Perceived Weight of a Rod under Augmented and Diminished Reality Visual Effects

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ABSTRACT

We can use augmented reality (AR) and diminished reality (DR) in combination, in practice. However, to the best of our knowledge, there is no research on the validation of the cross-modal effects in AR and DR. Our research interest here is to investigate how this continuous visual changes between AR and DR would change our weight sensation of an object. In this paper, we built a system that can continuously extend and reduce the amount of visual entity of real objects using AR and DR renderings to confirm that users can perceive things heavier and lighter than they actually are in the same manner as SWI. Different from the existing research where either AR or DR visual effects were used, we validated one of cross-modal effects in the context of both continuous AR and DR visuo-haptic. Regarding the weight sensation, we found that such cross-modal effect can be approximated with a continuous linear relationship between the weight and length of real objects. Our experimental results suggested that the weight sensation is closely related to the positions of the center of gravity (CoG) and perceived CoG positions lie within the object's entity under the examined conditions.

CCS CONCEPTS

• **Human-centered computing** → **Mixed / augmented reality**; **User studies**; • **Computing methodologies** → *Mixed / augmented reality*; • **Hardware** → Haptic devices;

*This author designed all experimental procedures.
†This author clarified the novelty and designed paper structures.
‡This author conducted experiments.
§this author integrated AR system.
¶This author defined the research direction.

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KEYWORDS

Visuo-haptic system, augmented reality, diminished reality, weight sensation, sense of ownership

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1 INTRODUCTION

Senses work in collaboration with one another, not individually. Therefore, senses mutually complement information, and we receive the resultant stimuli. This complementary effect, a so-called cross-modal phenomena, shows that we can handle multiple senses by giving a single sensory irritation to the user instead of giving multiple stimuli corresponding to each sensory system [8]. For example, a visual-weight illusion known as a size-weight illusion (SWI) is one such phenomena [13]. SWI makes the user feel that objects with the same weights differ, depending on the size. [3]. Thus, SWI can change the perceived weight–which usually requires large-scale instruments to change the actual weight–by simply changing the visual effects. The use of this phenomenon can simplify system configurations, making them cost-effective.

Cross-modal phenomena are reproducible in augmented reality (AR) environments. AR is capable of changing the appearance of real-world objects fully or partially. For example, changes in the appearance of an object by a hand would induce SWI and change the sense of the object's weight. However, AR has a practical limitation; AR overwraps the visual stimuli with computational visual effects (i.e., AR cannot reproduce smaller visual stimuli than the real one). In other words, SWI in AR is capable of making only the user feel that the object is lighter than it actually is by making the size larger.

Diminished reality (DR) can, on the other hand, visually remove real-world information (i.e., DR and AR have opposite concepts). Briefly, DR makes objects invisible by overlaying synthetic background pictures onto the object [9]. DR can, therefore, make an object to be held by a hand smaller than it actually is by visually removing part of the object. In theory, SWI effects in DR make things heavier as opposed to SWI in AR.

In practice, we can use AR and DR in combination. However, to the best of our knowledge, there is no research on the validation of the cross-modal effects of AR and DR. Our research interest here is to investigate how continuous visual changes between AR and DR would change our weight sensation of an object. Consequently, our contribution in this research is to answer the following questions:

- How do the AR and DR visual modifications change the perceived center of gravity (CoG)? For example, in AR and DR, is the CoG perceived at a position where there is no entity after visually extending or shortening the object, or is it perceived within the entity?
- How do the AR and DR visual modifications change the perceived weights? For example, do AR and DR always make things lighter or heavier, respectively?
- Are there any limitations on the illusions?

2 RELATED WORK

2.1 Visuo-Haptic Experiments in VR space

Virtual reality (VR) enables us to not only reproduce the real-world phenomenon in a fully virtual world but also to newly create arbitrary phenomenon as we desire. This vital aspect of VR has pushed psychological studies, especially in visuo-haptics, forward to tackle challenging issues in this field by presenting contradicting multimodal stimulus to the user, which has not been achievable using real space.

Zenner and Kruger [16] and Fujinawa *et al.* [5] utilized VR spaces to validate the effects of visuo-haptics. In these two studies, they used a passive object with a motorized spindle to change its CoG, and they showed that the perceived weight can be significantly altered with this mechanism that changes the object's properties slightly.

While these findings are positively recognized in the field, we also recognize the inconsistency between the real and virtual worlds' experiences induced from the incompleteness of the video-game-quality virtual world and geometric remapping from the daily life experiences to those in the virtual world. This inconsistency is noticeable, especially in the visuo-haptic field where a user must touch real or virtual objects via his/her avatar body, and, therefore, a sense of ownership is hardly achieved. To avoid such unnecessarily arguable phenomenon in visuo-haptic studies, AR can be an alternative. AR adds visual effects to the real world without changing the appearance of the user's body. Consequently, the see-through capability of AR would give us the convincing feelings from the raw visual world without invading the body ownership existing there by nature.

2.2 Visuo-Haptic Experiments in AR space

While AR technology can partially solve limitations in VR, it casts some technical difficulties. Issartel *et al.* [6] observed visuo-haptic effects of virtual objects colliding with each other in an AR space. Taima *et al.* [14] built a system to modify the movement of a handled object to evoke the visuo-haptic effect in an AR space. Punpongsanon *et al.* [11] proposed an AR-based technique using a visuo-haptic mechanism. Their system visually controls the appearance of soft objects to manipulate the softness perceived by a user pushing the physical object. In another example, cross-modal effects of a real object with visual effect overlay are validated. There is also an example, in which cross-modal effects of a real object with visual effect overlay are validated. Omosako *et al.* [10] observed that the CoG of a real object can be perceived differently when a larger virtual object is superimposed onto the real one. They also observed a similar phenomenon when the virtual object is smaller than the real one. However the conditions and the experiments were not conducted with sufficient thoroughness. From these attempts, various effects of AR visual stimuli to haptic sensations regarding roughness, weights, and the CoG have been validated.

2.3 Visuo-Haptic Experiments in DR space

Buchmann *et al.* [2] showed preliminary results on the performance improvements for manual operations with semitransparent workers' hands under a fixed head pose. Cosco *et al.* [4] performed real-time 6DoF DR to visually remove a bulky haptic device occluding the user's workspace and confirmed that this visual effect can increase performance. While diminishing real objects with DR techniques has been considered effective, Tanaka *et al.* [15] presented results showing that the diminished object tends to be perceived as heavier.

Bayart *et al.* [1] proposed a pioneering system using both AR and DR for virtual painting onto real objects. This system could erase a visual obstacle for the painting target with a DR process. Although we found some systems having both AR and DR rendering pipelines, to the best of our knowledge, no experiments have been performed to confirm effects to haptic and the other sensations with cross-modal effects (i.e., AR and DR). AR and DR are individually confirmed as able to influence haptic sensations, but these two modalities have not been combined in a single experimental condition. Therefore, the continuity of the influence of AR and DR visual effects to the haptic sensations has not been explored.

2.4 Size-Weight Illusion (SWI)

SWI is an illusion of weight sensation induced by visual effects. Due to the illusion, we misinterpret that objects with the same weight are heavier when the size is smaller than it is and vice versa. Rock *et al.* [12] reported that objects held by a hand with a magnifier give different weight sensation from those without a magnifier. Koike *et al.* [7] validated that a haptic device, SPIDAR, can be used to induce SWI. However, most of the related research validated the illusion in the real space or visual stimuli for SWI are indirectly presented in a display from a different perspective.

3 OVERVIEW OF AR–DR VISUO-HAPTIC EXPERIMENTS

3.1 System Setup

In the following experiments, a video see-through-type head-mounted display (HMD) and an AR platform system were used to implement DR effects. To allow the test subject to freely move his or her head during the experiments, the subject's head motion was acquired

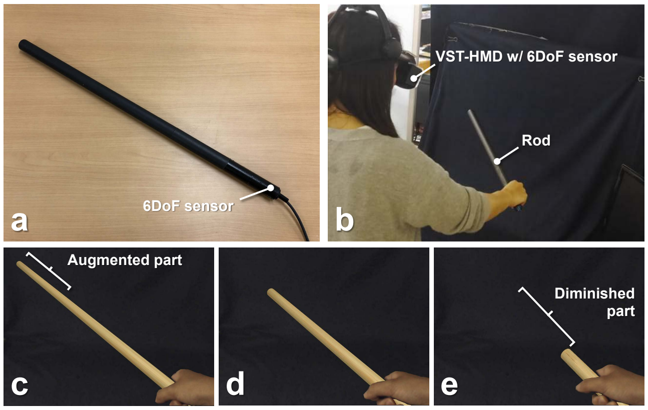

Figure 1: Extending and shortening a real rod using AR and DR techniques, respectively. a) a physical rod with 6DoF sensor (a Polhemus Fastrak receiver), b) the user with a VST-HMD tracked in 6DoF gazes at the rod and waves the rod at every constant time interval. c) 160% length rod with AR, d) 100% length rod with a texture overlay, and e) 30% length rod with DR.

using magnetic sensors. The system operated at 30 fps. The subjects reported that they did not experience a time lag or shift in the preliminary experiments.

We adopted a simple method for erasing objects by using DR for this study. We created a 3-D model of the environment in figure 1 from multiview images using a 3-D reconstruction tool, Agisoft PhotoScan, in advance. Figure 2 shows the 3D scan data used in the our experiments. We used a 100g rod of 24mm diameter and 60cm length. We defined a part of a rod within 10cm from the end to be grasped. The rods were masked for chroma-key composition of the above-mentioned 3-D environment model.

3.2 Research Questions and Hypotheses

In this experiment, we investigated the relationship between the visual range of real objects and the weight perception. Specifically, we considered the following research questions:

(1) When sticks are diminished by DR, depending on the range to be diminished, will subjects feel them as heavier as or lighter than normal?
(2) Similarly, as we increase that range, does the weight perception change to become lighter or heavier uniformly?
(3) Does the change in the appearance of real objects from AR extension to DR reduction and vice versa continuously influence the visuo-haptic illusion?
(4) Even if we use sticks of different weights, will the subjects feel them to be as heavy or as light as they are?

From these research questions, we formulated the following hypotheses to be validated in the following psychological study.

H1 The shorter the rod is, the heavier it feels to participants
H2 The longer the rod is, the lighter it feels to participants
H3 These transitions in experienced heaviness are continuous
H4 Perceived positions of the weights vary depending on visual AR/DR visual stimuli

Figure 2: Pre-scanned background data for DR.

H5 The perceived positions influence to the weight sensation

4 PSYCHOLOGICAL STUDY: WEIGHT

In Experiment 1, we evaluated effects of virtually extended or shortened rods to the weight sensation based on magnitude estimation method to confirm the H1, 2, and 3. For all conditions in this experiment, we used the same physical rod.

4.1 Procedures

In order to eliminate differences in the way that participants might swing the rods, we instructed the participants on how to swing the rods the same way, by holding the handle part and swinging the rods up and down with their right hand. Participants held the rods so that they could be seen on-screen. The degree of swing was 40 degrees, and the tempo was 100 BPM.

For the evaluation, we used a magnitude estimation method. In this method, the magnitude of the sensation in the evaluation stimulus is answered by a proportional value for the standard stimulus (100). For example, participants answer 200 if the evaluation stimulus feels twice as heavy as the standard stimulus. If they feel half the weight, they answer 50. The standard stimulus was a virtual rod of the same length as the real object. The evaluation stimulus was set to 30%, 60%, 130%, 160% the length of the real object. In the experiment, since three evaluation stimuli were performed, the number of trials per person was $4 \times 3 = 12$ trials. In addition, considering fatigue of the arm, there was a sufficient break every 4 trials. The sample included 10 participants. The test procedure was conducted as follows:

Start:

(1) Participants wear HMD
(2) Participants swing a standard stimulus rod
(3) One evaluation stimulus is randomly selected from the four patterns, and the participants swing it
(4) Participants are asked to answer the weight felt by the evaluation stimulus with the proportional value of the standard stimulus
(5) Steps 1-4 were repeated 3 times for all patterns

End.

4.2 Results

Figure 3 shows the results of Experiment 1. The vertical axis shows the evaluation values answered by the participants (in magnitudes), and the horizontal axis shows lengths of the virtually extended or shortened rod. In this box plot, the top, middle, and bottom lines of the box represent the value of the first quartile, the median, and the value of the third quartile, respectively. The cross marks are placed at the mean of the evaluation values from 10 participants. The error bars show the maximum and minimum values.

A 60 cm rod is a reference, and its weight is assumed to be 100 in magnitude. Therefore, if a participant's answer is a higher value than 100, then it means that the participant perceived the rod heavier, and vice versa.

From the results in Figure 3, we found the following:

(i) The participants perceived virtually shortened rods heavier than they actually were (ii) The participants perceived virtually extended rods lighter than they actually were (iii) A correlation existed between the evaluation values and the lengths of the augmented and diminished objects

(i) Regarding visually shorter rods than the actual length, we observed larger median and mean values than the reference. We can interpret this as visually shorter rods than the actual length (60 cm) are perceived to be heavier. From this result, **H1** is supported.

(ii) On the other hand, for the extended rods of 80 cm and 100 cm, the median and mean values of evaluation values were smaller than the reference rod. This shows that visually longer rods than the actual length (60 cm) are perceived to be lighter. Consequently, as with SWI, we confirmed that visually longer and shorter rods of the same weights are perceived lighter and heavier, respectively.

An analysis of variance (ANOVA) (Tukey Kramer test) found significant differences between 20 cm and 80 cm, 20 cm, and 100 cm, 40 cm and 80 cm, and 40 cm and 100 cm combinations. This result shows that 60cm ± 40cm with virtual stretching is within an effective range for the visuo-haptic illusion. From this result, **H2** is supported.

iii) We analyzed the results to see if there is a relationship between evaluation values, y, lengths of the virtual modified rods, x, using linear regression analysis. Based on the results of the study, evaluation values are related to lengths of the virtually modified rods: $y = -0.76x + 156.04(R^2 = 0.44)$ with $R^2 \geq 0.40$.

In other words, based on the coefficients in the equation, we found that the perceived weight decreases monotonically as the length increases.

5 PSYCHOLOGICAL STUDY: COG

We've confirmed that the virtually extending and reduction of the length of the rod influence to the weight sensation. Next, we measured positions of perceived CoG and how the CoG influence the weight sensation to confirm the H4 and 5.

5.1 Procedures

The method of grasping and swinging the rod is the same as in Experiment 1. A red dot is placed on the rod and the participants answer the perceived centroid position by moving the point. Participants are required to hold the rod with the right hand and answer the position of the CoG by operating the keyboard with the left hand. For the evaluation, virtual rods of 30%, 60%, 100%, 130%, and 160% length of the real object was used. In the experiment, since this evaluation stimulus 5 pattern is executed three times each, the

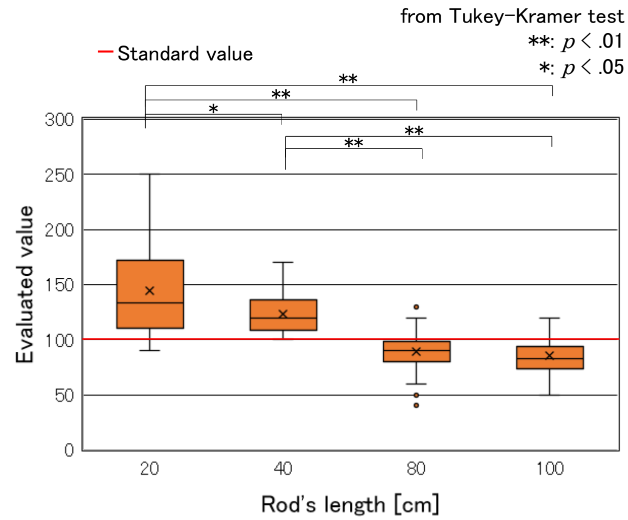

Figure 3: Relationship between perceived weights and rod's length.

number of trials per person is 15 (= 5 × 3) trials. As in Experiment 1, considering fatigue of the arm, there is a sufficient break every 5 trials.

The procedure of the experiment is as follows.

Start:

(1) Participants wear HMD
(2) Randomly choose one type from five types of costumes
(3) Participants shake sticks until they perceive the CoG position
(4) Participants will move the red point and answer the perceived centroid position
(5) Steps 1-4 were repeated 3 times for all patterns

End.

5.2 Result

Figure 4 shows the results of Experiment 2. The vertical axis shows the position of the CoG answered by the participants, and the horizontal axis shows lengths of the virtually extended or shortened rod. In this box plot, the top, middle, and bottom lines of the box represent the values of the first quartile, the median, and the third quartile, respectively. The cross marks are placed at the mean of the answered CoG from 10 participants. The error bars show the maximum and the minimum values. From the results in Figure 4, we found the following:

(i) The participants answered the CoG closer to their hand than the actual CoG (ii) The participants answered the CoG further to their hand than the actual CoG (iii) The position of the CoG answered by the participants was weakly related to the length of the rod

(i) ANOVA (Tukey Kramer test) also found significant differences between 100 cm and 60 cm rod conditions. This result shows that the participants perceived the position of the CoG of the virtually shorter rod closer to their hand than that of the actual 60cm rod. In other words, we found that shortening a rod using DR processing

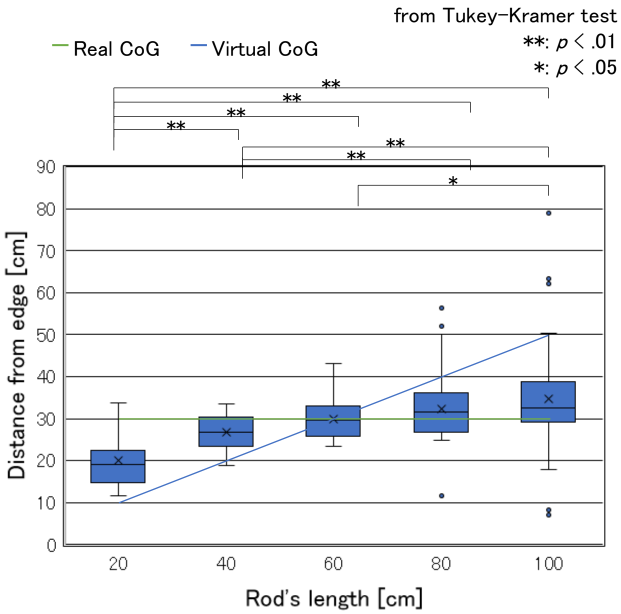

Figure 4: Relationship between perceived CoG and rod's length.

changes the position of the perceived CoG even though the position of the actual CoG is unchanged.

(ii) ANOVA (Tukey Kramer test) also found significant differences between the 100cm and 60cm rod conditions. This result shows that the participants perceived the position of the CoG of the virtually longer rod closer to the tip of the rod than that of actual 60cm rod. We, therefore, found that extending a rod using AR processing changes the position of the perceived CoG.

(iii) We analyzed the results to determine if there is a relationship between answered CoG positions, y, and lengths of the virtual modified rods, x, using linear regression analysis. Based on the results of the study, evaluation values are weakly related to lengths of the virtually modified rods: $y = 0.17x + 18.29(R^2 = 0.25)$ with $R^2 \geq 0.2$. From this result, **H4** is supported.

6 DISCUSSIONS

According to the results in Experiments 1 and 2, we observed correlations between the weight and length and between the CoG and the length of rods visually modified by AR and DR techniques. Concretely, these visuo-haptic relationships are continuous and linear among AR and DR. These results suggest that special compensations would not be needed for combining AR and DR techniques in the context of the visuo-haptic weight illusion. From this result, **H3** is supported.

Here, we should also consider the relationships between the weight and CoG. Under visual modifications to a real rod with AR and DR visual augmentation and diminishing, we confirmed that the rod felt lighter as the rod became longer. On the other hand, the position of the CoG shifted farther from the hand as the rod became longer. In other words, the shorter the rod became, the heavier the rod would be perceived. This fact is consistent with physical laws in our daily life in the context of the moment of inertia since the CoG is placed closer to the hand. In Experiment 1 on weight sensations, we observed significant differences between 20cm and 40cm rods, while not between 80cm and 100cm. Similar results are obtained in Experiment 2 on the CoG as well. What these results suggest is that weight sensations and CoG would have relationships, and illusions in CoG could induce illusions in weight sensations. From this result, **H5** is supported.

One of our research questions was to confirm that 'perceived weights can be where there is no entity after visually extending or shortening the object, or is it perceived within the entity in AR and DR visuo-haptic simulations?' In other words, one of our goals in this research was to clarify positions of the weight under AR and DR visual effects. In Experiment 2, the length of the physical rod was 60 cm, and for the 100 cm rods, the participants reported that they felt the position of the CoG at 50cm from their hands (without outliers). Therefore, The CoG was within the physical rod. On the other hand, the CoG for the 20cm rod in Experiment 2, one-third of the participants perceived weights out of the physical rod. These results suggest that the position of CoG can be changed only on the real object using visuo-haptic techniques. In this research, we changed only the length of the rod and did not change anything else. As the next step, we need to confirm the visuo-haptic illusions under other various conditions such as changing weights, length, and thickness of the physical rod.

7 CONCLUSIONS

In this paper, we built a system that can continuously extend and reduce the amount of visual entity of real objects using AR and DR renderings to confirm that users can perceive things heavier and lighter than they actually are in the same manner as SWI. Different from the existing research where either AR or DR visual effects were used, we validated one of cross-modal effects in the context of both continuous AR and DR visuo-haptic. Regarding the weight sensation, we found that such a cross-modal effect can be approximated with a continuous linear relationship between the weight and length of real objects. Therefore, we also suggested that no special compensation is required for the visuo-haptic illusions under such continuous AR-DR renderings. Our experimental results suggested that the weight sensation is closely related to the positions of the CoG and perceived CoG positions that lie within the object's entity under the examined conditions.

The future directions will include further clarifying relationships between the weight and CoG by increasing variations of visual modifications of AR and DR renderings such as the changing the sickness and the size of the objects. Changes in weight perceptions induced by the visuo-haptic illusions under AR and DR visual augmentations can influence the muscle activity level and fatigue. We would like to validate the relationship and develop AR-DR applications.

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REFERENCES

[1] Jean-Yves Bayart, Benjamin Didier and Abderrahmane Kheddar. 2008. Force feedback virtual painting on real objects: A paradigm of augmented reality haptics. In *EuroHaptics*. 776–785. https://doi.org/10.1007/978-3-540-69057-3_99

[2] Volkert Buchmann, Trond Nilsen, and Mark Billinghurst. 2005. Interaction with partially transparent hands and objects. In *Australasian Conf. on User interface*, Vol. 40. 17–20.

[3] A. Charpentier. 1891. Experimental study of some aspects of weight perception. *Archives de Physiologie Normales et Pathologiques* 3, 5 (1891), 122–135.

[4] Francesco Cosco, Carlos Garre, Fabio Bruno, Maurizio Muzzupappa, and Miguel A. Otaduy. 2013. Visuo-haptic mixed reality with unobstructed tool-hand integration. *IEEE Trans. on Vis. and Comput. Graph.* 19, 1 (2013), 159–172. https://doi.org/10.1109/TVCG.2012.107

[5] Eisuke Fujinawa, Shigeo Yoshida, Yuki Koyama, Takuji Narumi, Tomohiro Tanikawa, and Michitaka Hirose. 2017. Computational design of hand-held VR controllers using haptic shape illusion. https://doi.org/10.1145/3139131.3139160

[6] Paul Issartel, Guéniat Florimond, Sabine Coquillart, and Mehdi Ammi. 2015. Perceiving mass in mixed reality through pseudo-haptic rendering of Newton's Third Law. In *IEEE Virtual Reality*. 41–46. https://doi.org/10.1109/VR.2015.7223322

[7] Y. Koike, J. Kim, and S. Duk. 2006. Role of stiffness in weight perception. *Japanese Psychological Research* 48, 3 (2006), 174–187.

[8] A. Lecuyer, S. Coquillart, A. Kheddar, P. Richard, and P. Coiffet. 2000. Pseudo–haptic feedback: Can isometric input devices simulate force feedback?. In *Proc. IEEE Virtual Reality*. 83–90.

[9] Shohei Mori, Sei Ikeda, and Hideo Saito. 2017. A survey of diminished reality: Techniques for visually concealing, eliminating, and seeing through real objects. *IPSJ Trans. on Computer Vision and Applications* 9, 17 (2017). https://doi.org/10.1186/s41074-017-0028-1

[10] Hiroki Omosako, Asako Kimura, Fumihisa Shibata, and Hideyuki Tamura. 2012. Shape-COG illusion: Psychophysical influence on center-of-gravity perception by mixed-reality visual stimulation. In *Proc. IEEE Virtual Reality*. 65–66.

[11] Parinya Punpongsanon, Daisuke Iwai, and Kosuke Sato. 2015. SoftAR: Visually manipulating haptic softness perception in spatial augmented reality. *IEEE Trans. on Visualization and Computer Graphics (TVCG)* 21, 11 (2015), 1279–1288.

[12] I. Rock and C. S. Harris. 1967. Vision and touch. *Scientific American* 216, 5 (1967), 96–104.

[13] J. C. Stevens and L. L. Rubin. 1970. Psychophysical scales of apparent heaviness and the size-weight illusion. *Attention, Perception, & Psychophysics* 8, 4 (1970), 225–230.

[14] Yuki Taima, Yuki Ban, Takuji Narumi, Tomohiro Tanikawa, and Michitaka Hirose. [n. d.]. Controlling fatigue while lifting objects using pseudo-haptics in a mixed reality space. In *Haptics Symposium (HAPTICS)*.

[15] Miho Tanaka, Ayushi Misra, Kana Oshima, Satoshi Hashiguchi, Shohei Mori, Asako Kimura, Fumihisa Shibata, and Hideyuki Tamura. 2017. Further experiments and considerations on weight perception caused by visual diminishing of real objects. In *Proc. Int. Symp. on Mixed and Augmented Reality (ISMAR)*. 160–161.

[16] André Zenner and Antonio Krüger. 2017. Shifty: A weight-shifting dynamic passive haptic proxy to enhance object perception in virtual reality. *IEEE Trans. on Vis. and Comput. Graph.* 23, 4 (2017), 1285–1294. https://doi.org/10.1109/TVCG.2017.2656978