Virtual Reality and Older Hands: dexterity and accessibility in hand-held VR Control

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ABSTRACT
Whilst the VR Headset has a sense of commonality with users, VR hand controllers are largely incongruent with each other. This paper examines the common ground between VR developments in the area of hand control devices. This paper looks at VR controllers through the lens of older people, specifically for the purpose of including people from any age in the opportunity to enjoy the benefits of VR experiences. This study uses Fitts’ Index of Difficulty to determine areas of concern in terms of dexterity and accessibility. The study recommends a standardized approach to agility and access in VR hand control development.

Author Keywords
Virtual Reality; VR; Older People; Dexterity; Usability; Accessibility; Equity; Ergonomics; Fitts; Haptics.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
Virtual Reality (VR) equipment has historically been developed across custom-made bespoke vectors. VR equipment does not share a set of fully standardized characteristics in terms of hand control. Although VR headsets share many common features, their accompanying VR hand controllers are less closely aligned [5]. The individual dexterity of users deserves increased consideration if VR acceptance is planned to extend beyond the gaming fraternity, and into mainstream usage [2]. The work of Bhardwaj [1] highlights the anthropomorphic inconsistencies of hand controllers, in particular in terms of button sizing, button action, and positive pressure differences.

The majority of VR equipment has been tailored to suit gaming, and with that gaming an accompanying set of users from younger age cohorts [6]. From a holistic perspective, the development of VR hand control devices is unevenly focused on one particular age demographic of predominantly game-oriented users. Thus there is the need for a more balanced consideration of VR hand control devices that considers the full age-range and user requirements of the global VR audience [10]. As VR equipment becomes more universal across non-gaming usages and with older users, there is a need to evaluate the authenticity of VR control by means of hand held control devices. The benefits of including home-based VR systems within accessible reach of older people are expected to greatly increase the health and wellbeing of older people [16]. This study discusses the challenges of overcoming dexterity divergences within the development of control functions in VR without significant losses in reality.

BACKGROUND TO THE STUDY
To retain an authentic and universal sense of reality, the challenge is to incorporate hand controller features that retain close ergonomic similarities with human physical and manual dexterity and agility [4]. The human hand, in younger and older forms, has varying characteristics [14]. A VR controller should be capable of retaining the corresponding touch, sensation, and hand positioning in line with individual user age, agility, or movement. A VR controller should allow people of all ages to have authentic access to a VR experience [3]. Younger cohorts using VR equipment are comparatively faster adopters of this form of technology and form a substantive portion of the online gaming world [7].

Figure 1. Variations in VR Hand Controllers

Accessibility guidelines allow universal access to technology [13]. The WCAG 2.0 Guidelines exist to promote a culture
of increased access to technology [18]. The transition to accessible technology use is far more of a process than it is a static outcome that can be overlooked [9]. VR developers have introduced some uniformity which then allows for the progression of a more accessible approach to VR headsets [12]. However, there is little evidence to support the same uniformity in VR hand controllers (Figure 1). Sample hand controllers from major VR equipment manufacturers demonstrate unique differences in hand controller specifications. These differences are identifiable in terms of controller shapes, hand grips, button sizes, shapes, textures, and colors. They are different in terms of their haptic qualities, their pressure sensitivities, and their responsiveness. An experience using one hand controller is rarely similar to that of another.

This paper advocates for usability and accessibility reform in the development of VR Hand Controllers. The research described here shows a comparison of different controller formats. It compares measurements in terms of design, button placement, dexterity, and functionality by means of a set of simple comparison tests. These measurements are charted using Fitts’ Index of Difficulty (Fitts IoD) and by looking at conformance with ISO standards within the ISO 9241-9 group of standards [20, 21]. These relate to variations of control using non-keyboard input devices as are used by VR Hand Controllers.

ISSUES OF GRIP, TOUCH, AND HAPTICS
A great deal of the developmental focus has been placed on the headset and visual characteristics [7]. VR hand controllers have moved beyond single control devices to controllers where two hands hold, grip, and touch something to exercise control within the virtual environment (Figure 2).

At the same time there is a divergence of development in the evolution of VR-specific hand-based control. One vector includes hand controllers such as the HTC Vive, Oculus Rift, Nintendo Switch, Sony PlayStation VR and the Mixed Reality Hand controllers of HP and Dell. These are based on a physical “hand held” controller / wand using interactions driven by touch and feel (Figure 3). They typically include haptic and touch-sensitive control and deploy different forms of handheld grip.

Figure 2. Oculus Rift Hand Controllers

The first two versions are “palm-down” holding formats, whilst the third requires a “palm up” clasp-like holding position. Of the palm-down holding formats, one employs a pistol-like grip to accentuate a trigger finger for fast and repetitive actuation of various functions (Figure 4). The second palm-down / palm-in holding formats is more comparable to a “hand shake” grip.

![Figure 3. HTC Vive Hand Controllers](image)

Figure 3. HTC Vive Hand Controllers

The second type of hand control is more closely aligned with control by means of gesture rather than holding a physical hand control device. They do not require physical touch of a controller, but instead rely upon gestured actions near a receptor or monitor screen [17].

![Figure 4. Nintendo Hand Controllers](image)

Figure 4. Nintendo Hand Controllers

HAND-HELD CONTROLLERS ORIGINS
Early controller iterations made little attempt to represent equivalent functioning of human hands, and allowed for non-human “machine-like” interactions such as shooting objects as part of a game. As hand controllers have further developed for VR, the limitations of previous control devices have challenged those seeking to integrate the anthropometric requirements of the human body into VR control [2]. VR has moved beyond gaming and entertainment to additionally service areas of education, training, medical, marketing, advertising, and tourism [17]. The earlier hand-controller formats focused on the game-play of young adults in virtual environments where “reality” was not the dominant characteristic of the virtual environment.

VR equipment has been largely designed to meet the appetite of the gaming industry [17, 19]. Most early hand controllers came as a single unit. The shift to dual-hand controllers has emphasized the transparent immediacy feature which characterizes the user experience of being immersed in VR [19]. In reality, human movement is more accurately described by the actions of independently moving arms and hands, rather than relying on a single grasped or touched element. Single hand controllers do not provide an authentic user experience in a natural environment [15, 17].

Older VR users seek authentic reality-based experiences [19]. Such practices are limited by devices requiring high
dexterity and rotational movements of digits. Studies have shown challenges between aging and dexterity in terms of sensing, strength, grip and pinch [22]. The functionality of hand control is important [4]. Human hands retain the capability to recognize things using touch more than other senses. Studies indicate that the sense of touch provides valuable sensory feedback to older hands [11].

In a VR environment a person of any age can experience initial difficulty because they cannot see the hand controllers. This can be further intensified if the hand controller includes non-intuitive bespoke functions. Such features bring about unsatisfactory experiences in the pursuit of an authentic reality-based experience. The design and placement of buttons with suitable haptic features can add greater reality to human dexterity rather than game-related functionality.

To test the need for a renewed consideration of VR hand controllers, two hypotheses were established to determine areas of reform in the development of VR hand controllers.

H$_1$: That VR hand controllers are less accessible and usable to some people on the basis of age and dexterity.

H$_2$: That VR controllers have lower levels of authenticity through lower uniformity in terms of control features.

The first hypothesis examined accessibility for people of all ages and considers a range of manual and dexterity-based capabilities. To do this, VR hand controllers were considered in terms of their functionality. The study took measurements using Fitts’ Index of Difficulty as well as comparisons with ISO 9241-9. The second hypothesis examined VR controllers to determine consistency in shape, size and functionality. Each controller was examined to determine differences in terms of usability and authenticity.

**METHOD**

Five hand controllers were selected for a comparative study to assess usability within VR environments. They were chosen on the basis of three criteria. The first considered market status. The second considered control interaction and the third considered function and feature differentiation. Each VR controller was weighed, and measured to collate physical characteristics. Buttons and track pads were examined to determine size, accessibility, shape, texture, access, and positioning. The expected holding position was recorded. Controllers were judged on the basis of digit rotation, button access and lateral dexterity. The study considered the ease of access to buttons, the number of buttons, their proximity to each other, and the method of contact (Table 1). Button, toggle, and trigger placements recorded button clustering. Measurements were recorded by using a Fitts’ law approach to tactile interaction [8]. A pilot sample of older adults over 65 years was used to validate control access and function capabilities. Respondents used a set of discrete Fitts tasks as described in Table 1.

<table>
<thead>
<tr>
<th>Control Features</th>
<th>Explanation of Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Button access thumb</td>
<td>Number of buttons accessed by thumb within range according to Fitts IoD</td>
</tr>
<tr>
<td>Button access index finger</td>
<td>Number of buttons accessed by index finger within range according to Fitts IoD</td>
</tr>
<tr>
<td>Button access middle finger</td>
<td>Number of buttons accessed by middle finger within range according to Fitts IoD</td>
</tr>
<tr>
<td>Button access ring finger</td>
<td>Number of buttons accessed by ring finger within range according to Fitts IoD</td>
</tr>
<tr>
<td>Thumb access + Rotation</td>
<td>Evaluate Range of Motion required to access all designated thumb contacts</td>
</tr>
<tr>
<td>Tethered or Wireless</td>
<td>Check whether controller presents in tethered or cable-free configuration</td>
</tr>
<tr>
<td>Button Placement + Spacing</td>
<td>Evaluate placement of buttons in clusters with comparison to Fitts IoD</td>
</tr>
<tr>
<td>Button Texture/Non-Slip</td>
<td>Evaluate buttons according to surface textures and examine for nonslip surfaces</td>
</tr>
<tr>
<td>Force on Button</td>
<td>Evaluate downwards button force in accordance with Fitts IoD</td>
</tr>
<tr>
<td>Raised Button Surfaces</td>
<td>Examine button surfaces for raised button surfaces</td>
</tr>
<tr>
<td>Controller Hand Position</td>
<td>Record Hand location Palm Up versus Palm Down positioning</td>
</tr>
<tr>
<td>Positioning</td>
<td>Record symmetrical layout left to right</td>
</tr>
<tr>
<td>Weight and Size</td>
<td>Record weight and size of each controller</td>
</tr>
<tr>
<td>Placement and Complexity</td>
<td>Record and evaluate positioning based on location, clustering, separation, complexity according to Fitts IoD</td>
</tr>
</tbody>
</table>

Table 1. Method for VR Hand Controller Assessment

**ANALYSIS AND DISCUSSION OF RESULTS**

Results showed high levels of disparity in terms of button placement and access, individual finger allocations, thumb dexterity, and button spacing (Table 2).

**VR Hand Controller Button Irregularities**

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Button placement and access</td>
</tr>
<tr>
<td>2</td>
<td>Expected Finger / Button allocations</td>
</tr>
<tr>
<td>3</td>
<td>Reliance on Thumb movement and rotation</td>
</tr>
<tr>
<td>4</td>
<td>Button spacing inconsistencies</td>
</tr>
</tbody>
</table>

Table 2. Areas of Disparity in hand control devices.

**Buttons, Thumbs, surfaces and textures**

The results showed irregularity with button placement. Some controllers placed buttons in an arc-like dispersion pattern and some used track pads or toggles with different function
allocations. There was a heavy reliance on thumb rotation. Results indicated the need for increased thumb extension whilst maintaining controller grip. Some controllers placed an emphasis on the index finger. There was variation in terms of thumb and index dominance. Some spacing followed a crosswise lateral array. Other controllers used clustering with irregular spacing (Table 2). There was variation with surfaces and button textures. Some used raised surfaces, whilst others mirrored the casing of controllers (Table 3).

<table>
<thead>
<tr>
<th>Surfaces and Textures</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight, balance and thickness</td>
<td>Surface consistencies and button differentiation</td>
<td>Button textures and sensory features</td>
</tr>
</tbody>
</table>

Table 3. Areas of Disparity in surfaces and textures.

Weight, size, surface textures and sensory variations
Controllers varied in terms of size and weight. The scale of the differences was a challenge in terms of prolonged usage. All controllers had plastic casing with different weighting and size configurations. The results showed difficulty in sensing buttons in some controllers. Some buttons were close fitting within casings, resulting in access difficulty. Some buttons were more distinguishable by their shapes and textures than others. Some buttons gave a positive action whilst others were less responsive (Table 3).

Symmetry and complexity
Some controllers were asymmetrical. Toggle positioning was inconsistent between left and right controllers. Some controllers had a complex array of functions whilst others had clusters of buttons in proximity to each other. Controllers were inconsistent in terms of functionality.

<table>
<thead>
<tr>
<th>Examination Focus</th>
<th>Oculus Rift</th>
<th>HTC Vive</th>
<th>Dell MR</th>
<th>Sony P/S</th>
<th>Nintendon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buttons access thumb</td>
<td>4</td>
<td>11 with T/pad</td>
<td>4</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Buttons access index finger</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Buttons access middle finger</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Buttons access ring finger</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Thumb Access and Rotation</td>
<td>***</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>Tethered (T) / Wireless (W)</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>T</td>
</tr>
<tr>
<td>Button Positioning</td>
<td>***</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
</tbody>
</table>

The study showed broad disparity across function and design. The results of the controller comparisons showed incongruent design in all five tested VR hand controllers (Table 4). The results support reducing thumb-based button control and standardization of buttons using thumb interaction. Adherence to a Fitts’ approach suggests that button placement and proximity should conform to a range of spacing. Proximity-based button placements would benefit from a range of 6mm to 8mm separation.

Summary of Dissimilarities
The study showed broad disparity across function and design. The results of the controller comparisons showed incongruent design in all five tested VR hand controllers (Table 4). The results support reducing thumb-based button control and standardization of buttons using thumb interaction. Adherence to a Fitts’ approach suggests that button placement and proximity should conform to a range of spacing. Proximity-based button placements would benefit from a range of 6mm to 8mm separation.

CONCLUSION
Unlike VR headsets with high functional similarity, VR hand controllers share fewer parallels in design, and interaction. The results support the hypothesis that VR hand controllers have inconsistent levels of accessibility where high levels of dexterity are required to achieve a normative range of access. Older people are predisposed to less authentic interactions with VR environments. The results also support the hypothesis that VR controllers are less accessible to some people based on normal age and dexterity restrictions. The study showed that VR hand controllers have a higher correlation with individual bespoke functionalities than with a standardized relationship for authentic human interaction.

We conclude that the further development of VR Hand Controllers requires reform to ensure an authentic human experience. This study concludes there is widespread disparity in terms of hand position, grip position, button and tactile interaction, and symmetry. Authentic reform should reduce the numbers of buttons, and invoke consistent spacing between buttons on controllers. The aim of this research was to establish the need to reform consistent controller design in terms of ergonomic and dexterity-based interaction. There is a need to reconnect human dexterity and accessibility using a uniform approach to VR hand controller development.
REFERENCES


