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Original Article

The acute effect of throwing training with virtual reality on boccia competitive performance in healthy adults

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Abstract. [Purpose] This study aimed to investigate the differences in the acute effects of virtual and actual throwing training on throwing performance. [Participants and Methods] Twenty healthy men and six women with no boccia experience were randomly divided into the virtual and non-virtual groups. The task involved throwing boccia balls at target sets of 2 (short), 5 (middle), and 9 m (long). Both the groups were trained in three rows for each condition. The distance from the ball to the target was calculated as throwing accuracy for both pre- and post-training. Confidence in throwing was measured using a visual analog scale pre-and immediately post-training. A two-way analysis of variance with a post-hoc Bonferroni test or t-test was conducted for throwing accuracy and confidence. [Results] For throwing accuracy, the post hoc test results showed that both groups improved after training, but only in the middle-distance throw. Throwing confidence improved after training in both groups. [Conclusion] Boccia-throwing training using virtual reality may have an acute training effect comparable to that of actual training.

Key words: Boccia, Throwing performance, Virtual reality

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INTRODUCTION

Boccia is a sport designed for individuals with severe disabilities; in a survey conducted in Japan in 2021, boccia was played in the highest percentage (68.1%) of facilities dedicated to or prioritized for individuals with disabilities and has recently become popular in Japan[1)]. In boccia, players compete to see how close they can place a boccia ball (ball) on a target ball called a jackball. Therefore, improving throwing accuracy is important to improve the performance of boccia players[2)]. Players train in the gymnasium to improve their throwing accuracy. However, individuals with disabilities who play boccia have difficulty with mobility, which often limits their participation in training[3)].

Virtual reality (VR) creates virtual space to immerse players in, mirroring reality[4)]. VR facilitates confidence because it enables successful experiences to be reproduced, allowing the player to concentrate on the task without fear of failure[5)]. In table tennis, the hitting performance of a group of healthy adults training in VR improved more than that of a group not practicing at all[6)]. Thus, throwing training with VR potentially improves throwing accuracy and confidence in throwing (confidence) without visiting a training location. However, whether VR training is more instantly effective than non-VR training in boccia throwing accuracy and confidence is unclear.

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This study aimed to investigate differences in the effects of VR throwing training and conventional throwing training using only a boccia ball (ball) on throwing accuracy and confidence in young healthy adults with no boccia experience. The effectiveness of VR in boccia training in young healthy adults could contribute to the application of VR as a training tool for boccia players with disabilities. The hypotheses were as follows: (1) the group VR training would have better throwing accuracy and confidence than the group training only with the ball, and (2) the higher the confidence and immersion during VR training, the better the throwing accuracy.

PARTICIPANTS AND METHODS

This study comprised 26 healthy adults (20 men and 6 women) with no previous boccia experience. All the participants were right-handed. The participants were randomly divided into two groups of 13 (10 men and 3 women). One group trained throwing with VR (VR group), and the other trained throwing only with a ball without VR (non-VR group). The demographic data for the participants were as follows (mean ± standard deviation [SD]): VR group (age [21.5 ± 1.9 years], body mass [59.7 ± 10.5 kg], height [166.6 ± 9.2 cm]) and non-VR group (age [21.8 ± 1.5 years], body mass [58.8 ± 9.6 kg], height [167.0 ± 8.3 cm]). The inclusion criteria were as follows: (1) no orthopedic disease of the upper or lower limbs or trunk within the last 6 months, (2) no previous experience of boccia, and (3) no history of visually induced motion sickness. The exclusion criteria were as follows: (1) with corrected visual acuity of ≤0.5 and difficulty viewing VR video and (2) with difficulty viewing VR video or performing the task movements due to physical illness or pain on the day of measurement. According to the Declaration of Helsinki, the purpose and methods of the study were fully explained to the participants, and their written consent was obtained. This study was approved by the Ethical Committee for Epidemiology of Hiroshima University (approval number: E2023-0416).

The protocol used in this study is illustrated in Fig. 1. As a warm-up, the participants were trained in throwing movements using a ball (Handi Life Classic 12-panel model; Handi Life Sport, Skibby, Denmark) for 5 min. Throwing accuracy and confidence were measured as pre-training and post-training.

The task was to perform underhand throws with the ball grasped from above in a seated position. Three throwing distances were set for each group: 2 m (short), 5 m (middle), and 9 m (long)[7]. A circular piece of paper with a 270-mm circumference, the same standard as the ball, was placed as the target at the end of a straight line from the zero-throw line for each condition. The participants threw 15 balls in total, with five balls in each condition. The balls were thrown in a random order.

In the VR group, the participants wore a head-mounted display (HMD) (Meta Quest 2; Meta Corporation, Menlo Park, CA, USA) and were trained to throw the balls by timing the movements of their upper limbs in the VR video as much as possible while watching VR videos of the throwing motion. VR video was shot from a first-person perspective using a 360° camera (Insta 360 ONE X2, Shenzhen Arashi Vision, Shenzhen, China). Furthermore, the VR video showed that the thrown ball was attached to the target in each condition, i.e. the ball was accurately approaching the target. The non-VR group was trained to throw using only the ball. Both groups drew nine balls, with three balls for each condition (Fig. 2).

Throwing accuracy was calculated as the distance from the target to the ball (cm). Throwing accuracy was measured by taking images of the target and ball positions in each task movement from above with a smartphone (iPhone 14, Apple Inc.,

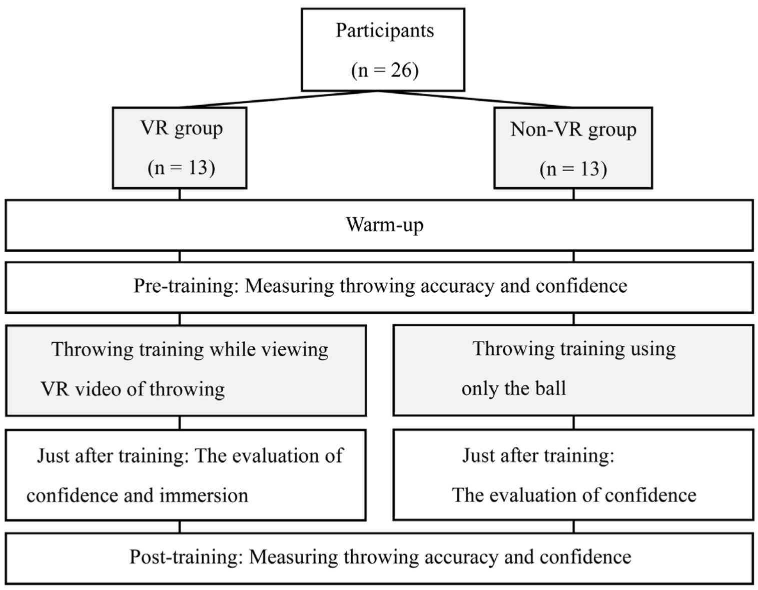

Fig. 1. The protocol in this study. VR: virtual reality.

Cupertino, CA, USA). It was calculated from the images taken using the image analysis software Image J ver. 1.53 (National Institute of Health, Bethesda, MD, USA). A measuring tape (Million Open OTR30, Yamayo Measuring Machine Co., Ltd., Tokyo, Japan) was included in the image, and the unit was set to cm based on the measuring tape in the image. The mean, maximum (max), and coefficient of variation (%: CV) were determined as an index of throwing accuracy from three of the five throws under each condition, excluding the maximum and minimum values. CV was calculated from the mean and SD. The ratio of throwing accuracy pre- and post-training (%: post-/pre-ratio) was calculated. Confidence was assessed using the visual analog scale (VAS) pre- and post-training and immediately after training (just after training)[8]. Immersion evaluation (how much the participants felt they were throwing in the VR video) was conducted at training of the VR group using the VAS, as was their confidence. Confidence and immersion scores were considered higher the closer the score was to 100 mm.

SPSS version 29.0 for Mac (IBM Corporation, Armonk, NY, USA) was used for the statistical analyses. The Shapiro–Wilk test was used to confirm the normality of each measurement item. To compare the throwing accuracy between the VR and non-VR groups, a two-way analysis of variance (ANOVA) was performed with group (VR and non-VR groups) and time (pre- and post-training) as factors. To compare the confidence between the VR and non-VR groups, a two-way ANOVA was performed with group (VR and non-VR groups) and time (pre-, post-training, and just after training) as factors. Post-hoc analyses via a Bonferroni or t-test were performed when necessary. The Pearson product–rate correlation coefficient was used to confirm the relationship between the VR group's confidence just after training and the post-/pre-ratio, and the VR group's sense of immersion and the post-/pre-ratio, when normality was found, and Spearman's rank correlation coefficient when normality was not found. The level of significance was set to 5%.

RESULTS

Table 1 presents measurement of throwing accuracy and the results of the two-way ANOVA. Regarding throwing accuracy, only the CV of the long throw showed an interaction ($p<0.05$). Post-training results showed significantly lower values in the non-VR group than in the VR group ($p<0.01$). The non-VR group was significantly lower in post-training than in pre-training ($p<0.05$). The main effect of time was found for the mean and max values of the middle and long throws ($p<0.05$). The post-hoc-test results showed that the mean and max values of middle and long throws were significantly lower post-training than pre-training in both groups ($p<0.05$).

Table 2 shows the results of two-way ANOVA for each measure of confidence. No significant interaction was found ($p=0.585$), but there was a significant main effect of time ($p<0.01$). Post-hoc-test results showed significantly higher values for just after training and post-training compared with pre-training (respectively $p<0.05$).

No significant correlation was found between the post-/pre-ratio and confidence in the VR group (mean post-/pre-ratio [short: $r=-0.287$, $p=0.342$; middle: $r=-0.239$, $p=0.432$; long: $r=-0.213$, $p=0.485$], max post-/pre-ratio [short: $r=-0.515$, $p=0.072$; middle: $r=-0.173$, $p=0.571$; long: $r=-0.277$, $p=0.359$], CV post-/pre-ratio [short: $r=-0.468$, $p=0.107$; middle: $r=0.033$, $p=0.915$; long: $r=-0.151$, $p=0.622$].

The immersion score just after training for the VR group was 59.8 ± 19.2 mm, and there was no significant correlation among the immersion score and the mean post-/pre-ratio (short: $r=0.118$, $p=0.702$; middle: $r=0.024$, $p=0.939$; long: $r=-0.268$, $p=0.376$), max post-/pre-ratio (short: $r=0.173$, $p=0.571$; middle: $r=0.093$, $p=0.763$; long: $r=-0.268$, $p=0.376$), and CV post-/pre-ratio (short: $r=0.286$, $p=0.343$, middle: $r=0.278$, $p=0.358$, long: $r=0.091$, $p=0.768$).

DISCUSSION

This study investigated the differences in the effects of throwing training with VR and throwing training with a ball only on throwing accuracy and confidence in young healthy adults with no previous boccia experience. Contrary to our

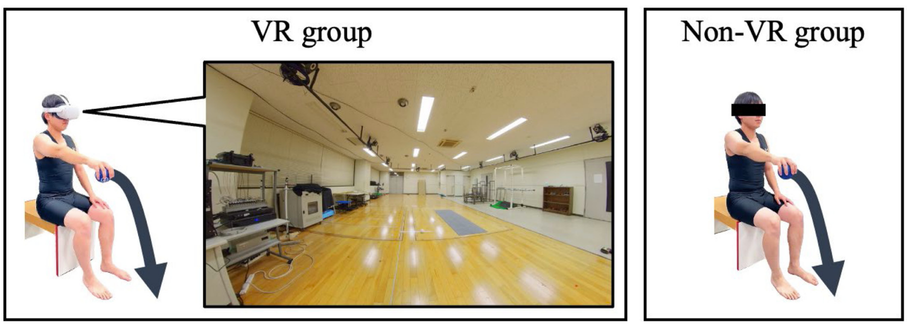

Fig. 2. Throwing training in the VR and non-VR groups.
The VR group was trained to throw by timing the movements of the upper limbs in the VR video while watching the first-person VR video of the throwing motion. The non-VR group was trained to throw using only the ball. VR: virtual reality.

Table 1. Comparison of throwing accuracy between group and time as factors by two-way ANOVA

		VR (n=13)		Non-VR (n=13)	
		Pre	Post	Pre	Post
Short	Mean (cm)	26.7 ± 11.3	24.4 ± 11.9	25.3 ± 15.2	22.0 ± 11.1
	Max (cm)	37.1 ± 15.9	34.8 ± 14.5	35.8 ± 17.1	32.4 ± 14.8
	CV (%)	42.8 ± 38.0	48.3 ± 24.2	49.9 ± 36.9	55.3 ± 27.8
Middle	Mean (cm)	50.8 ± 14.1	31.9 ± 15.8*	49.1 ± 21.4	37.8 ± 16.2*
	Max (cm)	71.1 ± 16.9	42.7 ± 18.0*	66.0 ± 24.0	50.5 ± 19.6*
	CV (%)	39.9 ± 17.1	38.3 ± 19.1	38.0 ± 20.6	36.1 ± 22.7
Long	Mean (cm)	87.7 ± 31.0	72.5 ± 29.0*	93.9 ± 23.6	80.6 ± 23.9*
	Max (cm)	115.8 ± 33.2	104.4 ± 39.5*	126.6 ± 25.7	97.5 ± 27.9*
	CV (%)[+]	34.7 ± 24.0	45.0 ± 19.2	37.9 ± 16.1	26.0 ± 13.4[a, b]

Values are presented as the mean ± standard deviation (SD), *: Statistically significant main effect of the time ($p<0.05$), [+]: Statistically significant interaction (group × time) effect ($p<0.05$), [a]: Difference between post-training CV in VR and post-training CV in Non-VR group ($p<0.01$), [b]: Difference between pre-training CV in Non-VR and post-training CV in Non-VR group ($p<0.05$).
ANOVA: analysis of variance; VR: Virtual reality; CV: Coefficient of variation.

Table 2. Comparison of confidence between group and time as factors by two-way ANOVA

	VR (n=13)			Non-VR (n=13)		
	Pre	Training	Post	Pre	Training	Post
Confidence	35.5 ± 13.6	50.2 ± 12.2**	52.6 ± 18.3**	38.5 ± 15.3	52.2 ± 15.4**	47.3 ± 18.6**

Values are presented as the mean ± standard deviation (SD), **: Statistically significant main effect of the time ($p<0.01$).
ANOVA: analysis of variance; VR: Virtual reality.

hypothesis, throwing accuracy in the VR group improved post-training in both groups under moderate conditions. The throwing confidence improved in both groups after throwing training. There were no significant correlations between throwing accuracy and confidence in throwing, or between throwing accuracy and immersion.

The throwing accuracy in the short throw did not change between groups or between time. Regardless of whether VR was used, it is necessary to set the difficulty of the task movement in consideration of the skill level of the participant during training[9]. Therefore, we assume that the short condition did not show any training effect in either group because the participants were able to easily throw the target close to them, even before the throwing training.

In the middle, both groups showed improved throwing accuracy after throwing training. In the motor learning of sports movements, the linkage between body image and movement is important and the use of feedback is effective[10]. In the motor learning of sports movements using VR, movement patterns can be accurately learned by visually presenting movement trajectories[11]. In the VR group, the physical movements of the upper limbs during the throwing motion could be recognized in the VR space by practicing throwing while watching VR videos from a first-person perspective using an HMD. Viewing VR videos of the ball accurately approaching the target object led to the learning of the trajectory of the throwing motion, which may have improved throwing accuracy. In contrast, the non-VR group obtained visual feedback from the path of the thrown ball through throwing training. Thus, we propose that the non-VR group learned motion from the visual feedback and improved their throwing accuracy.

In the long throw, throwing accuracy improved in post-training only in the non-VR group. One of the limitations of VR is that the depth of the space may be perceived more incorrectly than in the non-VR condition[12]. A target 9 m away cannot be accurately recognized in VR videos because the depth in the VR space is not easily perceived.

Confidence improved after throwing training in both groups ($p<0.05$). No significant correlation was found between confidence after throwing training and the post-/pre-ratio of throwing accuracy. Repeated successful experiences increase confidence in task movements[13]. Furthermore, in training using VR, training effects are more likely to be obtained when a participant's confidence improves[14]. The confidence of the VR group increased after watching VR videos and repeating successful experiences, and it is possible that the training effect was comparable to that of the non-VR group in terms of throwing accuracy. Further studies focusing on confidence and throwing accuracy are required to clarify the factors that improve throwing accuracy during training with VR.

The immersion score of the present study was 59.8 ± 19.2 mm, and no significant correlation was found between the immersion scores after throwing training and the post-/pre-ratio of throwing accuracy in the VR group. Compared with the immersion scores in a previous study using VR for prosthetic walking training (71.5 mm), the immersion in the present study was not high[15]. To increase immersion, VR feedback in accordance with the movement of the participant is necessary[16]. In this study, the participants only performed throwing movements according to the VR videos, and the movements of the target were not reflected in these videos, which we consider as having failed to enhance the sense of immersion.

The above results suggest that throwing training in combination with VR improves throwing accuracy and confidence. However, contrary to this hypothesis, it could not be stated that throwing training with VR improved throwing accuracy or confidence compared with throwing training without VR; further consideration of the VR video settings is required to increase the immersive experience to generate further training effects of throwing training with VR. The results of the middle of this study suggest that training using VR is comparable to training using only a ball, and VR can potentially be used as a new training method to improve the accuracy of boccia throwing if the settings of VR videos are considered. Moreover, training using VR, which is not affected by the training environment, can lead to the expansion of the training environment for individuals with disabilities playing boccia, whose participation in conventional training is likely to be limited.

This study has some limitations. First, only the acute effects of the VR throwing training were investigated. The long-term effects of throwing training have not been fully investigated and cannot be determined from the results of this study. Second, the kinematic mechanism of the changes in throwing accuracy following VR-based throwing training is unclear. Third, the sample size is small. A larger study is needed to clarify the application of VR as boccia training in more detail. It is necessary to confirm the effects of VR training in different participants, such as experienced boccia players, and to confirm long-term training effects from multiple perspectives by conducting kinematic measurements.

In conclusion, boccia throwing training using VR potentially produces acute training effects comparable to those of conventional training, and VR could contribute to the expansion the training environment as a new training tool for boccia players, including those with disabilities. To generate further training effects, it is necessary to focus on immersive experiences and develop a VR setting environment.

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Conflict of interest

There are no conflicts of interest to declare.

REFERENCES

1) Japan Boccia Association: About Boccia. https://www.japan-boccia.com/about/ (Accessed Apr. 2, 2024)
2) Koper M, Nadolska A, Urbański P, et al.: Relationship between pre-competition mental state and sport result of disabled boccia athletes. Int J Environ Res Public Health, 2020, 17: 8232. [Medline] [CrossRef]
3) Bezyak JL, Sabella S, Hammel J, et al.: Community participation and public transportation barriers experienced by people with disabilities. Disabil Rehabil, 2020, 42: 3275–3283. [Medline] [CrossRef]
4) Ahmadpour N, Randall H, Choksi H, et al.: Virtual reality interventions for acute and chronic pain management. Int J Biochem Cell Biol, 2019, 114: 105568. [Medline] [CrossRef]
5) Bing EG, Brown ML, Cuevas A, et al.: User experience with low-cost virtual reality cancer surgery simulation in an african setting. JCO Glob Oncol, 2021, 7: 435–442. [Medline] [CrossRef]
6) Michalski SC, Szpak A, Saredakis D, et al.: Getting your game on: using virtual reality to improve real table tennis skills. PLoS One, 2019, 14: e0222351. [Medline] [CrossRef]
7) Reina R, Domínguez-Díez M, Urbán T, et al.: Throwing distance constraints regarding kinematics and accuracy in high-level boccia players. Sci Sports, 2018, 33: 299–306. [CrossRef]
8) Yoshimura M, Kurumadani H, Hirata J, et al.: Virtual reality-based action observation facilitates the acquisition of body-powered prosthetic control skills. J Neuroeng Rehabil, 2020, 17: 113. [Medline] [CrossRef]
9) Guadagnoli MA, Lee TD: Challenge point: a framework for conceptualizing the effects of various practice conditions in motor learning. J Mot Behav, 2004, 36: 212–224. [Medline] [CrossRef]
10) Yamada H, Tanaka S, Kimura S, et al.: Connecting scientific knowledge to sports skill improvement: biomechanisms of sensory-motor learning. J Soc Biomechanisms, 2021, 45: 71–74 (in Japanese).
11) Kawamura S: VR for sports skill improvement. Trans Virtual Real Soc Jpn, 2002, 7: 8–15 (in Japanese).
12) Kiyokawa K: Head-mounted display. J Inst Image Inf Telev Eng, 2015, 69: 825–828 (in Japanese).
13) Stepan K, Zeiger J, Hanchuk S, et al.: Immersive virtual reality as a teaching tool for neuroanatomy. Int Forum Allergy Rhinol, 2017, 7: 1006–1013. [Medline] [CrossRef]
14) Tieri G, Morone G, Paolucci S, et al.: Virtual reality in cognitive and motor rehabilitation: facts, fiction and fallacies. Expert Rev Med Devices, 2018, 15: 107–117. [Medline] [CrossRef]
15) Fukui K, Maeda N, Komiya M, et al.: Walking practice combined with virtual reality contributes to early acquisition of symmetry prosthetic walking: an experimental study using simulated prosthesis. Symmetry (Basel), 2021, 13: 2282. [CrossRef]
16) Cipresso P, Giglioli IA, Raya MA, et al.: The past, present, and future of virtual and augmented reality research: a network and cluster analysis of the literature. Front Psychol, 2018, 9: 2086. [Medline] [CrossRef]