THE VALIDITY OF USING VIRTUAL REALITY HEAD-MOUNTED DISPLAY FOR AGILITY TRAINING

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Virtual reality (VR) provides a fully controlled environment with the potential of making sports training easier. However, to date very few studies concerned creating a locomotion training environment enabling multi-directional movements for mimicking realistic locomotion. This study aims to investigate the validity of using low-cost VR head-mounted display (HMD) for agility training in a virtual environment (VE) for 'real-walking' locomotion. Three male college participants (age: 24.00±1.00years, height: 1.68±0.09m, weight: 65.63±4.65kg) participated in this study. They completed two agility ladder training tasks: the forward and backward icky shuffle, in the real environment (RE) and VE. The correlations of the segment trajectories in the RE and VE were calculated. The correlations of the segment trajectories between the two environments were also calculated. The *z*-test results showed that no significant difference was obtained in the consistency of the movements between the two environments. High correlations in the segment trajectories were obtained between the virtual and real training environment. The results indicated that it is feasible to use VR HMD for agility training.

KEYWORDS: biomechanics, virtual environment, agility ladder, real-walking locomotion.

INTRODUCTION: Virtual reality (VR) aims to give the participants a sense of presence (mentally or physically) in an interactive computer-simulated environment, by acquiring some meaningful inputs from the participants (e.g. positions and actions) and converting the feedback to one or more senses (Sherman and Craig, 2003). Since 2013, many of low-cost VR head-mounted displays (HMDs) have been developed. They have overcome many previous restrictions for reviving the focus on VR (Boletsis, 2017; Olszewski, Lim, Saito, & Li, 2016). There are many advantages of using VR in sports training. For example, every single parameter in the virtual environment (VE) can be accurately controlled and tuned; extra information and guide can be given instantly; players' viewpoints can be updated in realtime by coaches; and the training scenarios (simulated equipment and people) can change quickly to match any competitive situation (Bideau et al., 2010; Miles, Pop, Watt, Lawrence, & John, 2012). The existing studies in VR mainly focused on endurance sports, e.g. cycling, rowing and running, etc. One reason is that these sports can be translated into VE easily (Neumann et al., 2017). However, in reality many ball sports (such as football, basketball, volleyball, and tennis) contain patterns of randomized intermittent, dynamic, and skilled movements (RIDS) (Bloomfield, Polman, O'donoghue, & McNaughton, 2007). Although some studies focused on using VR in ball sports training, they usually chose 'walking-in-place', 'controllers/joysticks' or 'gesture-based' locomotion techniques to control the movements in VE, but not 'real-walking' locomotion (Boletsis, 2017). Meanwhile, agility training has been validated as one effective conditioning training method for RIDS sports (Bloomfield, Polman, O'donoghue, & McNaughton, 2007). To the best of our knowledge, research focusing on agility training VE that contains multi-directional movements with fully immersive VR HMD has not been conducted. Therefore, this study aims to investigate the validity of using VR HMD in agility training with a 'real-walking' locomotion VE.

METHODS: Three male college students (age: 24.00±1.00years, 1.68±0.09m, 65.63±4.65kg) were recruited in this study. All of them have a normal or corrected-to-normal vision, and did not report any neurological disorder or musculoskeletal injury within the last six months. This study has been approved by the National Cheng Kung University Governance Framework for

Human Research Ethics, and all participants signed the informed consent before the experiment. A piece of 3.5m×2m artificial grass was placed in the laboratory on which a 4.5m×1m agility ladder was laid (Fig.1). The HTC Vive system (HTC, Taiwan) was used to provide an immersive environment for the participants in this study. It provides a room-scale play area up to 4m×3m. A VE was rendered through Unity3D (Unity Technology, USA), a cross-platform game engine, with the same experimental setup as in the real environment (RE) (Fig.2). The HTC Vive HMD provides a combined resolution of 2160 × 1200 pixels, with a refresh rate of 90 Hz. The field of view (FOV) is about 110˚. During the experiment, the participants were asked to perform a common agility ladder training: the icky shuffle, in both forward and backward directions (Fig. 3). Each participant completed six trials (three forward and three backward) in both the RE and VE. Ten reflective markers were placed on both sides of anterior superior iliac spine (ASIS), greater trochanters, lateral knees, ankles and the fifth metatarsal-phalangeal joints of the participants. Three high-speed cameras (Basler AG, acA800-510uc, Germany, 250Hz) were used to collect the kinematics data. All data were digitized using Kwon3D software, and were low-pass filtered by a 4^{th}-order Butterworth Filter, with a cut-off frequency of 6Hz. The displacement of the centre of mass (COM) of each lower extremity segment of a complete cycle in each trial, in both lateral-medial (Y-axis) and vertical (Z-axis) axes, were calculated by Kwon3D software. We calculated the correlations of the displacement of the COM of the segments that performed in the RE (i.e. C_R) and VE (i.e. C_{VR}), respectively. Moreover, the correlations of the displacement of the COM of the segments between the RE and VE were calculated as $C_{R\text{-}VR}$. Since the correlation coefficients cannot be directly averaged and tested for the difference, each correlation was first altered by Fisher's *z* transformation, and the difference between C_R and C_{VR} was evaluated by the *z*-test. All statistical analysis was performed with SPSS 18.0 (IBM, USA) and Microsoft Excel 2016. The significant level was set at .05.

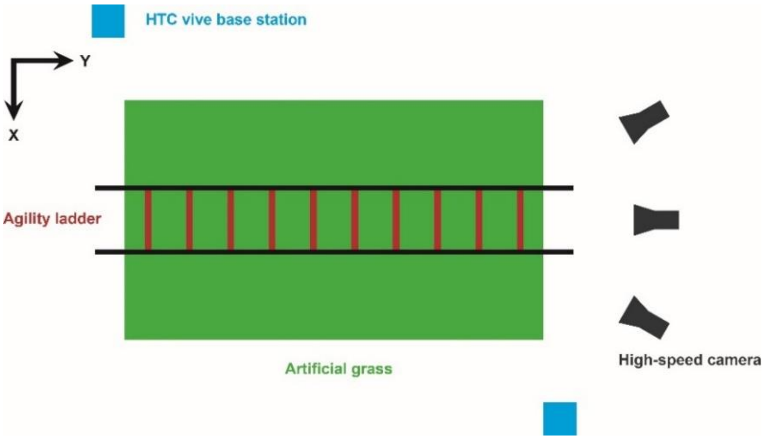

Figure 1: Experimental setup

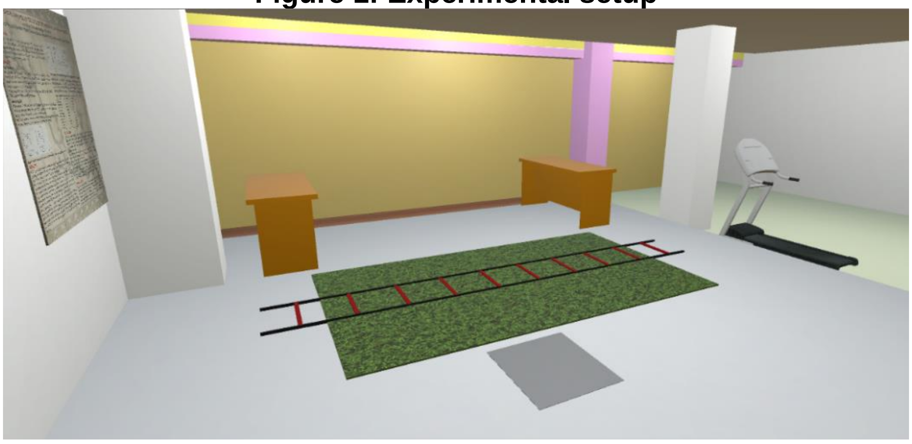

Figure 2: The virtual environment

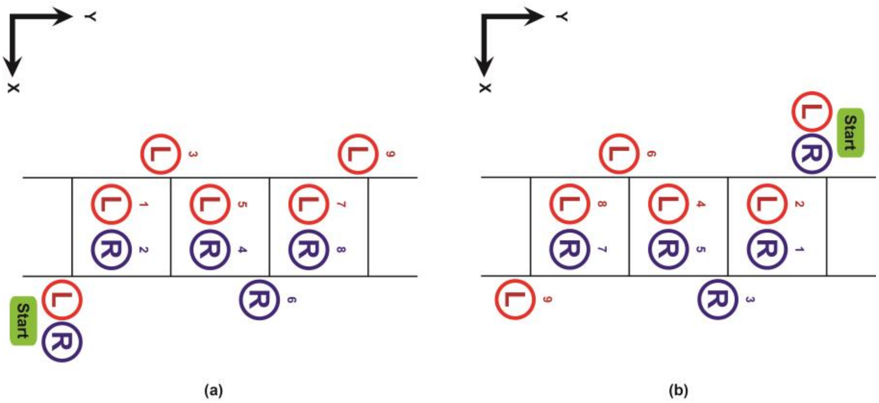

Figure 3: (a) Forward icky shuffle, (b) Backward icky shuffle.

RESULTS: The correlation coefficients of the segment trajectories in RE, VE, and between the two environments, and their *z* values after fisher's z transformation were shown in Table1. First, we calculated the correlations ($C_{R\text{-}VR}$) of the segment trajectories between the RE and VE to investigate the similarity of the movements between the two different environments. The high correlations from 0.97 to 0.98 in Y-axis, and from 0.76 to 0.88 in Z-axis were obtained.
Second, C_R and C_{VR} that represent the consistency of the movement when the participants performed their agility training in the same environment were also calculated. C_R obtained high correlation 0.98 in Y-axis, and vary from 0.84 to 0.93 in Z-axis, while C_{VR} obtained high correlation 0.97 in Y-axis, and from 0.81 to 0.90 in Z-axis. By calculating *z*-test after transforming all the correlations to *z* value, none of the Z value were greater than or equal to 1.96, or less than or equal to -1.96, this indicates that no significant difference between the two environments in the consistency of the movement at the 0.05 level.

Table 1. The correlation coefficients of the displacement of the COM of segments in RE, VE, and between the two environments.

Segment		Axis	$C_{R\text{-}VR}$	C_R (Z_R)	C_{VR} (Z_{VR})	*Z*
Foot	Left	Y-axis	0.97	0.98 (2.21)	0.97 (2.12)	-0.24
		Z-axis	0.76	0.84 (1.23)	0.81 (1.13)	-0.29
	Right	Y-axis	0.97	0.98 (2.34)	0.97 (2.13)	-0.58
		Z-axis	0.78	0.88 (1.37)	0.85 (1.26)	-0.28
Shank	Left	Y-axis	0.97	0.98 (2.24)	0.97 (2.06)	-0.49
		Z-axis	0.80	0.89 (1.44)	0.83 (1.19)	-0.68
	Right	Y-axis	0.97	0.98 (2.31)	0.97 (2.15)	-0.44
		Z-axis	0.80	0.93 (1.31)	0.85 (1.27)	-0.11
Thigh	Left	Y-axis	0.98	0.98 (2.34)	0.97 (2.15)	-0.52
		Z-axis	0.88	0.93 (1.62)	0.90 (1.47)	-0.41
	Right	Y-axis	0.98	0.98 (2.34)	0.97 (2.13)	-0.58
		Z-axis	0.83	0.87 (1.35)	0.88 (1.38)	0.07

DISCUSSION: The technology of VR is growing rapidly, with a large range of applications in different fields. The present study applied VR technology to agility training. By comparing the correlations of the movements, we can investigate differences in segment trajectories, but the results cannot reflect constant translations between the movements due to the difference in segment initial positions (Bideau et al., 2004).
High C_R and C_{VR} correlations indicate that the participants repeated almost the same movements under the same task, and their movements in the VE are as consistent as in the RE, since no significant difference was found between the two environments. The slightly lower correlations in VE can be explained as the result of using VR HMD on dynamic balance. Robert, et al. (2016) concluded that VR HMD induces greater displacements of centre of pressure (COP) in dynamic balance and more complex balance conditions, which leads to larger body sway. This effect could possibly be explained by the sensorimotor conflict and

poorer postural control due to the use of HMD. Meanwhile, high $C_{R\text{-}VR}$ correlations indicate that the movements in the VE are very similar to those in the RE. However, relatively lower correlations and higher deviations in the vertical axis than in the lateral-medial axis were obtained. It means that the participants have poorer reproducibility in the vertical movements, especially in the VE. This could be explained by the inaccurate distance judgments of the ground level in the VE. Many previous studies have shown the significant underestimation of absolute distance in VE, especially when using HMD. In addition, in this preliminary study, we only displayed the feet of the participants in our VE, but not the whole body. Further investigation should examine whether displaying the whole body of the participants improves estimation of the distance to the ground, i.e. improve the correlations in vertical axis.
Lastly, all the participants reported that they feel uncomfortable with the bulky HMD during the tasks. They think the vibration of the HMD and the limited FOV affected their performance. It is suggested to better fixate the HMD, and further experiment about the effect of the FOV on the performance should be examined in the future.

CONCLUSION: The present pilot study demonstrates that it is feasible to use VR HMD to develop an agility training VE for healthy adults.
Further experiments are needed to investigate the effect on other user groups, and the effect of transfer of training when using VR for agility training. Our ultimate goal is to develop a training VE for RIDS sports like football and basketball, with ‘real-walking’ locomotion just the same as in real world training. With the advantages of using VR in sports training, researches, coaches and athletes will able to have a better training quality in the future.

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