Original Article

Comparison of Oculus Rift and HTC Vive: Feasibility for Virtual Reality-Based Exploration, Navigation, Exergaming, and Rehabilitation

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Abstract

Introduction: The latest generation of head-mounted displays (HMDs) provides built-in head tracking, which enables estimating position in a room-size setting. This feature allows users to explore, navigate, and move within real-size virtual environments, such as kitchens, supermarket aisles, or streets. Previously, these actions were commonly facilitated by external peripherals and interaction metaphors.

Objective: The objective of this study was to compare the Oculus Rift and the HTC Vive in terms of the working range of the head tracking and the working area, accuracy, and jitter in a room-size environment, and to determine their feasibility for serious games, rehabilitation, and health-related applications.

Materials and Methods: The position of the HMDs was registered in a 10×10 grid covering an area of $25\,m^2$ at sitting (1.3 m) and standing (1.7 m) heights. Accuracy and jitter were estimated from positional data. The working range was estimated by moving the HMDs away from the cameras until no data were obtained.

Results: The HTC Vive provided a working area ($24.87\,m^2$) twice as large as that of the Oculus Rift. Both devices showed excellent and comparable performance at sitting height (accuracy up to 1 cm and jitter <0.35 mm), and the HTC Vive presented worse but still excellent accuracy and jitter at standing height (accuracy up to 1.5 cm and jitter <0.5 mm). The HTC Vive presented a larger working range (7 m) than did the Oculus Rift (4.25 m).

Conclusion: Our results support the use of these devices for real navigation, exploration, exergaming, and motor rehabilitation in virtual reality environments.

Keywords: Virtual reality, Head-mounted display, Serious games, Rehabilitation, Exergaming, Navigation

Introduction

VIRTUAL REALITY (VR) is defined as the simulation of an environment or activity through the real-time stimulation of one or more sensory channels, thus allowing for real-time user interaction.[1] Since VR's very beginnings, its feasibility and concept have been linked to existing technologies for stimulation and interaction. Actually, the characteristics of the technology have been shown to modulate immersion, the extent to which VR is capable of delivering an illusion of reality to a human participant's senses.[2] This immersion, in turn, affects presence, the sense of being in the virtual environment.[2,3] Given the importance of sight in human perception,[4] anatomically evidenced by the large number of brain areas involved in visual processing and cross-modal

association,[5] most development efforts have focused on improving visual stimulation. Traditional VR settings involve projected display screens that completely surround the viewer, known as Cave automatic virtual environment or CAVE systems,[6] or display screens fixed to the head near the eyes that completely substitute real-world input with computer-generated media, known as head-mounted displays (HMDs).[7]

The technology-mediated simulation of enriched ecologically valid environments and the provision of controlled sensory stimulation are especially interesting for serious games, rehabilitation, and health-related applications.[1] However, adapting VR for rehabilitation has revealed some weaknesses, such as the side effects of display characteristics, as well as obstacles, such as the cost/benefit of the technology, that prevent its adoption in most rehabilitation centers.[8]

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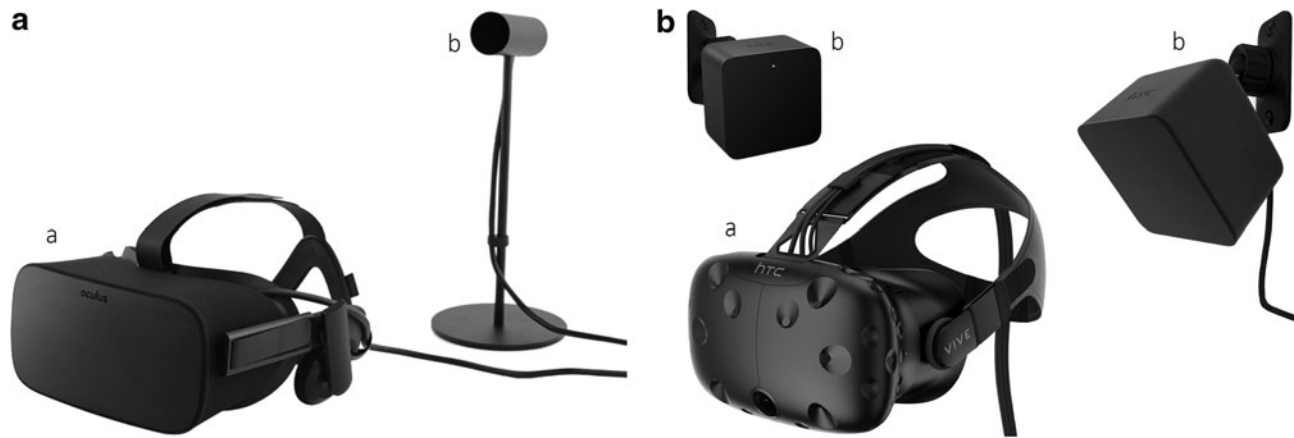
FIG. 1. Two last-generation head-mounted displays, the **(a)** Oculus Rift and **(b)** the HTC Vive, were analyzed in this study. Both devices consisted of a display **(a)** and a tracking module **(b)**.

Concurrent with the renewed interest in VR,[9] an increasing number of systems have been presented in the past years.[10–13] As described by the manufacturers, these new devices provide improved features, such as higher resolution, faster refresh rate, and wider field of view, at dramatically lower costs than early systems. In addition, new HMDs include built-in tracking mechanisms to estimate the position and orientation of the head in real time, which enables perspective correction and allows users to freely move, at least to some extent, as in the real world in a room-size environment. From the clinical point of view, the possibility to move and walk as in the real world could maximize the ecological validity of virtual environments and tasks that require users to move, such as walking and navigating simulations or exergaming and serious games for motor rehabilitation.[14–17] These tasks could also increase skill transference from the virtual to the real world.[18] Although the HMDs' tracking features might be determinant for these applications, their characteristics and feasibility still remain unknown.

The objective of this study was threefold: (1) to compare the working area, accuracy, and jitter of the head tracking of two of the most renown last generation HMDs, the Oculus Rift Consumer Version 1 (Oculus VR, Irvine, CA) and the HTC Vive (HTC Corporation, Taoyuan City, Taiwan) in a room-size setting; (2) to determine the working range of both devices; and (3) to model the dependence of the accuracy of the head tracking systems with distance.

Materials and Methods

Instrumentation

This study involved both the Oculus Rift and the HTC Vive (Fig. 1). The characteristics of both headsets have been provided by their manufacturers (Table 1) and can also be

TABLE 1. COMPARISON OF THE SPECIFICATIONS OF OCULUS RIFT AND HTC VIVE

	Oculus Rift	*HTC Vive*
Display	OLED	OLED
Display size	90 mm × 2456 ppi	91.9 mm × 2447 ppi
Resolution	2160 × 1200 pixels	2160 × 1200 pixels
Refresh rate	90 Hz	90 Hz
Field of view		
Horizontal	94°	110°
Vertical	93°	113°
Lens type	Fresnel	Fresnel
Lens adjustment	IPD (58–72 mm), lens-to-eye distance (adjustable with optional glasses spacer)	IPD (60.8–74.6 mm), lens-to-eye distance (''eye-relief'' adjustment)
Sensors	Accelerometer, gyroscope, magnetometer	Accelerometer, gyroscope
Integrated camera	No	Yes
Audio	Microphone, integrated supra-aural 3D spatial audio headphones (removable)	Microphone, jack for external headphones
Wireless	Bluetooth	Bluetooth
Ports	Proprietary headset connector (HDMI/USB 3.0)	HDMI 1.4, USB 3.0 × 2
Materials used	Plastic, IR-transparent fabric, glass, foam rubber	Plastic, glass, foam rubber
Weight (excluding cable)	470 g	563 g

The table describes the characteristics of the head-mounted displays used in the study.

found elsewhere.[19] Regarding tracking, the Oculus Rift uses a microphone-shaped IR camera designed to be fixed on a conventional table and tilted toward the HMD. This IR camera locates a constellation of IR LEDs that are embedded in the headset but not directly visible (Fig. 1a). The HTC Vive, in contrast, uses two base stations designed to be fixed on a wall above head height, ideally more than 2 m. Each base station must be placed facing the other at a maximum distance of 5 m, and also tilted toward the HMD (Fig. 1b). Similar to lighthouses, the base stations include two stationary LED arrays that flash at 60 Hz and two active spinning laser emitters that throw a beam of light after each flash. The headset has a constellation of photodiodes that estimate the series of flashes. The position and orientation of the headset can be estimated from the delay between the flash emitted by the LED array and that emitted by the spinning emitter in each photodiode.

A VR-ready high-end computer, equipped with an 8-core Intel® Core™ i7-6700K @ 4.00 GHz, 16 GB of RAM, and a NVIDIA® Geforce® GTX 980 with 12 GB of GDDR5, was used with both HMDs during the experiment. The 1.10.0 and 1.1.1 versions of the tracking plugin for Unity were used for the Oculus Rift and the HTC Vive, respectively.

Procedure

To estimate the working area, accuracy, and jitter of the tracking of both systems in a room-size setting, a 10×10 grid with 50×50 cm squares was marked on the floor covering an area of 25 m². The Oculus tracking camera was fixed at a height of 70 cm, centered along the x axis, at $x = 2.5$ m, $y = -0.75$ m (Fig. 2a). The HTC Vive base stations were placed on a lateral of the grid at a height of 250 cm, at positions $x = 1.5$ m, $y = 3.0$ m and $x = 5.0$ m, $y = -0.5$ m, respectively, at the maximum distance recommended by the manufacturer (5 m) (Fig. 2b). Each was oriented to the other and tilted 40°. The HMDs were sequentially placed in all the grid's intersection and border points (121 points in total) at 1.7 and 1.3 m, the approximate heights of a subject's head in the standing and sitting positions, respectively, using a spe-

cially designed device that prevented movement and allowed height adjustment.[17,20] For the points where tracking data were available, the positions of both HMDs, always oriented in the $-\hat{y}$ direction (Fig. 2), were registered for 5 seconds at 50 Hz.

To estimate the working range of both systems' tracking, a measuring tape was fixed on the floor along the longitudinal axis of the Oculus Rift's tracking camera and a base station of the HTC Vive. Following the same procedure previously described, the positions of both HMDs, always oriented to the tracking camera or base station, were registered for 5 seconds at 1.3 and 1.7 m every 25 cm, moving away until no tracking data were obtained.

Data analysis

At each point of the grid, accuracy (e) was estimated as the mean difference between the position of the HMD measured in the real world and its estimated position. Jitter (j) was calculated as the standard deviation in the estimated position in the time interval as follows[17]:

$$e = \frac{1}{N} \sum_{i=1}^{N} |X_i - \tilde{X}_i| \qquad (1)$$

$$j = \sqrt{\sum_{i=1}^{N} \frac{X_i^2}{N} - \bar{X}^2}, \qquad (2)$$

where N is 250, the number of measurements provided by the tracking system for 5 seconds at 50 Hz; X_i is the real position of the headset, estimated as the distance from the origin of coordinates to the HMD in the real world; $\tilde{X}_i$ is the estimated position of the headset provided by the Unity plugin; and $\bar{X}$ is the mean position during these 5 seconds. The mean and standard deviation for all points were estimated for both accuracy and jitter. Data were separately analyzed inside and outside the working area recommended by the manufacturers: for the Oculus Rift, a circle of radius
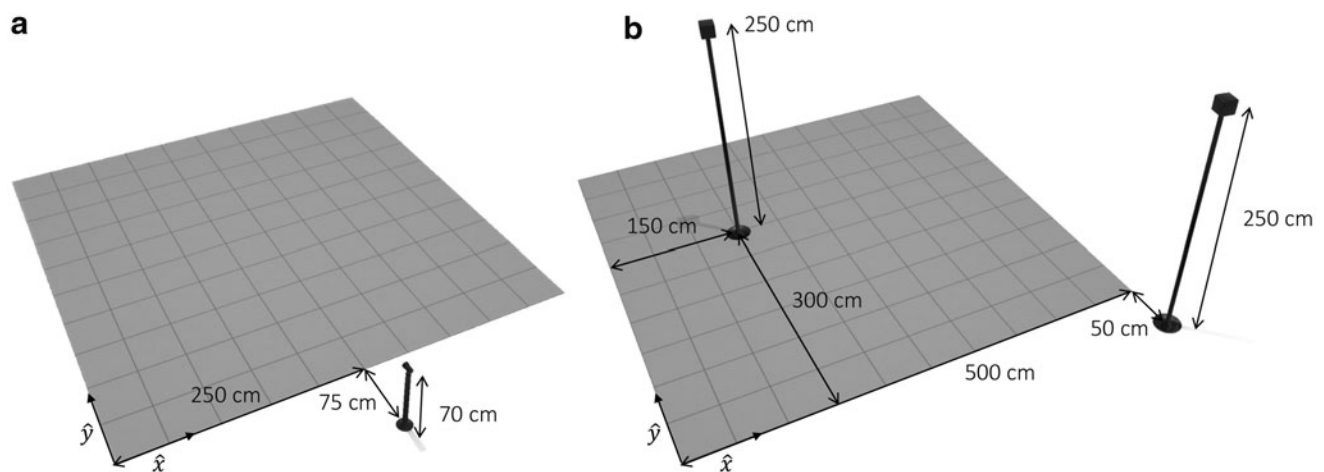
FIG. 2. A 10×10 grid with 50×50 cm squares was marked on the floor. **(a)** The Oculus tracking camera was fixed at a height of 70 cm, centered along the x axis, at $x = 2.5$ m, $y = -0.75$ m. **(b)** The base stations of the HTC Vive were placed on a lateral of the grid at a height of 250 cm, at positions $x = 1.5$ m, $y = 3.0$ m and $x = 5.0$ m, $y = -0.5$ m, respectively, one oriented to the other and tilted 40°, at the maximum distance recommended by the manufacturer (5 m).

50 cm was centered in the longitudinal axis of the camera at 1.25 m away; for the HTC Vive, the inner area of the rectangle was defined by the base stations.

All analyses were computed with MATLAB Release 2013b (The MathWorks, Inc., Natick, MA).

Results

The experimental results showed a working area of 11.75 m^2 for the Oculus Rift and 24.87 m^2 for the HTC Vive at all heights, which greatly exceeded the maximum recommended working areas of 2.75 and 6.25 m^2 for both devices, respectively. Figure 3 depicts the working areas of both devices.

Regarding accuracy and jitter, better results on both parameters were detected inside the recommended working area for both devices (Table 2). Similar values were obtained for accuracy and jitter at both heights for both devices, except for the HTC Vive's accuracy, which was better at lower heights. Both devices showed comparable performance at sitting height, both within and beyond the recommended working area. At standing height, however, the HTC Vive presented worse accuracy and jitter.

The working range of the Oculus Rift's tracking system was 4.25 m at both heights, starting at 0.25 m away from the camera. The HTC Vive presented higher working ranges at both heights, up to 6.75 m at a sitting height and 7 m at a standing height.

Discussion

This research involved comparing the working area, working range, accuracy, and jitter in a room-size setting for two latest-generation HMDs: the Oculus Rift and the HTC Vive. The HTC Vive provided a potential working area of nearly 25 m^2, twice as large as that of the Oculus Rift, and a working range of 7 m. Both devices showed excellent performance in terms of accuracy and jitter.

Both the Oculus Rift and the HTC Vive provided a working area that largely exceeds the spatial requirements of most nonimmersive VR-based serious games, exergames, and motor rehabilitation applications.[15,21–25] Moreover, the working area of the head tracking of the latest-generation HMDs potentially enables navigation in life-size virtual environments, such as kitchens,[26,27] supermarket aisles,[28,29] or streets,[30,31] which have been traditionally used in rehabilitation and health-related applications due to their functional implications. Navigation within these virtual environments has been commonly facilitated by external peripherals (joysticks, keyboards, etc.), but the head tracking of the new HMDs could overcome this abstraction and enable human navigation and exploration, thus enhancing the ecological validity of the tasks and facilitating skill transference.[18] This capability could also be combined with other techniques to ''virtually'' enlarge the walking area, such as dynamic layout generation,[32] redirect walking,[33] or motion compression.[34] Navigation could be especially feasible with the HTC Vive, whose working area is twice as large as the area provided by the Oculus Rift. In addition, the HTC Vive has a 360° field of view, which enables natural exploration in all spatial directions. The HTC Vive's use of two base stations, in contrast to only one camera, and its specific tracking mechanism (see Instrumentation section) could explain this difference. The addition of more cameras to the Oculus Rift setting, which was enabled from version 1.6 of the runtime package, together with a dramatic increase of the working area, could improve the results presented here. It is important to highlight that these cameras are not currently included in the standard bundle and should be acquired additionally.

The HTC Vive's larger working area could also explain its worse accuracy for the standing height when considering the whole area. This fact could evidence the distance
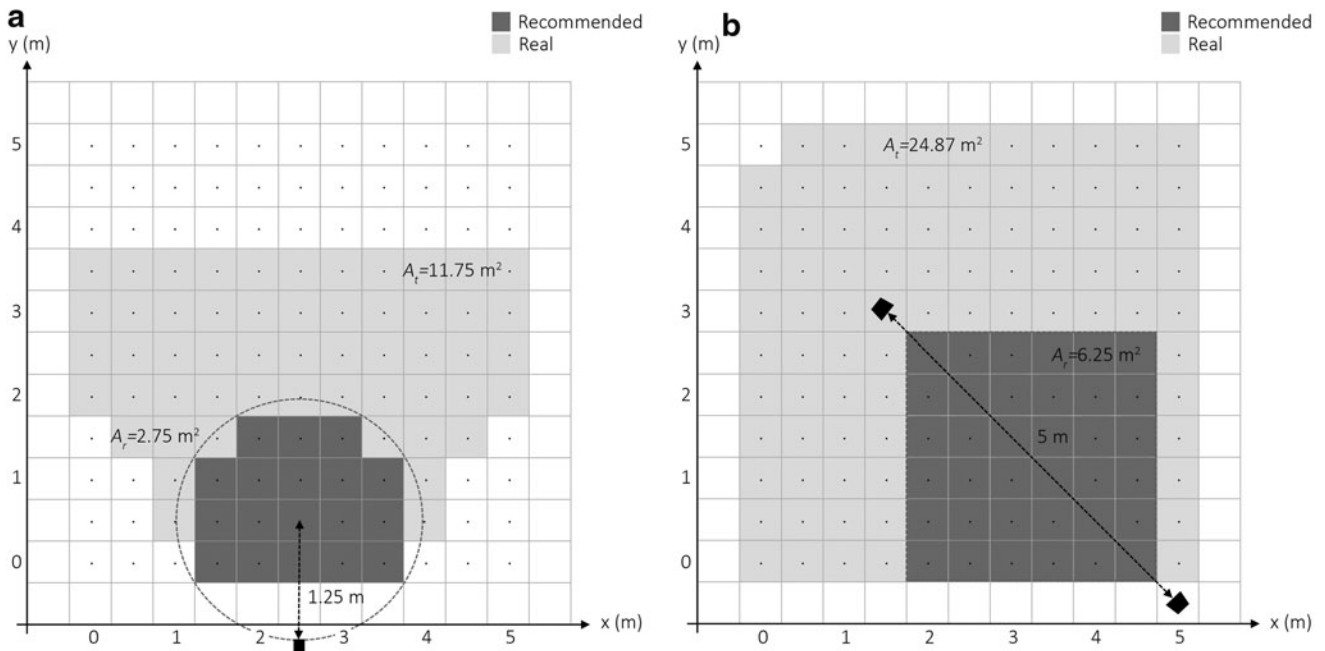
FIG. 3. Comparison of the recommended and real working area registered for **(a)** the Oculus Rift and **(b)** the HTC Vive.

Table 2. Accuracy and Jitter Data

	On the floor (0 m)		Sitting position (1.3 m)		Standing position (1.7 m)	
	Oculus Rift	HTC Vive	Oculus Rift	HTC Vive	Oculus Rift	HTC Vive
Accuracy (cm)						
Inside	—	0.58 ± 0.45	0.76 ± 0.53	0.75 ± 0.69	0.61 ± 0.55	1.22 ± 1.18
Outside	—	0.85 ± 0.84	1.03 ± 0.74	0.93 ± 0.72	0.92 ± 0.75	1.49 ± 1.38
Jitter (mm)						
Inside	—	0.19 ± 0.26	0.12 ± 0.18	0.23 ± 0.33	0.13 ± 0.46	0.31 ± 0.56
Outside	—	0.27 ± 0.37	0.25 ± 0.48	0.32 ± 0.44	0.36 ± 0.54	0.44 ± 0.99

Mean values of the accuracy and jitter of both devices at different heights inside and outside the working area. Data are expressed in terms of mean and standard deviation.

dependence of this variable, which seems to be greater for the Oculus Rift. However, the performance of both tracking systems, even in the worst case, should be highlighted and put into context. First, the Oculus Rift's head tracking accuracy, with average values ranging from 0.6 to 1.2 cm, represented <0.35% of its working range. In turn, the HTC Vive's head tracking accuracy, with average values ranging from 0.9 to 1.5 cm, represented <0.21% of its working range. Second, both HMDs' head tracking accuracies proved to be smaller than those of other optical cameras and electromagnetic systems used in VR-based serious games and rehabilitation.[20] Third, jitter was even more noteworthy, since the HMDs included for analysis showed only 10% of the jitter provided by motion tracking systems commonly used in VR.[20] Fourth, although the accuracy of the HMDs' head tracking proved to be up to three times worse than marker-based solutions,[17] jitter was up to three times smaller and does not require multiple markers to be attached to the ceiling, which makes set up easier and more affordable. Finally, and most importantly, results should be referred to human perception. During passive observation of static visual information in a big LCD screen, head movements have been reported to be up to 2 cm in average, with peaks of 3–4 cm,[35] which is 45–90 times the jitter of the HMDs' tracking. Interestingly, head sway under similar conditions was nearly two orders of magnitude higher than the jitter provided by the HMDs' head tracking, which could make it virtually imperceptible and prevent cybersickness or other deleterious effects.

Conclusion

The experimental results for working area, accuracy, and jitter of the latest-generation HMDs' tracking support the use of these devices not only as a feasible alternative for VR-based health applications, such as serious games, exergames, and motor rehabilitation systems, but also to enable the navigation and exploration of real-life size virtual environments, without any remarkable adverse effects.

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Author Disclosure Statement

No competing financial interests exist.

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