Quantitative Evaluation of Changes in Weight Perception Through Visual Transparency of Grasped Objects Using a Drainage Mechanism

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Abstract

Pseudo-haptics, a phenomenon in which manipulated visual information alters the perception of touch or force, has been widely studied in the VR community. This study quantitatively evaluates the effect of visually rendering a grasped object transparent on perceived weight. Participants lifted a bag in a VR environment and adjusted its weight using a water filling and draining mechanism until the transparent and opaque conditions felt subjectively equal in weight. In an experiment with 18 participants, a significant weight adjustment relative to the 2000 g reference weight was observed under the "Wooden Floor/No Bag Frame" condition, confirming a transparency-induced weight-reduction effect. In contrast, no significant difference was observed under the "Metal Floor" condition. Furthermore, among participants who perceived the transparent object as lighter, the average weight difference was approximately 40.8 g. These results quantitatively demonstrate that visual transparency can reduce perceived weight under specific background conditions.

Keywords

Pseudo-haptics, Weight perception, Visual transparency, Quantitative evaluation

1. Introduction

It is well known that, in virtual reality (VR) and augmented reality (AR) environments using head-mounted displays (HMDs), combining visual stimuli with other sensory modalities, such as touch, can produce perceptual illusions. In research combining VR with olfactory stimuli, Ariga et al. investigated the interaction between vection and olfactory stimuli [1]. In studies combining VR with tactile stimuli, such as Haptic Links by Evan et al. [2] and Capstan Crunch by Mike et al. [3], custom-developed devices enhanced the sense of realism in VR experiences. In the field of haptics, one such illusion is known as "pseudo-haptics," a phenomenon in which manipulating visual information induces an illusion of touch [4][5]. Early work on pseudo-haptic feedback demonstrated that modifying visual feedback in response to user motion can induce force-like sensations even without physical force feedback [6]. In addition, multisensory perception studies have shown that humans integrate visual and haptic information in a statistically efficient manner, suggesting that visual manipulation can strongly influence haptic perception [7].

In a previous study [8], we hypothesized that, if altering the size, color, or material of a virtual object affects weight perception, altering its transparency might also affect perceived weight. They therefore conducted an HMD-based experiment to examine changes in weight perception caused by making held objects visually transparent. The results showed that participants tended to perceive held objects as lighter when the objects were transparent. Because this result suggested that "transparency" itself was an important factor, we hypothesized that an object would be perceived as lighter when made transparent regardless of the background visible through it, and we conducted further experiments. In those experiments, participants wore an HMD, and we varied the color and texture of the floor visible

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through the transparent held object to examine changes in perceived weight during lifting. Specifically, we evaluated perceived weight while participants wearing an HMD grasped a real-world bag whose movements were synchronized with a bag in VR, and the bag was visually rendered transparent in the VR environment. The evaluation compared the bag's weight in a reference state with that in a comparison state, and participants reported how much lighter or heavier the bag felt using two questionnaires: a Likert scale and a visual analog scale (VAS). The results did not support the hypothesis that the object is perceived as lighter when made transparent regardless of the background; however, they qualitatively suggested that transparency can make the object feel lighter under specific floor color or texture conditions. Because previous studies evaluated weight perception only qualitatively using questionnaires, this study quantitatively evaluates changes in weight perception caused by visual transparency by asking participants to adjust the weight of a bag through water filling and draining until the transparent and opaque states feel equal in weight.

2. Related Work

2.1. Changes in Perceived Weight Due to Manipulation of Object Appearance in VR

Maehigashi et al. investigated whether manipulating the appearance of virtual objects produces weight illusions similar to those observed in the real world [5]. One type of weight illusion is the size–weight illusion (SWI), in which a small object is perceived as heavier than a large object of the same weight when held side by side [9]. Another is the brightness–weight illusion (BWI), in which a light-colored object is perceived as heavier than a dark-colored object of the same weight when held side by side [10]. A third is the material–weight illusion (MWI), in which objects made of materials that appear heavy, such as metal, are perceived as lighter, whereas objects made of materials that appear light, such as wood, are perceived as heavier, even when they have the same weight [11]. Maehigashi et al. showed that the effects of BWI and MWI in VR contradict those observed in the real world. In contrast, for size conditions, small objects were perceived as significantly heavier than large objects. This indicates that the SWI in VR is consistent with that observed in the real world. Furthermore, Flanagan and Beltzner showed that the SWI reflects a dissociation between perceptual judgments and sensorimotor predictions during object lifting [12]. This finding suggests that subjective weight perception cannot be fully explained by physical weight alone, supporting the need to evaluate perceived weight directly.

2.2. Reducing Fatigue Through Color Changes in AR

Ban et al. proposed a system that modifies the perceived weight of an object by changing its color to reduce fatigue when handling the object [13]. Their experiments were conducted in an AR environment, with luminance used as the visual characteristic to be modified. To develop an AR system for reducing fatigue during object handling, Ban et al. investigated how altering perceived object brightness affected both the muscle force generated during lifting and subjective fatigue. The integrated power spectral density (IPSD) measured using electromyography indicated the muscle force exerted by the participants in this experiment [14], and the product of this IPSD and the task completion time (IPSD × time) was defined as the workload during the fatigue task.

Evaluation was performed using both subjective and objective methods. For the subjective evaluation, the VAS method was used. Participants rated their fatigue on a 100-mm line, where the left end represented "not at all tired" and the right end represented "very tired," in response to the question, "How tired are you right now?" For the objective evaluation, muscle fatigue was assessed by measuring changes in electromyographic signals. Generally, as muscles fatigue, the mean power frequency (MEPF) and median power frequency (MDPF) decrease [15][16]. Spectral shifts are related to the conduction velocity of action potentials along muscle fibers. These values are used as criteria for evaluating muscle fatigue [17]. The results showed that the effect of object brightness on weight perception can also be induced when an object's color is virtually altered using AR. In addition, emphasizing object brightness significantly reduced the muscle fatigue accumulated during the fatigue task. They then quantified the effectiveness of the system by comparing the number of repetitions completed in a repetitive task while varying the brightness of the lifted object. Consistent with the results of the previous experiment, the findings indicated that increasing the brightness of the object lifted by the participant could reduce the fatigue accumulated during the task. The proposed method was also shown to improve participants' endurance. Recent studies have also explored methods for enhancing pseudo-haptic perception by combining visual manipulation with additional somatosensory cues. For example, Hirao et al. showed that tendon vibration can enhance pseudo-haptic perception during free arm motion in VR [18]. These studies indicate that pseudo-haptic effects can be strengthened by combining visual feedback with bodily or somatosensory information.

2.3. Research on Lightening the Weight of Held Objects Through Visual Transparency

In a preliminary experiment of a previous study, we conducted an experiment based on the hypothesis that "there may be a linear relationship between the visual transparency of an object's appearance and the weight perceived when it is lifted." In other words, we hypothesized that the object would feel heaviest when opaque and lightest when completely transparent. The weights of the objects participants were asked to hold during the experiment were 150 g and 220 g. We chose 220 g because, while we wanted to use a heavy object with real-world applications, we also considered that if the object were too heavy—even with planned rest breaks—arm fatigue during the experiment could prevent accurate weight perception. Therefore, we decided on the 220 g weight used in the study by Kotani et al. [19]. The 150 g weight was chosen to create a contrast with the 220 g weight and, with VR applications in mind, was based on the weight of the Oculus Quest 2 controller—150 g—which is on the lighter side among standard VR controllers. The experimental results showed that while the relationship between the visual transparency of the object's appearance and the perceived weight when lifted was not linear, there was a tendency for the object to be perceived as lighter when it was transparent.

Based on this preliminary experiment, we hypothesized that "transparency" itself influences weight perception when the held object is made visually transparent. We conducted the experiment under the hypothesis that "an object feels lighter when transparent, regardless of the background." Figure 1 shows the experimental setup and the images presented to the participants. In the experiment, images of the floor were projected onto the sides and top of a bag in the VR space to present a pseudo-transparent bag. We set up seven floor-texture conditions: white, black, white checkerboard, black checkerboard, wood, metal, and wood without the bag frame (Figure 2). We used a 7-point Likert scale (1: light–7: heavy) and the VAS method (0: light–100: heavy) for evaluation. The experimental results showed a tendency for the bag to be perceived as significantly lighter under certain conditions, such as the white-floor condition and the wooden-floor condition without the bag frame. However, the bag was not uniformly perceived as lighter across all background conditions, and thus the hypothesis was not supported. Nevertheless, the results suggested that perceived weight tended to decrease under conditions that evoked a strong sense of transparency, such as the white-floor, white-checkerboard floor, and wooden-floor conditions. Based on these findings, the present study conducts a quantitative evaluation.

3. Experiment on the Quantitative Evaluation of Changes in Weight Perception Due to Transparency

In this study, we evaluate weight perception while a participant wearing an HMD grasps a real-world bag whose movements are synchronized with a bag in a VR space, and the virtual bag is visually rendered transparent. Specifically, we compare the "Wooden Floor/No Bag Frame" condition, which produced the strongest difference in weight perception in the qualitative evaluation of the previous study, with the "Metal Floor" condition, which produced only a small difference in the previous study. These two conditions were selected because they were expected to provide the clearest observation

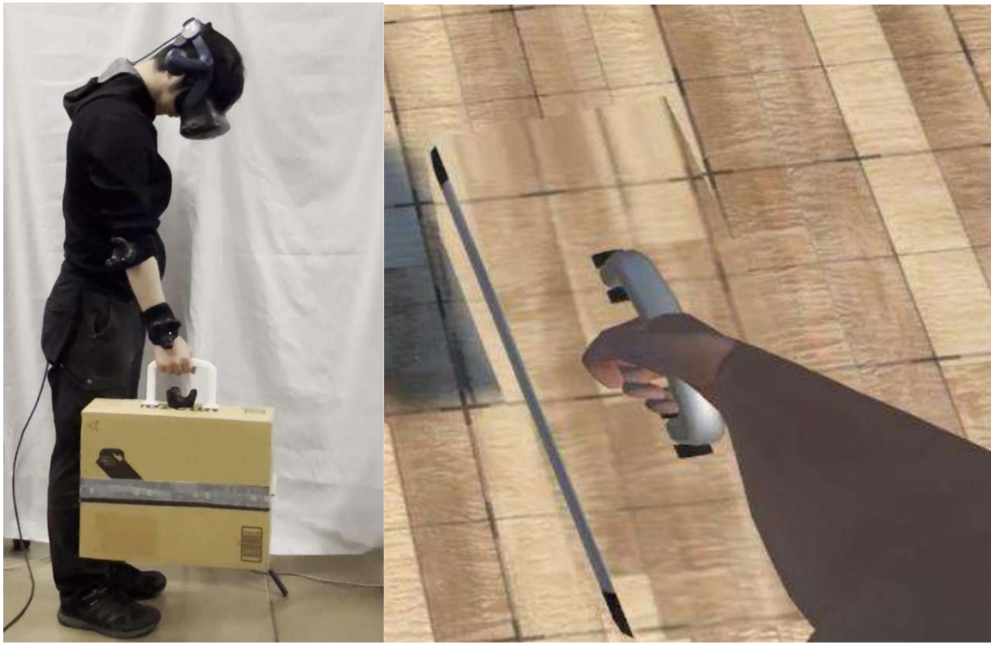

Figure 1: (left) The experiment in progress; (right) The video feed presented to the participant via the HMD

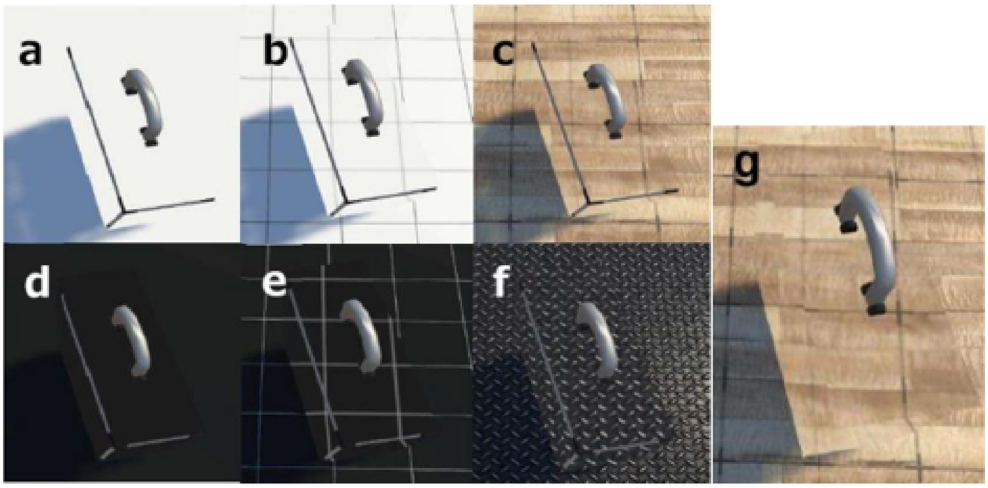

Figure 2: Bags made transparent on each floor texture in the previous study
(a: white, b: white checkered, c: wood, d: black, e: black checkered, f: metal, g: wood without bag frame)

of differences in weight perception caused by the floor texture, that is, the background visible during visual transparency. Figure 3 shows the visual stimuli presented to participants under each condition.

Additionally, as a modification from the previous study, VIVE trackers were attached to the wrist and elbow of the participant's dominant arm, and the experiment was conducted with the arm displayed within the VR environment (Figure 4).

In the VR environment, participants first lifted a bag that was either opaque or transparent and memorized its weight as the reference stimulus. Next, if the bag was opaque in its initial state, it was changed to transparent, and the participant lifted that bag. Similarly, if the bag was transparent in the initial state, it was changed to opaque, and the participant lifted that bag. The weight perceived at this stage served as the comparison stimulus. The participant then adjusted the weight of the bag by adding or removing water until the comparison stimulus matched the reference stimulus. After adjustment, the amount of water added or removed was used as a quantitative measure of the change in perceived weight caused by visual transparency.

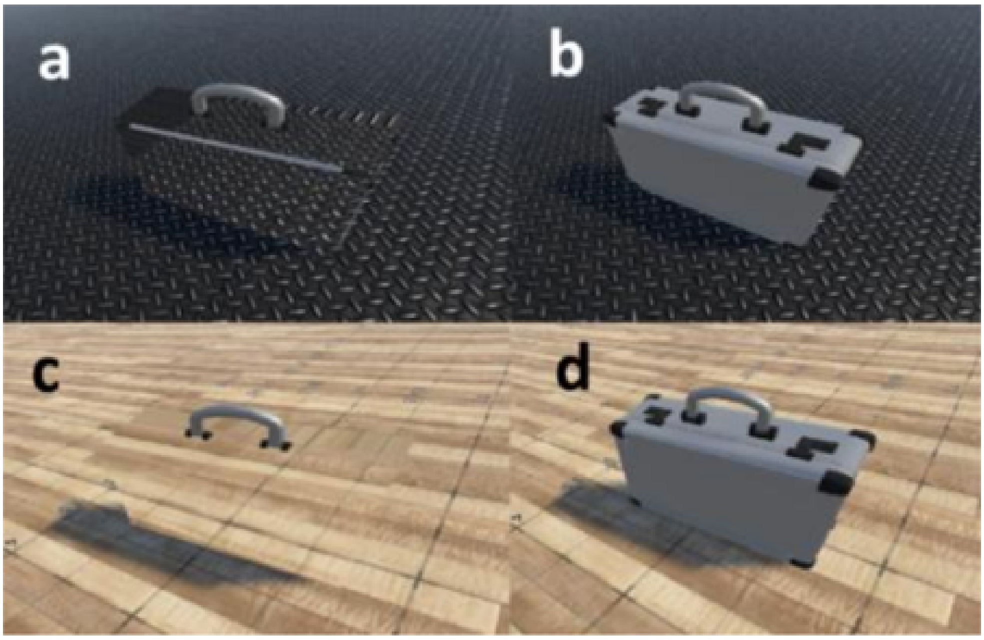

Figure 3: The bag in the VR environment viewed by participants under four conditions.
(a: Metal Floor/Transparent Reference, b: Metal Floor/Opaque Reference, c: Wooden Floor/No Bag Frame/Transparent Reference, d: Wooden Floor/No Bag Frame/Opaque Reference)

Figure 4: Arm rendering in a VR environment

3.1. Experimental Environment

Unity (2019.4.40f1) was used to create the virtual environment and the virtual bag. The HMD and controllers used were the VIVE Pro 2 (resolution: 2448 × 2448 pixels per eye, 4896 × 2448 pixels for both eyes, field of view 120 degree). VIVE Trackers were used to capture the position and rotation of the real-world bag and the participant's arms.

To implement the transparency effect, which makes the bag in the VR space appear pseudo-transparent, we first cast rays from the viewpoint toward the corners of the bag and obtained the coordinates at which they intersected the floor (Figure 5(a)). Next, we positioned the camera directly above the bag and hid the bag (Figure 5(b)). A homography transformation was applied to the floor image captured by the camera using the obtained coordinates (Figure 5(c)). By overlaying this processed image onto the surface of the bag, we achieved a transparency effect that tracks the movement of the viewpoint (Figure 5(d)). This reproduces a visual effect similar to a "transparent bag" in the real world.

Figure 6 shows the real-world bag equipped with the water filling and draining mechanism (the object to be grasped); Figure 7 shows the mechanism of the water filling and draining system; Figure 8 shows the weight adjustment controller; and Figure 9 shows the experimental setup.

The bag used was constructed by attaching a 3D-printed handle and a VIVE tracker to a wooden frame. Its dimensions are 46 cm wide, 16 cm deep, and 36 cm high. A water filling and draining mechanism using a pump activated by the controller was installed inside the bag. This mechanism allows the weight to be changed continuously and rapidly by having the participant hold the bag with their dominant hand and operate the controller with the opposite hand to fill or drain water. The water filling and draining mechanism was set to adjust the weight by approximately 10 g (10 ml) per second. This setting was chosen to minimize the burden on participants while allowing easy weight adjustment, because participants noted that if the volume of water added or drained was too large, fine adjustments would be difficult, and if it was too small, the time required for adjustment would increase, leading to longer bag-holding times and increased strain on the arms.

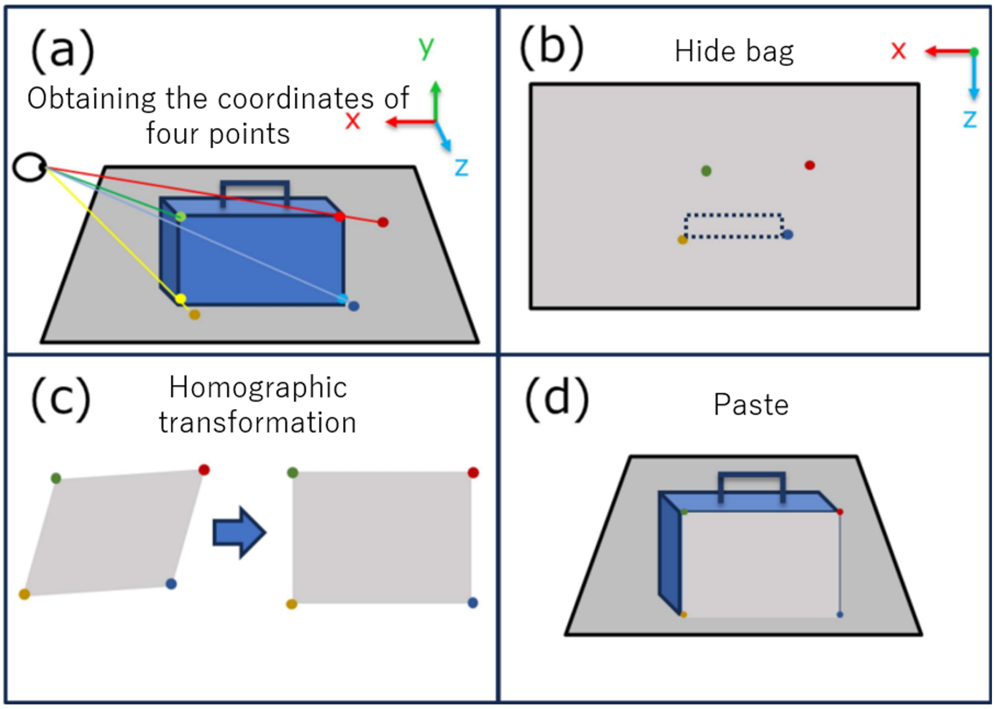

Figure 5: Transparency procedure
(a: coordinate acquisition at four points, b: bag hiding, c: homography transformation, d: image mapping)

3.2. Experimental Procedure

Figure 10 shows the experimental diagram and an example of the transparency effect observed by the participant within the VR space. Before the experiment began, participants were asked to complete a questionnaire via Google Forms, providing their name, gender, age, dominant hand, prior experience with VR using an HMD, and frequency of VR use. Subsequently, we provided instructions on how to grip the bag's handle, where to stand, and how the experiment would proceed. We then fitted the participants with the HMD and trackers, had them grip the bag's handle, and adjusted the length of the participant avatar's arms and the position of their hands within the VR space to ensure there was no sense of incongruity between the VR space and the real world. We then had the participants practice lifting the bag to ensure they understood the sensation of the bag's weight changes and were comfortable operating the controllers before beginning the experiment. The names of the experimental conditions were determined based on whether the initial state of the reference stimulus bag was transparent or opaque. If the reference stimulus started in a transparent initial state, it was named the "Transparent Reference"; if it started in an opaque initial state, it was named the "Opaque Reference."

Next, we describe the procedure for trials starting with the opaque reference condition. Figure 11 shows the experimental setup and the visual display seen by the participant. First, the participant is

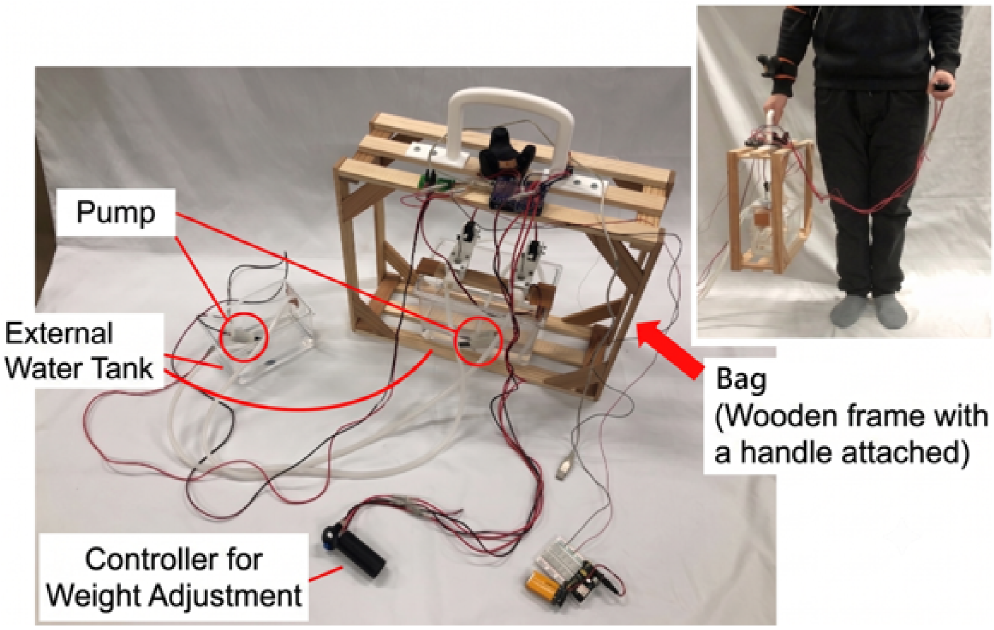

Figure 6: Real-world bag equipped with a water filling and draining mechanism

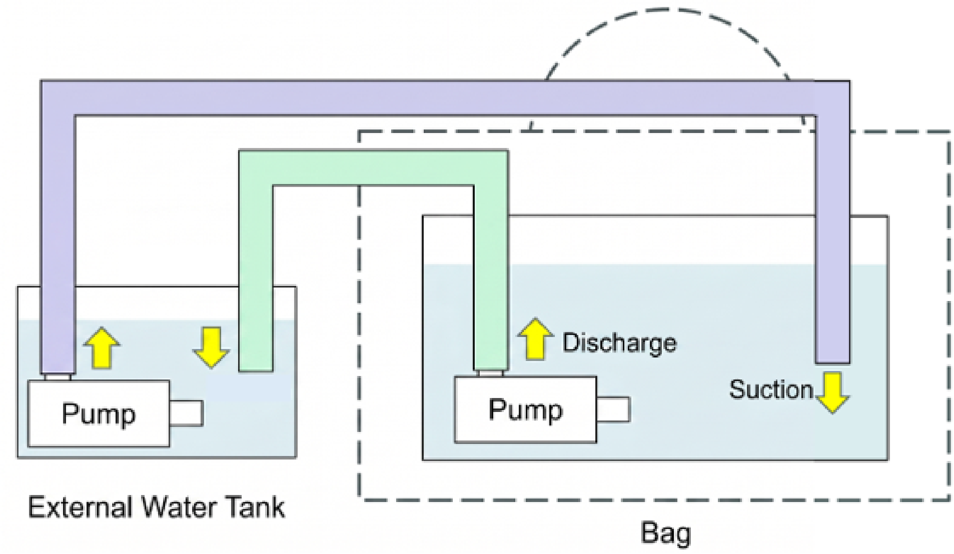

Figure 7: Diagram of the water filling and draining mechanism

presented with the reference stimulus—the bag in its opaque state. The participant was instructed to lift the opaque bag with their dominant hand and to memorize the perceived weight as the reference stimulus at that moment. Note that at this stage, the participant was not allowed to operate the weight-adjustment controller; they were only asked to assess their sense of weight (Figure 11(a)). Once the participant had completed memorizing the weight, they were asked to put the bag down, and the bag in the VR space was changed from opaque to transparent (Figure 11(b)). Next, the participant lifted the now-transparent bag again and adjusted its weight by adding or draining water from it (Figure 11(c)). Specifically, using a controller held in the hand opposite the one holding the bag, the participant operated the water filling and draining mechanism to adjust the weight of the transparent bag until it felt subjectively equal to the weight of the opaque bag memorized immediately prior (the reference stimulus). During this adjustment, if the participant felt the bag was heavier than in the opaque condition, they would make it lighter; if they felt it was lighter, they would make it heavier; and if their perceived weight remained

Figure 8: Weight adjustment controller

Figure 9: Experimental apparatus (left) and video displayed to the participant via the HMD (right)

unchanged, they would leave the weight as is and set the bag down. This process was repeated until the perceived weight of the current bag matched the remembered reference stimulus. Similarly, when starting with a transparent reference, the participant was asked to lift the transparent bag and memorize the weight perceived at that moment. Once the weight was memorized, the participant was asked to set the bag down, the bag's transparency was changed from transparent to opaque within the VR space, and the participant was asked to lift it again to adjust the weight by adding or draining water from the bag.

We next describe the process used to determine the physical weight of the bag used as the reference stimulus. The weight of the bag was varied in 1 kg increments between 1 kg and 10 kg, and several pilot participants were asked to hold the bag. The results indicated that weights of 8 kg or greater were unsuitable because they were too heavy, making it difficult to perceive the effect of transparency, and because the physical strain and fatigue became too great for repeated lifting. Additionally, weights of 5 kg or less tended to make it easier to perceive the difference between transparent and opaque states, so we decided to reduce the weight options to 1 kg, 3 kg, and 5 kg. Because 3 kg was initially found to be the easiest to perceive, we further tested 2 kg, 3 kg, and 4 kg. The 2 kg condition provided the clearest perceptual difference, so we decided to use a physical weight of 2,000 g for the reference stimulus. After each condition, we asked participants to complete a three-choice questionnaire—whether the bag felt lighter, heavier, or unchanged—to confirm whether they had operated the experimental apparatus

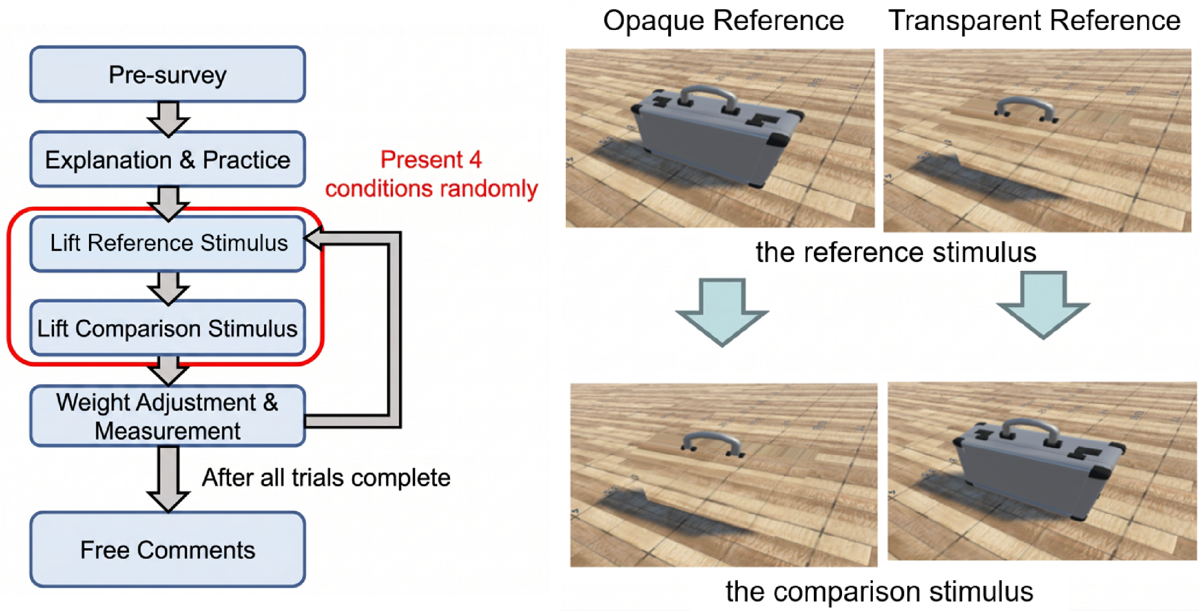

Figure 10: Experimental diagram (left) and example of rendering the bag transparent (right)

correctly, record their sensory experience during operation, and verify changes in weight perception and operational methods.

The experimental conditions were defined as follows: two floor-appearance conditions, "Metal Floor" and "Wooden Floor/No Bag Frame," and two initial-state conditions, "Transparent Reference" and "Opaque Reference." By combining these two factors, we designed four experimental conditions: "Metal Floor/Transparent Reference", "Metal Floor/Opaque Reference", "Wooden Floor/No Bag Frame/Transparent Reference" and "Wooden Floor/No Bag Frame/Opaque Reference". After completing these four conditions, participants were asked to provide free-form comments, and the experiment concluded. To reduce order effects, the four conditions were presented in random order.

4. Results and Discussion

4.1. Experimental Results

18 participants participated in this experiment. The group consisted of 17 males and 1 female, aged 20–24; 17 were right-handed and 1 was left-handed. Regarding the frequency of VR use, 2 participants reported "frequently," 7 reported "occasionally," and 9 reported "rarely." Among the 9 who reported "rarely," 4 had no prior VR experience. The experimental protocol was approved by the Ethics Committee of Ryukoku University (Approval No. 2024-64), and all participants provided informed consent prior to participation.

For each condition, Figure 12 shows the adjusted weight after participants used the water filling and draining mechanism until the comparison stimulus felt equal in weight to the reference stimulus, and Table 1 presents the summary statistics. A one-sample, one-tailed t-test at a 5% significance level was performed between the participant-adjusted weight and the initial physical weight of the bag (2000 g, hereinafter referred to as the "reference weight"). The results showed a statistically significant difference from the reference weight for the "Wooden Floor/No Bag Frame/Transparent Reference" and "Wooden Floor/No Bag Frame/Opaque Reference" conditions ($p < 0.05$). In contrast, no statistically significant difference was observed between the reference weight and the "Metal Floor/Transparent Reference" or "Metal Floor/Opaque Reference" conditions.

Regarding subjective judgments when the held object was made transparent, participants who perceived it as lighter, heavier, or unchanged were identified in each condition. The physical weight

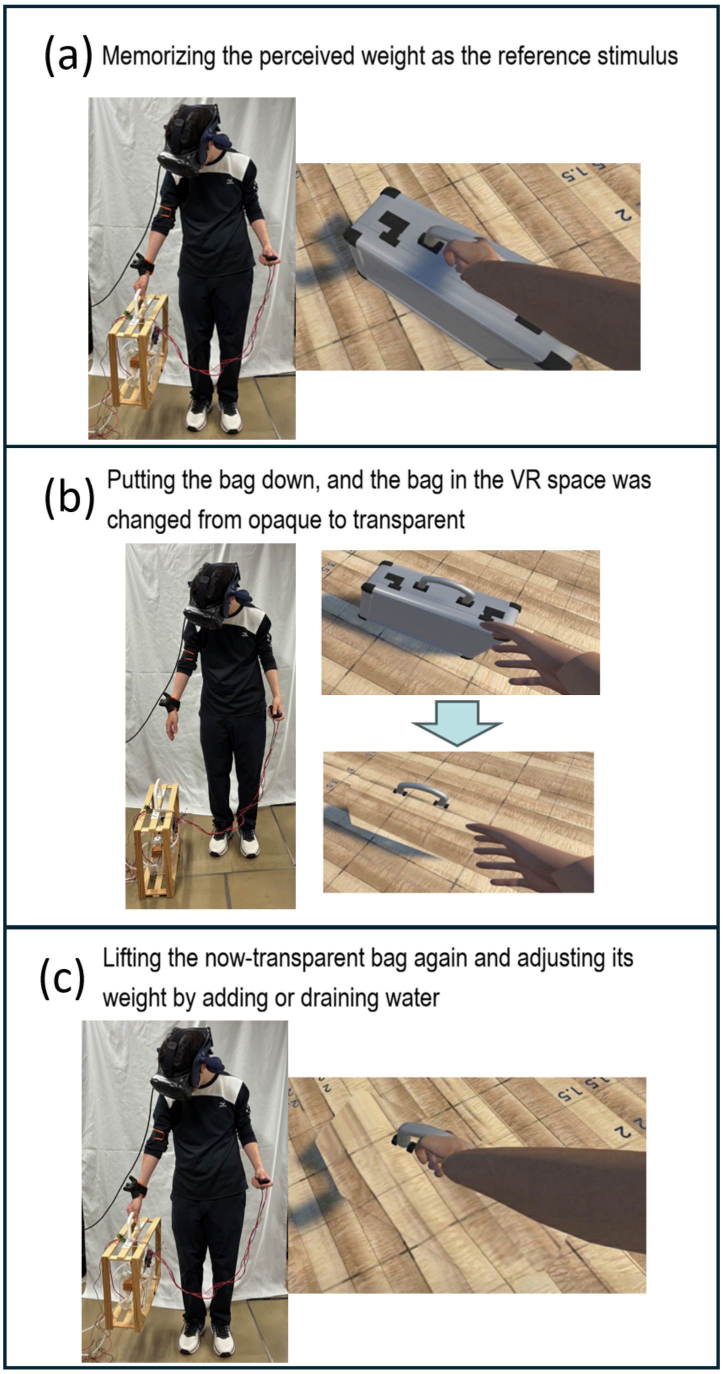

Figure 11: Experimental procedure (left) and example of rendering the bag transparent (right) in the opaque reference (The initial state of the reference stimulus bag is opaque.)

adjustments for participants who perceived the transparent bag as lighter or heavier are shown in Figures 13 and 14, and Table 2. Among participants who perceived the object as lighter, the numbers in each condition were 4 out of 18 for "Metal Floor/Transparent Reference," 8 out of 18 for "Metal Floor/Opaque Reference," 8 out of 18 for "Wooden Floor/No Bag Frame/Transparent Reference," and 10 out of 18 for "Wooden Floor/No Bag Frame/Opaque Reference." In this group, the largest change was observed in the "Wooden Floor/No Bag Frame/Transparent Reference" condition, with a mean adjustment of -47.4 g. The overall mean adjustment was -40.8 g, where a negative value indicates drainage from the bag. This indicates that, when the transparent bag on the wooden floor was perceived as lighter than the opaque bag, participants adjusted its physical weight to 1,959.2 g on average.

Among participants who perceived the bag as heavier, the numbers in each condition were 8 out of

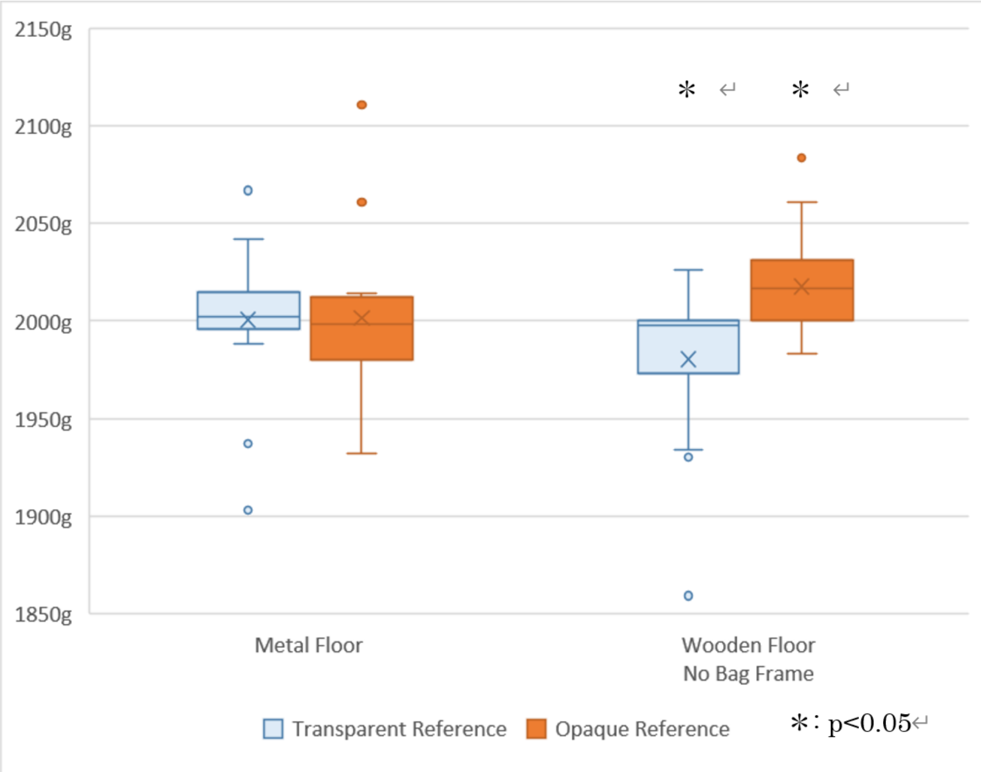

Figure 12: Physical weight after adjustment from the reference weight of 2000 g

Table 1
Physical weight after adjustment from the reference value of 2000 g

Condition	Minimum	Median	Maximum	Mean	SD
Metal Floor/Transparent Reference	1903.0	2002.0	2067.0	2000.50	35.162
Metal Floor/Opaque Reference	1932.0	1998.5	2111.0	2001.72	43.310
Wooden Floor/No Bag Frame / Transparent Reference	1859.0	1997.5	2026.0	1980.33	38.928
Wooden Floor/No Bag Frame / Opaque Reference	1983.0	2016.5	2084.0	2017.72	26.151

Table 2
Mean physical weight adjustment under each condition

	Metal Floor / Transparent Reference	Metal Floor / Opaque Reference	Wooden Floor No Bag Frame / Transparent Reference	Wooden Floor No Bag Frame / Opaque Reference	Four-condition Mean
Perceived as lighter	-44.75	-35.75	-47.375	-35.3	-40.794
Perceived as heavier	23.375	28.444	26.000	12.667	22.622

18 for "Metal Floor/Transparent Reference," 9 out of 18 for "Metal Floor/Opaque Reference," 1 out of 18 for "Wooden Floor/No Bag Frame/Transparent Reference," and 3 out of 18 for "Wooden Floor/No Bag Frame/Opaque Reference." In this group, the largest change was observed in the "Metal Floor/Opaque Reference" condition, with a mean adjustment of 28.4 g. The overall mean adjustment was 22.6 g, indicating an increase relative to the reference weight. This indicates that, when the transparent bag on the metal floor was perceived as heavier, participants increased the physical weight during adjustment.

In addition, the numbers of participants who reported in the questionnaire that their weight perception did not change and therefore did not adjust the weight were 6 out of 18 for "Metal Floor/Transparent Reference," 1 out of 18 for "Metal Floor/Opaque Reference," 9 out of 18 for "Wooden Floor/No Bag

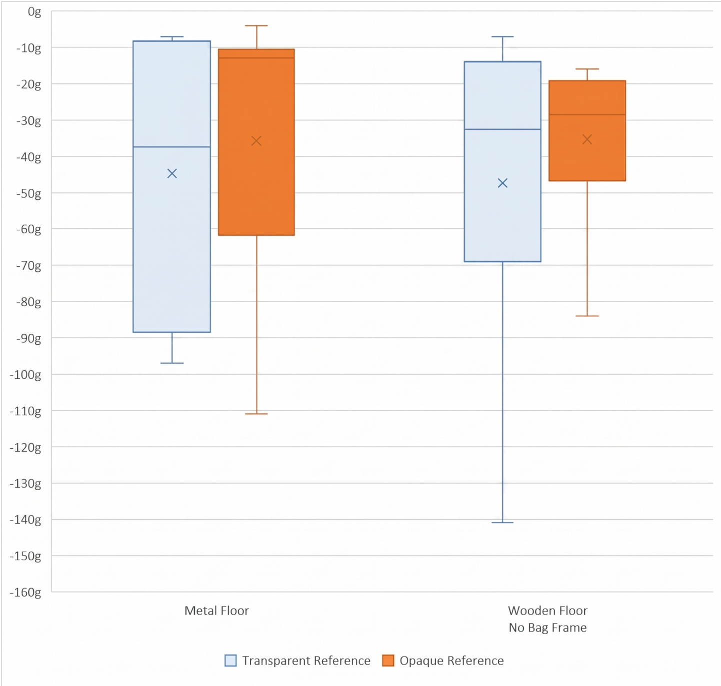

Figure 13: Physical weight adjustment among participants who perceived the transparent bag as lighter

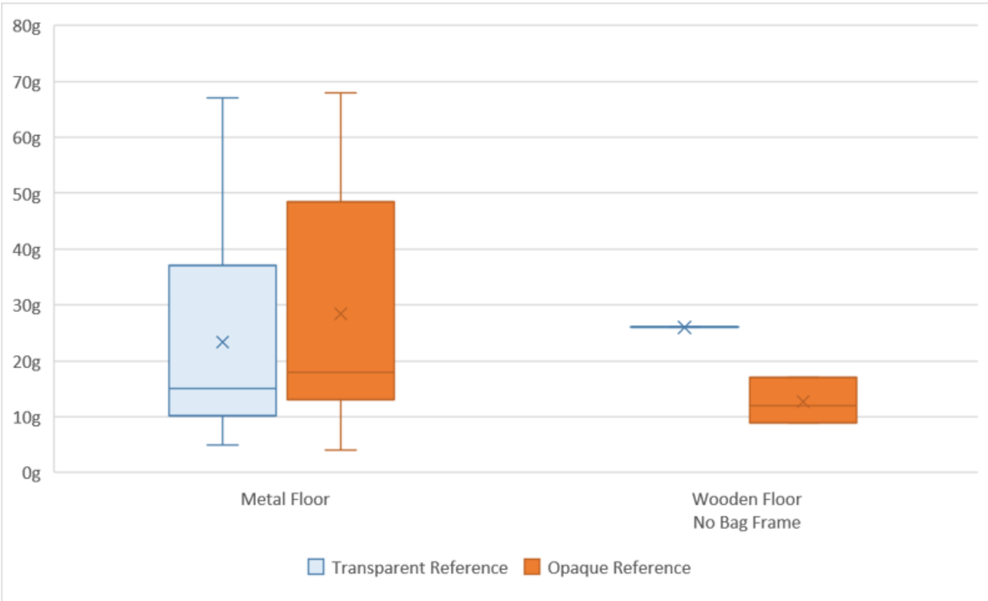

Figure 14: Physical weight adjustment among participants who perceived the transparent bag as heavier

Frame/Transparent Reference," and 5 out of 18 for "Wooden Floor/No Bag Frame/Opaque Reference." The largest number was observed in the "Wooden Floor/No Bag Frame/Transparent Reference" condition.

5. Discussion

Qualitative evaluations in previous studies using the Likert scale and VAS method suggested that transparent objects tended to be perceived as lighter under conditions involving a wooden floor and no bag frame. The results of the quantitative evaluation in this study show that, under the Wooden Floor/No Bag Frame condition, the weight adjusted by participants through filling and draining differed significantly from the reference weight (2000 g). This quantitatively demonstrates that participants experienced a weight-perception illusion in which the transparent bag felt lighter. These results support the findings of previous qualitative studies and quantitatively confirm the weight-reduction effect of visual transparency in terms of physical weight values, with a difference of approximately 40.8 g under the condition that induced the strongest illusion. In contrast, no significant difference was observed under the Metal Floor condition. This trend is consistent with previous research and reaffirms that the effect of transparency varies depending on floor texture. One possible reason for the strong effect observed under the Wooden Floor/No Bag Frame condition is that the absence of the bag's outline reduced the object's physical presence, potentially emphasizing a sense of transparency and making the bag feel more "airy" or "massless." In contrast, under the Metal Floor condition, the complexity of the background texture and the evocation of the material properties of metal may have maintained a sense of weight. Because many participants did not perceive a change in weight perception under the "Wooden Floor/No Bag Frame/Transparent Reference" condition, the order in which transparency and opacity are switched may affect weight perception.

Among participants who perceived the object as lighter in the questionnaire, 8 out of 18 were in the "Wooden Floor/No Bag Frame/Transparent Reference" condition, and 10 out of 18 were in the "Wooden Floor/No Bag Frame/Opaque Reference" condition. This indicates that even under the "Wooden Floor/No Bag Frame" condition, which produced the greatest change in weight perception, the illusion was induced in only about half of the participants. Therefore, future work should investigate conditions and methods that can induce the illusion in a larger number of people.

The evaluation method used in this study included a task in which participants adjusted the weight themselves; consequently, it enabled a more quantitative assessment of weight perception than conventional Likert-scale or VAS-based evaluations. The fact that trends consistent with those observed in qualitative evaluations were obtained as quantitative values demonstrates the validity of this method. However, future studies should examine whether the time and effort required for the adjustment process involving filling and draining the bag may cause adaptation in weight perception.

6. Conclusion

In this study, we quantitatively evaluated the effect of visual transparency of grasped objects in a VR space on weight perception, focusing on conditions for which previous research had suggested an effect. The experimental results confirmed that, under the Wooden Floor/No Bag Frame condition, visual transparency significantly reduced perceived weight. Specifically, the results showed that a physical weight increase of approximately 40.8 g is required to make a transparent bag feel as heavy as an opaque bag. This finding demonstrates that the magnitude of the weight illusion caused by visual transparency can be quantitatively expressed as a difference in physical weight. The results also showed that even under the "Wooden Floor/No Bag Frame" condition, which produced the greatest change in perceived weight, the illusion was induced in only about half of the participants. Moreover, the hypothesis from previous studies, namely that "bags feel lighter regardless of the background when transparent," was not supported in the Metal Floor condition, as no statistically significant difference from the reference weight was observed even in the quantitative evaluation. As future work, we plan to conduct experiments using bags rendered transparent in AR. This method involves displaying the background image visible through the bag on the bag itself to reproduce a state close to transparency.

Declaration on Generative AI

During the preparation of this work, the author(s) used Prism, GPT-5.5, and DeepL for translation, grammar, ,finding relative work, sentence-level, and spelling checks. The author(s) also used GPT-5.5 to generate the LaTeX code for Tables 1 and 2. After using these tools/services, the author(s) reviewed and edited the content as needed and accept full responsibility for the publication's content.

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