance of the pointer was the same as that in the pseudo-haptic rating task, and the position of the starting line was the same as the floor line in the pseudo-haptic rating task. The target line position had three variations: the same position as in the pseudo-haptic rating task and positions 50 px above and below it.

The participants practiced the pointing task five times with the pointer visible to experience the sense of distance beforehand. Afterward, the participants performed six trials with the pointer hidden, and we measured the distance by which the participants' responses deviated from the target line as the absolute error (E in Fig.4). As in the pseudo-haptic rating task, participants were instructed to move the mouse in a straight vertical direction in the haptic/visual pointing task. We used the absolute error as the vertical error from the target line.

In this study, we used the length of this absolute error (E) for each trial as the accuracy of the sense of the mouse pointer's position (i.e., the proprioception of the mouse pointer). The smaller E is, the shorter the distance from the target line to the user's response position, indicating that

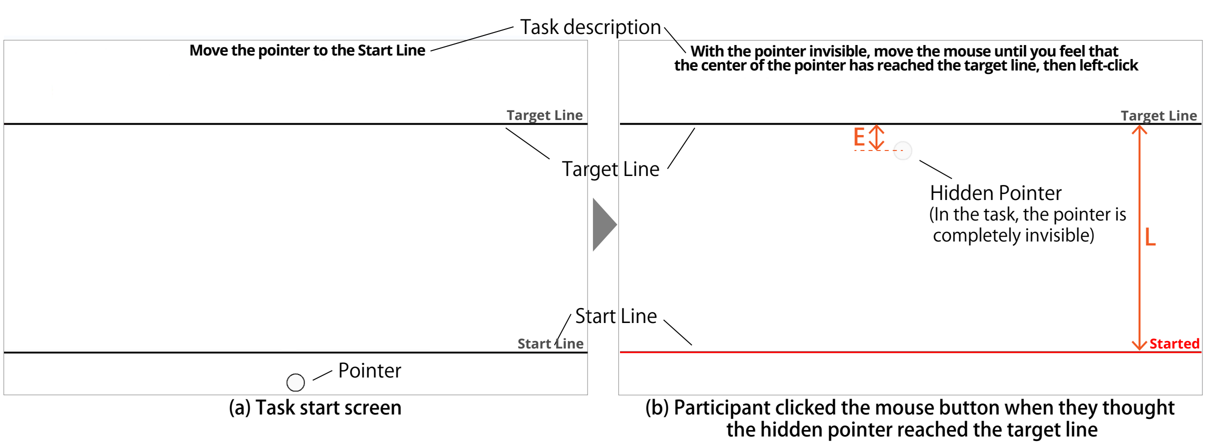

Fig. 4. Haptic pointing task. The participant moved the pointer to the target line by mouse operation, while the pointer was not visible. E represents the distance of the pointing error, and L represents the distance from the start line to the target line.

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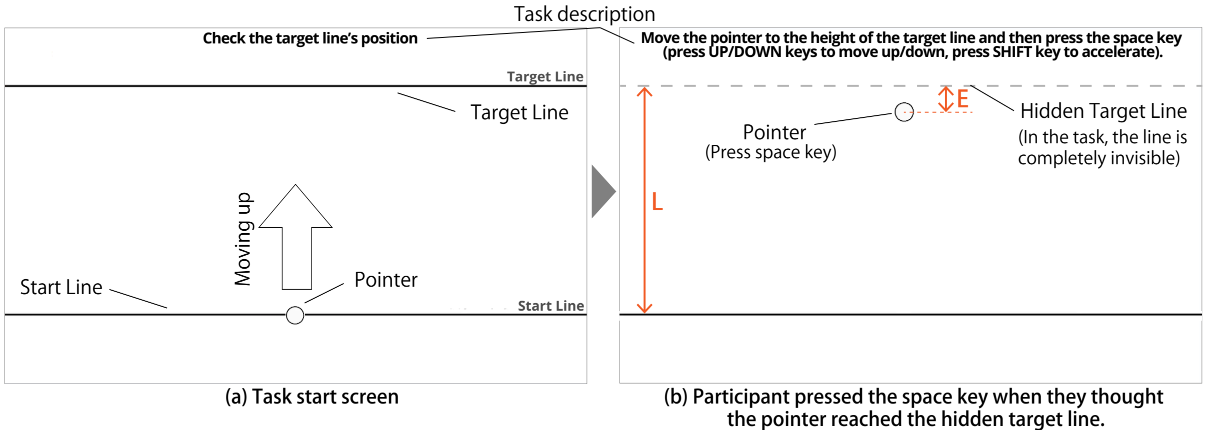

Fig. 5. Visual pointing task. The participant moved the pointer to the target line by keyboard input, while the target line was not visible. E represents the distance of the pointing error, and L represents the distance from the start line to the target line.

the user's proprioception is accurate. It has been reported that the absolute error (E) increases with the distance to the target position (L) in pointing tasks that hide the pointer, such as the one performed in this study [52], [60]. As mentioned above, there were three conditions for the position of the target line, and we presented each condition twice at random. Since the distance between the start and target lines (L in Fig.4) varied depending on this condition, we defined the error score of the task as E/L. The smaller this score was, the higher the pointing accuracy.

3.4 Visual pointing task

We also designed a task to verify the accuracy of visual detection of the pointer position.

In this task, the target line was first displayed to the participants. After 5 s, the line was hidden, and participants were instructed to move the pointer to the position where the target line had been displayed (Fig.5). To avoid the influence of proprioception, the pointer was moved up and down by pressing up or down arrow keys on the keyboard and not by controlling the mouse. The participants were instructed to press the space key when they felt that the pointer had reached the position where the target line had been displayed. The appearance of the pointer and the movement from the bottom to the top were the same as in the pseudo-haptic rating task and the haptic pointing task. The position of the starting line was the same as in the haptic pointing task. The position of the target line had three different variations: the same position as in the pseudo-haptic rating task and positions 50 px above and below it.

The participants practiced this pointing task five times with the target line visible to experience the sense of distance beforehand. After that, the participants performed six trials, and we measured the distance by which the participants' responses deviated from the target line (E in Fig.5). In this task, the error score was set in the same way as in the haptic pointing task (error score = E/L).

3.5 Post-task questionnaire

After finishing all tasks, participants were given a questionnaire to collect information about the frequency of mouse use. The frequency of mouse use was rated on a 5-point scale from 5 (Use a mouse almost every day) to 1 (Do not use a mouse at all on a daily basis). As a dummy task, we also asked about the dominant hand and the hand that operates the mouse. These two questions were not included in the evaluation.

3.6 Instructional Manipulation Check

A potentially serious problem in online surveys is the damage to data caused by the occurrence of "satisficing." Satisficing originally referred to "the behavior of determining and pursuing procedures that meet the minimum necessary to achieve an objective" [61], and in this context, it means that the participant acts without devoting the appropriate amount of attention to the research [62]. Skipping the reading of instructional text is one example of satisficing. For this reason, we introduced a question to detect satisficing in the questionnaire. Specifically, an attention check test called the instructional manipulation check (IMC) [63] was included in the experimental explanation of the task screen and in the post-task questionnaire.

In the explanation of the experiment, a button labeled "Next" was placed below the explanatory text, and participants were able to click on the button to move to the next explanation. As the IMC, we prepared a screen in which the participant had to click on the text instead of the button to proceed. On this screen, the instruction to click on the text instead of pressing the button was hidden in the description of the experiment so that the participants would not notice it unless they carefully read the description. If the participants clicked the "Next" button instead of the button in the text, their data were excluded from the analysis. Moreover, in the post-task questionnaire, the question "Choose 4 for this question" was included among the 5-point-scale questions, and the data of the participants who answered other than 4 were excluded from the analysis.

Finally, we excluded participants who gave inappropriate responses in the haptic and visual pointing tasks. Specifically, we excluded participants who responded to these tasks by barely moving the pointer from the start line (the distance they moved the pointer was less than 0.1 L in

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TABLE 1
Number of participants in the experiment used in the analysis for each age and gender group.

	20s	30s	40s	50s	60s
male	43	46	46	45	50
female	51	49	43	50	45

Figs.4 and 5) in all trials. This type of participant may have planned to finish the experiment quickly by shortening the time to move the pointer.

3.7 Participants

In this experiment, data were collected from males and females in their 20s, 30s, 40s, 50s, and 60s. Therefore, the participants were categorized into 10 groups according to gender and age. Since we recruited 60 participants for each group using Lancers, a total of 600 people participated in this experiment. The Ethics Committee of the University of Tokyo approved the experiments (21-127). We acquired a written consent form from all participants.

Participants who were found to have been satisficing in the IMC were excluded from the analysis. The number of participants used for the data analysis was 468. Table 1 shows the age and gender breakdown of the participants.

Considering the application, obtaining results in a runaway condition was important, so we did not control the monitor size or the initial mouse settings. However, we instructed the participants to join the experiment under the same conditions as those in which a mouse is used to operate a desktop PC in terms of screen size, resolution, participant posture, the distance between the eyes and screen, and mouse cursor speed. In addition, we indicated the desk surface size on which participants could operate the mouse in advance, and participants were instructed not to place anything that would interfere with mouse operation on the desk surface.

As the environment of the monitors used by the participants was not controlled in this experiment, some participants may have experienced display lag in response to mouse input. However, since the system was running locally, there was no system delay due to network bandwidth. Since the lags were considered to be almost uniform within participants, the statistical results were considered to be largely unaffected.

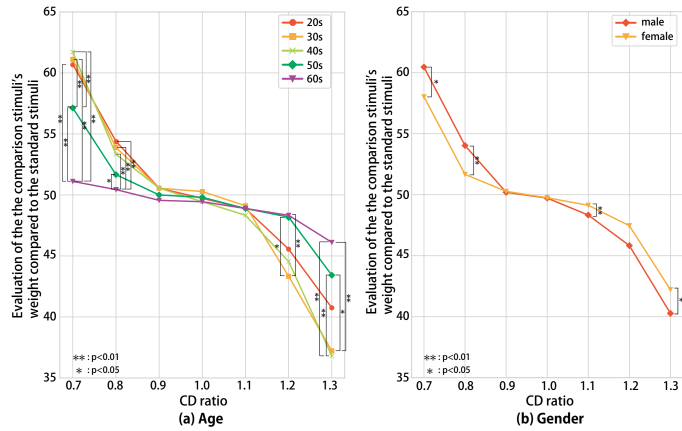

Fig. 6. Evaluation of weight at each CD ratio by age and gender (median).

3.8 Results

3.8.1 *Relationship between age, gender, and the effectiveness of illusion*

We visualized the subjective weight ratings of each CD ratio by age and gender at the median (Fig.6). The vertical axis shows the weight evaluation of the virtual object at each CD ratio compared to the standard stimulus (CD ratio: 1.0). A larger/smaller value indicates that the participants felt that the virtual object was heavier/lighter. When this value was 50, the participant evaluated the comparison stimulus as having the same weight as the standard stimulus. Consistent with a previous study [6], we observed that the smaller/larger the CD ratio, the heavier/lighter the virtual object feels as a general trend for every age and gender group.

The normality of the 70 groups for each experimental condition was tested by the Shapiro–Wilk test, and a significant difference from the normal distribution was found for 46 groups. Therefore, we analyzed this data as nonparametric data. To investigate the effects of participants' age, gender, and CD ratio, statistical tests were conducted using the aligned rank transform (ART [64]) ANOVA, which can be used with non-parametric data. The full multifactorial ANOVA model used was a 2 (gender) × 5 (age) × 7 (CD ratio) model. Each row of data entered using ANOVA is assumed to be an independent observation. In the pseudohaptic rating task, participants completed six trials for each CD ratio, so we averaged the six trials within participants

TABLE 2
Results of Aligned Rank Transform (ART) ANOVA for each CD ratio with participant's age and gender.

		CD ratio 0.7	0.8	0.9	1.0	1.1	1.2	1.3
main effect	Gender	$F_{1,458}=4.02$ $\eta_p^2=0.019$	$F_{1,458}=5.18$ $\eta_p^2=0.025$	$F_{1,458}=0.13$ $\eta_p^2=0.000$	$F_{1,458}=0.61$ $\eta_p^2=0.001$	$F_{1,458}=8.26$ $\eta_p^2=0.031$	$F_{1,458}=3.40$ $\eta_p^2=0.013$	$F_{1,458}=4.18$ $\eta_p^2=0.020$
	Age	$F_{4,458}=6.29$ $\eta_p^2=0.061$	$F_{4,458}=4.22$ $\eta_p^2=0.029$	$F_{4,458}=2.32$ $\eta_p^2=0.020$	$F_{4,458}=0.96$ $\eta_p^2=0.010$	$F_{4,458}=1.34$ $\eta_p^2=0.011$	$F_{4,458}=4.39$ $\eta_p^2=0.035$	$F_{4,458}=4.01$ $\eta_p^2=0.032$
TWI	Gender and Age	$F_{4,458}=0.55$ $\eta_p^2=0.005$	$F_{4,458}=0.92$ $\eta_p^2=0.009$	$F_{4,458}=1.37$ $\eta_p^2=0.009$	$F_{4,458}=0.48$ $\eta_p^2=0.002$	$F_{4,458}=2.22$ $\eta_p^2=0.019$	$F_{4,458}=1.91$ $\eta_p^2=0.013$	$F_{4,458}=0.21$ $\eta_p^2=0.002$

TWI : two-way interaction
: $p<.01$, : $p<.05$

for each CD ratio condition before analysis. Since gender and age are between-participant factors and CD ratio is a within-participant factor, the analysis was conducted as a mixed design with three factors.

The results of the three-way repeated measures ANOVA applying ART in the mixed condition showed that the main effect was significant only for the CD ratio ($F(6, 2748) = 288.5, p < 0.01, \eta_p^2 = 0.40$), and there was no significant main effect for either the age ($F(4, 458) = 2.23, p = 0.10, \eta_p^2 = 0.010$) or gender ($F(1, 458) = 0.0113, p = 0.91, \eta_p^2 = 0.000027$). The significant two-way interactions were gender × CD ratio ($F(6, 2748) = 4.68, p < 0.01, \eta_p^2 = 0.023$) and age × CD ratio ($F(24, 2748) = 2.54, p < 0.01, \eta_p^2 = 0.055$), and the two-way interaction between gender and age was not significant ($F(4, 458) = 0.572, p = 0.68, \eta_p^2 = 0.0053$). Furthermore, the three-way interaction was significant ($F(24, 2748) = 2.24, p < 0.01, \eta_p^2 = 0.020$). Therefore, we divided the data by CD ratio because the heaviness response by participants who perceived the larger effect of pseudo-haptics changed depending on the CD ratio, and we tested the simple main effect and simple interaction using two-way repeated measures ANOVA with ART. The results showed that the simple main effect of gender was significant for CD ratios of 0.7, 0.8, 1.1, and 1.3, and the simple main effect of age was significant for CD ratios of 0.7, 0.8, 1.2, and 1.3, as shown in Table 2. The simple interaction between age and gender was not significant for any of the CD ratios.

Then, we conducted a post-hoc test using the Mann–Whitney U test on each CD ratio, for which a main effect of age and gender was identified. In the test for age, Holm correction was applied to correct for multiplicity. The results are summarized in Fig.6.

3.8.2 *Results of the haptic/visual pointing task*

First, Fig.7 shows the results of the haptic pointing task for each age and gender of participants. The values in the figure show the error scores of the pointing task, as described in the previous section. The normality of these results was checked by the Shapiro–Wilk test for 10 groups in each age and gender condition, and a significant difference from the normal distribution was found for 7 groups. Therefore, a two-way repeated measures ART ANOVA in the mixed condition was conducted. It was confirmed that there was a significant main effect of gender ($F(1, 458) = 5.57, p < 0.05, \eta_p^2 = 0.025$). Thus, this test showed that the error of the haptic pointing task was smaller for males than for females. However, there was no significant main effect of age ($F(4, 458) = 1.42, p > 0.10, \eta_p^2 = 0.012$) and no significant interaction effect between age and gender ($F(4, 458) = 0.82, p > 0.10, \eta_p^2 = 0.0031$).

On the other hand, the results of the visual pointing task for each age and gender group of the participants are shown in Fig.8. The values depicted in the figure show the error scores of the pointing task. The smaller this value, the higher was the accuracy of the visual detection of the pointer position. The normality of these results was checked by the Shapiro–Wilk test for 10 groups in each age and gender condition, and a significant difference from the normal distribution was found for 8 groups. Therefore, a two-way repeated measures ART ANOVA in the mixed condition

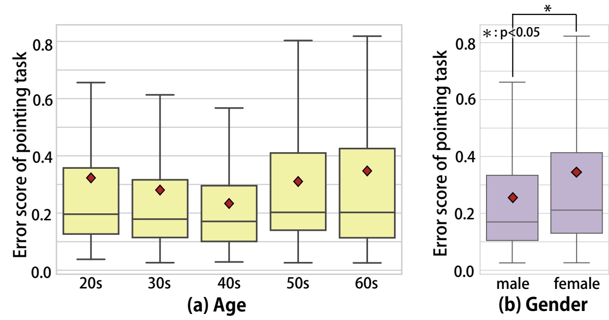

Fig. 7. Error scores of haptic pointing task for each age and gender group.

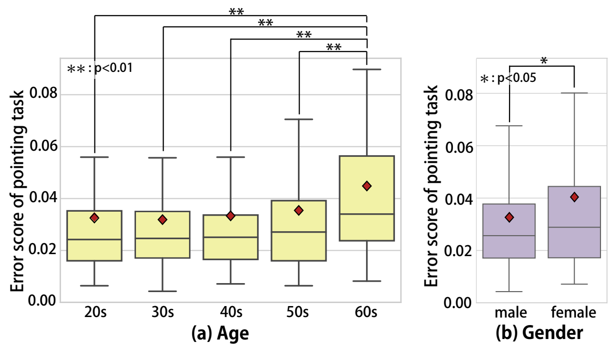

Fig. 8. Error scores of the visual pointing task for each age and gender group.

was conducted. It was confirmed that there was a significant main effect for age ($F(4, 458) = 4.57, p < 0.01, \eta_p^2 = 0.050$). However, there was no significant main effect for gender ($F(4, 458) = 0.92, p > 0.10, \eta_p^2 = 0.001$) and no interaction effect between age and gender ($F(4, 458) = 1.02, p > 0.10, \eta_p^2 = 0.006$). Then, as a post-hoc test, a Mann–Whitney U test with Holm correction was applied to the error score of the pointing task for age. This test revealed that the error scores for people in their 60s were significantly higher than those for people in their 20s, 30s, 40s, and 50s.

3.8.3 *Relationship between the effectiveness of pseudo-haptics and the accuracy of detecting pointer position using proprioception or vision*

Based on the relationship between the results of the haptic/visual pointing task and the age and gender of the participants, we analyzed the relationship between these results and the effectiveness of pseudo-haptics. To analyze the results according to these pointing task results, we divided participants into two groups by median splits, which were used in [65], [66]. For each pointing task, the participants in the top 50% of task performance, that is, those with a small error score in the pointing task, were defined as the "high accuracy group," and the participants in the bottom 50% of task performance, that is, those with a large error score in the pointing task, were defined as the "low accuracy group."

Subsequently, the effect of the performance of the haptic and visual pointing task on the perception of pseudo- haptic weight was analyzed. The full multi-factorial ANOVA model used was a 2 (group factor divided by the performance in the Haptic pointing task) × 2 (group factor divided by the performance in the Visual pointing task) × 7 (CD ratio) model. Similar to the analysis in Section

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3.8.1, we averaged the six trials within participants for each CD ratio condition before analysis. As the group factors divided by the performance in the Haptic/Visual pointing task are between-participant factors and CD ratio is a within-participant factor, the analysis was conducted as a mixed design with three factors. Consequently, there were significant two-way interactions between each group factor divided by accuracy of the haptic/visual pointing task × CD ratio (haptic pointing task × CD ratio: $F(6, 2784) = 4.97, p < 0.01, \eta_p^2 = 0.027$, visual pointing task × CD ratio: $F(6, 2784) = 4.94, p < 0.01, \eta_p^2 = 0.026$). Conversely, the interaction between pointing tasks and the three-way interaction effect were not significant (two-way interaction between vision and haptic pointing task: $F(6, 2784) = 0.268, p = 0.32, \eta_p^2 = 0.00062$, three-way interaction: $F(6, 2784) = 0.0947, p = 0.64, \eta_p^2 = 0.00022$). Therefore, we analyzed the relationship between the perception of pseudo-haptic weight and the task performance in the haptic and visual pointing tasks, respectively.

The median weight ratings for each CD ratio based on the results of the haptic pointing task for each of these participant groups are plotted in Fig.9(a). We conducted a two-way repeated measures ART ANOVA, and it was confirmed that there was a significant main effect for CD ratio ($F(6, 2796) = 274, p < 0.01, \eta_p^2 = 0.38$), and there was a significant interaction effect between the CD ratio and participant group ($F(6, 2796) = 4.89, p < 0.01, \eta_p^2 = 0.026$). The main effect for the group of haptic pointing task results was not significant ($F(1, 466) = 2.62, p = 0.11, \eta_p^2 = 0.0059$). Then, we applied the Mann–Whitney U test for the weight rating of each participant group at each CD ratio. As a result, it was confirmed that in the haptic pointing task, when the CD ratio was 0.7, 0.8, and 1.3, the group with high proprioceptive accuracy in mouse manipulation felt the virtual object was significantly heavier (lighter) than the group with low accuracy when the CD ratio was small (large) (Fig.9(a)).

On the other hand, the median weight ratings for each CD ratio based on the results of the visual pointing task for each of these participant groups are plotted in Fig.9(b). For each participant group, Fig.9 summarizes the median weight ratings for each CD ratio. We conducted a two-way repeated measures ART ANOVA, and it was confirmed that there was a significant main effect for the CD ratio ($F(6, 2796) = 274, p < 0.01, \eta_p^2 = 0.38$), and the main effect for the group of visual pointing task results was not significant ($F(1, 466) = 0.0700, p = 0.79, \eta_p^2 = 0.00016$). There was a significant interaction effect between the CD ratio and the group of visual pointing task results ($F(6, 2796) = 5.10, p < 0.01, \eta_p^2 = 0.031$). A Mann–Whitney U test was applied to the weight ratings of each group of visual pointing task results for each CD ratio. The results showed that at CD ratios of 0.7, 0.8, 1.2, and 1.3, the group with higher accuracy in detecting the pointer position in vision perceived the virtual object to be significantly heavier (lighter) than the group with lower accuracy at small (large) CD ratios (Fig.9(b)).

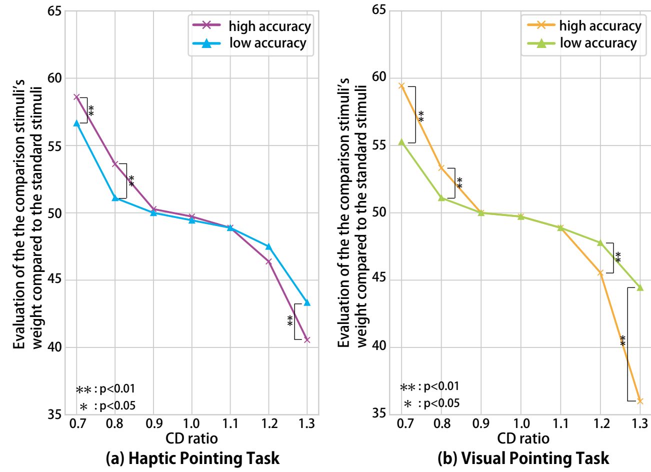

Fig. 9. Evaluation of weight at each CD ratio for each group divided by accuracy of haptic/visual pointing task. The median scores of each group are plotted.

3.8.4 *Relationship between frequency of mouse use and the effectiveness of pseudo-haptics*

Fig.10 shows the proportion of the number of people that responded with each frequency of mouse use rating. Next, we analyzed the relationship between the frequency of mouse use, effectiveness of pseudo-haptics, and score of pointing tasks. Participants who used a mouse less frequently or equal to response 4 (Use once or twice a week) were classified as the group that did not use a mouse much, and those who answered 5 (Use almost every day) were classified as the group that used a mouse much.

Fig.11 (a) shows the relationship between the frequency of daily use of the mouse and the result of pseudo-haptic rating task. We conducted a two-way repeated measures ART ANOVA, and it was confirmed that there was a significant main effect for the CD ratio ($F(6, 2796) = 274, p < 0.01, \eta_p^2 = 0.38$), and the main effect for the frequency of mouse use was not significant ($F(1, 466) = 2.36, p = 0.12, \eta_p^2 = 0.0054$). There was a significant interaction effect between the CD ratio and the frequency of mouse use ($F(6, 2796) = 9.60, p < 0.01, \eta_p^2 = 0.042$). A Mann–Whitney U test was applied to the weight ratings of the frequency of mouse use groups at each CD ratio. As a result, the group that used a mouse frequently felt that the virtual object was significantly heavier (lighter) at CD ratios of 0.7 and 1.3 when the CD ratio was small (large) than the group that used a mouse infrequently.

Moreover, Figs.11 (b) and (c) show the relationship between the frequency of daily use of a mouse and the error score of the haptic/visual pointing task. The Mann–Whitney U test was applied to the error scores for each of the pointing tasks, and it was confirmed that the error scores for the haptic pointing task were significantly smaller in the group with a higher frequency of daily mouse use than in the group with a lower frequency of daily mouse use.

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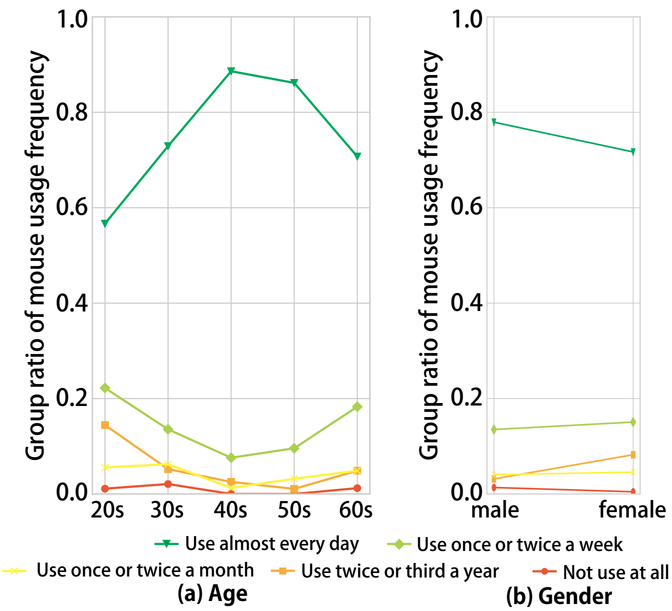

Fig. 10. Proportion of the number of people answering with each frequency of mouse use rating by age and gender.

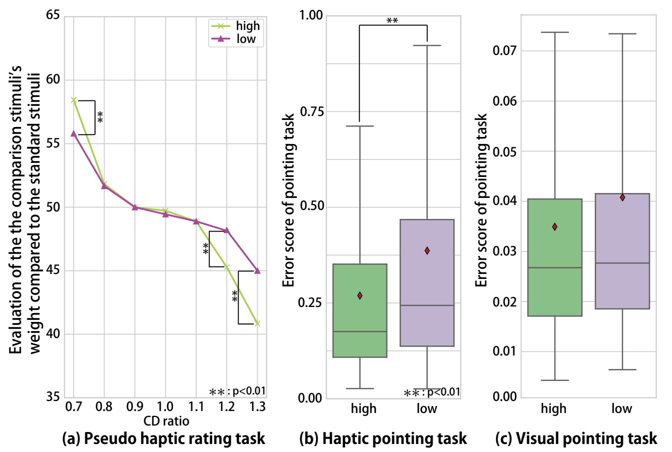

Fig. 11. Differences in task results between groups with high ("Use almost every day") and low ("Use once or twice a week" - "Not use at all") mouse use.

3.8.5 *How much factors of the accuracy of detecting pointer position and mouse use frequency explain the variations in the effectiveness of pseudo-haptics depending on age and gender*

To quantify how much the factors we focused on (i.e., the accuracy of pointer position detection using vision and proprioception, along with the frequency of mouse use) can explain the variations of the effectiveness of pseudo-haptics depending on age and gender, we conducted a multiple regression analysis. The frequency of mouse usage, initially collected on a scale from 1 to 5, was converted to the equivalent number of usage days per year, to create a continuous variable comparable to the error scores in haptic and pointing tasks. The conversion from a categorical variable to a continuous variable was approximated as follows: 5 - use almost every day (312.84 days, calculated as 52.14 weeks $\times$ 6 days), 4 - once or twice a week (78.2 days, calculated as 52.14 weeks $\times$ 1.5 days), 3 - once or twice a month (18.0 days, calculated as 12 months $\times$ 1.5 days), 2 - twice or third a year (2.5 days), and 1 - not use at all (0 days).

Once the conversion was applied, each of the three independent variables - the error scores in haptic and pointing tasks and the number of annual mouse usage days - were standardized to have a mean of 0 and a standard deviation of 1. The dependent variable was the rating scores for weight when a CD ratio of 0.7 was presented. We then computed mean values for each of the independent and dependent variables, grouped by age and gender, before conducting the multiple regression analysis.

The resulting regression model reported an R-squared value of 0.796 and an adjusted R-squared of 0.694, suggesting that this model could explain approximately 70% of the variations in the effectiveness of pseudo haptics. This showing that a large part of the variations depending on age and gender can be explained by the factors we focused on. The standardized regression coefficients showed that both the haptic task error scores (β = -6.27) and vision pointing task error scores (β = -10.6) had a negative relationship with the effectiveness of pseudo-haptics. This implies that lower error scores in these tasks were associated with greater pseudo-haptic effectiveness. On the other hand, the number of days using a mouse in a year exhibited a minor, positive association with the pseudo-haptic effectiveness (β = 0.239).

4 Discussion

Through this study, we were able to clarify the effects of age and gender on the pseudo-haptics, which were previously known only empirically. Specifically, Fig.6 results shows that the effectiveness of pseudo-haptics in mouse operation was significantly weaker for participants in their 50s and 60s than for participants in younger age groups (H1). The results also show that males perceived the effect of pseudo-haptics more strongly than did females (H2). These results are consistent with some optical [10] and cross-modal illusions [14], [24], indicating the differences in effect due to age and gender.

Since the pseudo-haptics research so far has been conducted mainly at universities, it seems that many of the participants were young (e.g., in their 20s). Therefore, it can be said that the experiments were conducted with people who are relatively affected by pseudo-haptics in general. To popularize pseudo-haptics as a haptic presentation technology to the more general public, it is important to be able to robustly present it to older people and females who are relatively less likely to perceive an effect.

Next, we discuss the reasons for the differences in the effectiveness of pseudo-haptic illusions by age and gender, by referring to other experimental results. The relationships between the effectiveness of pseudo-haptics and proprioceptive accuracy in mouse manipulation obtained from the results of the haptic pointing task suggest that the higher the proprioceptive accuracy in mouse manipulation, the stronger the perceived effect of pseudo-haptics (Fig.9(a)). This result suggests that the higher the accuracy of proprioception in mouse pointer manipulation, the more sensitive to the motion prediction error caused by the visual effect of pseudo-haptics, and the stronger the illusion effect. This explanation that the sensitivity to motion prediction error

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increases the amount of illusion of pseudo-haptics is consistent with the argument of Honda et al. [45]. This implies that our results do not support the hypothesis based on the MLE framework [40] as a mechanism of pseudo-haptics. In addition, Fig.9(b) shows that not only proprioception but also accuracy of visual perception may affect the effectiveness of pseudo-haptics. Specifically, it shows that the effectiveness of pseudo-haptics is larger for the participant group with higher accuracy in visual detection of the pointer position than in the group with lower accuracy. There is a possibility that the higher accuracy of visual detection contributed to the sensitivity of the prediction error, which led to a larger intensity of the pseudo-haptic effect. These possibilities can be inferred from the results of the multiple regression analysis.

The results of the haptic pointing task in terms of age and gender showed that pointing accuracy was the highest for those in their 40s in terms of age (Fig.7(a)). This result is not consistent with a previous study, which showed that proprioceptive accuracy decreases with age [51]. This result can be explained by the ratio of the number of people who used a computer mouse in daily life in age group (Fig.10). The reason that men in their 40s are familiar with the mouse might be that they have been using a mouse at work daily. Figs.10(a) and 7(a) show an inverse relationship between the ratio of the "using computer mouse almost every day" group by age and the median error of the haptic pointing task by age. Fig.11(b) shows that people who are accustomed to manipulating the pointer have high proprioceptive accuracy of the pointer position, suggesting that the results of the haptic pointing task are deeply related to the habituation of mouse operation. In addition, the results shown in Figs.11(a) and (b) and 9(a) suggest that people who are accustomed to manipulating the pointer with the computer mouse and who have higher proprioceptive accuracy of the pointer position are more sensitive to the mismatch between the actual mouse pointer movement and visually presented pointer movement, and this enhances the effectiveness of the illusion. Conversely, the results of Figs.8(a) and 10(a) show no correlation between the results of the visual pointing task and mouse use frequency. This may be related to the age-related decline in perceptual ability. We did not control for age-related perceptual and motor impairments because we considered it important to obtain uncontrolled results considering the application. In addition, Fig.7(b) shows that males have higher accuracy in the haptic pointing task than females, i.e., higher proprioception accuracy in mouse manipulation. This result might be related to the frequency of daily mouse use among the participants in this experiment, as shown in Fig.10(b). Therefore, the result that the effectiveness of pseudo-haptics was higher in males than in females, which differs from our hypothesis H2, may be related to the ability of the male and female participants in our experiment to manipulate computer mice.

Thus far, pseudo-haptic methods specific to various interface devices, including mouse and cursor, touchscreen, or gesture in the VR space have been developed [4]. Our result that the effect of pseudo-haptics changed depending on the familiarity with the mouse interface suggests that the perceptual intensity depends on the habituation to the interface device used for presenting pseudo-haptics. For example, since younger generations, such as those in their 10s or 20s, are more familiar with smartphones, pseudo-haptics presented using smartphones would be more effective for younger generations than for older generations. Further, if a new interface that replaces the mouse appears in the future for everyday use, pseudo-haptics specific to the mouse with a desktop environment might be less likely to be effective.

In summary, the results of this study indicate that the pseudo-haptic illusional effect is stronger for people with higher sensory accuracy, both visual and proprioceptive, in detecting pointer position. Therefore, it is thought that the illusory effect of pseudo-haptics can be enhanced by making the user clearly aware of the fact that the movement of an object that reflects the movement of the body, such as a pointer, deviates from the original movement. This results support our hypothesis H1-B regarding the relationship between participant's age and the effectiveness of pseudo-haptics. This seems to contradict the previous finding [30] that "it is important to hide the actual physical motion of the user or to keep it away from the visual presentation to strongly generate the effect of pseudo-haptics." However, it is possible that visual presentation and prior training help people recognize objects that reflect bodily movements, such as pointers, as their own movements and recognize that these movements have deviated from their original movements.

The results of this study may provide a hint for improving the effectiveness of the illusion effect of pseudo-haptics.

5 Limitations and Future Works

In this study, we examined the pseudo-haptics of pointer manipulation using a mouse in a desktop environment. In pseudo-haptics research, it is known that similar visual stimulus manipulations can produce similar effects (e.g., the presentation of a sense of weight [5], [30], [50]) in 3D as well as in 1D/2D. If the mechanism of pseudo-haptics is common, it is expected that the findings of individual differences in 1D/2D will be the same in 3D. The results of this experiment suggest that familiarity with mouse operation may affect the amount of illusory effect. Therefore, it is considered that familiarity with the system operation and accuracy of input position sense may also affect the strength of the pseudo-haptics effect in other environments, such as VR. However, a different type of pseudo-haptics, such as displaying the deformation of a virtual object, may have a different effect, so it is necessary to verify their effects.

Because we conducted an online experiment to collect data from a large number of participants, we were not able to fully control the experimental environment, nor could we conduct detailed interviews with each participant. In this experiment, the type of mouse, display size, and resolution used by the participants were not standardized, and these differences may constitute a bias. For example, if there is a bias in the type of display used depending on the age of the participants, it cannot be denied that this bias may have affected the results. Therefore, beyond factors such as familiarity with mouse use in daily life and the accuracy of pointer position detection through vision and proprioception, the experienced environment might influence the differences in the effects of pseudo-haptics across ages and genders. This suggests the need for more detailed verification in the future.

Furthermore, we have not yet been able to clarify why the effectiveness of pseudo-haptics is not high for those who do not fit into this category, for example, those who do not feel a strong pseudo-haptic effect despite a good performance in the haptic/visual pointing task. Moreover, users who are familiar with interactive systems, such as gamers, are likely to be skilled in interpreting the mechanical properties of virtual objects. Therefore, they are more likely to perceive the presentation of visual displacement in pseudo-haptics, and the illusory effect may appear stronger than people who don't usually play games. Such user attributes should also be collected through questionnaires to clarify the relevance of the effect to pseudo-haptics. To evaluate the magnitude of the pseudo-haptic effect, we adopted the task design, following previous studies on pseudo-haptics where participants answered the impression of the weight of an object with manipulation of the C/D ratio [59]. Thus, we could obtain the results on gender and age differences in effectiveness of pseudo-haptics in the ordinary task design in pseudo-haptics studies. However, the demand characteristics might affect the participants' responses. Using an evaluation metric comparable with the actual weight, we could accurately assess the effectiveness of pseudo-haptics [5].

In addition, due to the rule of the crowdsourcing service we used, we were unable to collect data from participants under the age of 20. In the case of pseudo-haptics, there are few reports on the illusional effect on teenagers and even younger children, whereas studies on optical illusions have been conducted on young people as young as 4 or 5 years old. It is possible that there is a specific tendency toward the effectiveness of pseudo-haptics in children.

6 Conclusion

The purpose of this study is to identify how user's age and gender affect the effectiveness of pseudo-haptics and to identify the factors that contribute to these differences. We collected data on the weight perception of people of various ages and genders. They were presented with pseudo-haptic stimuli that generated the perception of weight during computer mouse operation in a desktop PC environment, and we investigated the changes in the illusional effect depending on these differences in age and gender. In addition, to clarify the factors that affect pseudo-haptics, we investigated the effect of the habituation to the mouse operation and of the accuracy of visual and proprioceptive localization of the pointer.

The results of the experiment suggested that the effect of pseudo-haptics was significantly weaker for participants in their 50s and 60s than for participants in the younger age groups. Moreover, the results suggested that males perceived the effects of pseudo-haptics more strongly than did females. As a result of further examination, it was found that the pseudo-haptic effect was higher in people who used the mouse more frequently and had higher visual and proprioceptive accuracy in identifying the pointer position. It can be concluded that the effectiveness of the illusion is stronger in people who have higher sensory accuracy in the visual localization sense and proprioception of mouse operation, and those who are more sensitive to the deviation caused by the visual feedback of pseudo-haptics. The results of this study not only suggest the factors that cause individual differences in the effectiveness of pseudo-haptics but also provide hints for improving the pseudo-haptic effect.

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