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Review article

Immersion of virtual reality for rehabilitation - Review

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ABSTRACT

Virtual reality (VR) shows promise in the application of healthcare and because it presents patients an immersive, often entertaining, approach to accomplish the goal of improvement in performance. Eighteen studies were reviewed to understand human performance and health outcomes after utilizing VR rehabilitation systems. We aimed to understand: (1) the influence of immersion in VR performance and health outcomes; (2) the relationship between enjoyment and potential patient adherence to VR rehabilitation routine; and (3) the influence of haptic feedback on performance in VR. Performance measures including postural stability, navigation task performance, and joint mobility showed varying relations to immersion. Limited data did not allow a solid conclusion between enjoyment and adherence, but patient enjoyment and willingness to participate were reported in care plans that incorporates VR. Finally, different haptic devices such as gloves and controllers provided both strengths and weakness in areas such movement velocity, movement accuracy, and path efficiency.

1. Introduction

Musculoskeletal impairments are debilitating conditions and they interfere with the normal activities of daily living. According to the National Health Interview Survey (NHIS, 2015), musculoskeletal impairments negatively affect approximately 40% of the United States population (Katz, 2015). Some known disorders and disease that affect the musculoskeletal performance include chronic joint pain (Anderson et al., 1999), arthritis (Reginster, 2002), Parkinson's disease, Guillain-Barré syndrome, and cerebral palsy (Graham and Selber, 2003). The sensorimotor system, which involves the sensory, motor, and integration in maintaining joint homeostasis during bodily movements (Riemann and Lephart, 2002). There are observed associations between these musculoskeletal impairments and the sensorimotor system, the integration structure of sensory and motor processing elements during functional movements (Cioni et al., 1997). Rehabilitation and physical therapy have been the approach to improve the sensorimotor system and musculoskeletal health but often face issues with user adherence (Bassett and Prapavessis, 2007). Besides adherence challenges during the rehabilitation process, the annual expenses attempting to resolve cases of nonadherence could be around $300 billion (DiMatteo, 2004). It is important to address the challenges in existing rehabilitation paradigm to better the outcomes of musculoskeletal health interventions.

Recent research has explored the potential of using virtual reality (VR) as a mode of healthcare intervention and an alternative route for care delivery (Mantovani et al., 2003; Simone et al., 2006). Virtual reality is a computer generated graphical environment that offers opportunities for users to view and interact with the virtual environment in stereoscope (i.e., three-dimensional visuals). In interventions for physical impairments, VR has been proposed and utilized as an assistive rehabilitation technology for individuals suffering from stroke (Jack et al., 2001), cerebral palsy (Reid, 2002), severe burns (Haik et al., 2006), Parkinson's disease (Mirelman et al., 2010), Guillain-Barré syndrome (Albiol-Pérez et al., 2015), and multiple sclerosis (Fulk, 2005) among others. Supported by positive outcomes, Reid (2002) demonstrated improvement in children suffering cerebral palsy of both perceived performance abilities and satisfaction with performance when using VR as a tool for motor training. Using VR as a tool for healthcare may have enhanced ecological validity, real-time performance feedback, interface modification contingency, flexibility, as well as a safer practicing and training environment (Rizzo and Kim, 2005). VR also offers the ability to customize treatment needs while delivering increased adjustment of assessment and training procedures (Sveistrup, 2004).

Some recognized characteristics of VR that make interventions in healthcare advantageous include immersion and engagement in interactivity. Immersion describes the degree of which VR systems are able

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Table 1
Types of VR systems.

	Non-Immersive	Semi-Immersive	Fully Immersive
Viewing Mediums	Computer monitor, TV screen	Panoramic TV	Head mounted display (HMD), CAVE
Cost	Low	Medium	From low (HMD) to high (CAVE)
Sense of Immersion	Low	Medium-High	High

to deliver experiences that are extensive (i.e., multimodality sensory stimuli), surrounding (i.e., omnidirectional stimuli), inclusive (i.e., no external stimuli from the physical environment), vivid (i.e., richness of sensory information), and matching (i.e., user movement and system information match) (Slater et al., 1996). Immersion is an objective, "technology-related" aspect of virtual environments (Slater and Wilbur, 1997) whereas presence is a psychological, perceptual, and "feel of being there" (Slater et al., 1996). Immersion is an important feature of VR research because it influences a user's experience in VR and affect the user's sense of presence. There exists different VR technologies that can be group into three general categories – non-immersive, semi-immersive, or fully immersive. Table 1 lists the immersion categories and a few examples of the technology associated (Mujber et al., 2004). Several researchers have constructed frameworks and questionnaires to assess immersion and presence (Constantin and Grigorovici, 2003; Insko, 2003; Slater and Wilbur, 1997; van Baren and IJsselsteijn, 2008; Waterworth and Waterworth, 2001; Witmer and Singer, 1998). The potential for a specific user to become immersed in VR has even been shown to be subject to a person's personality traits (Samana et al., 2009). While physiological factors such as heart rate and skin conductance have been studied for correlation to immersion (Meehan et al., 2002) but these methods are used less often than questionnaires. Though immersion has been discussed in other domains like gaming (Ho, 2016), it has been largely discounted within the field of rehabilitation. Possible associations between immersion and user performance could be discovered with significant outcomes.

Some risks associated with immersion in a VE have been identified, such as simulator sickness. Extended participation can often lead to undesired physical symptoms such as eye strain, dizziness, and ataxia (Kolasinski, 1995). Therefore, it is important to account for these tendencies in experimental design and record any accounts of simulator sickness in the report.

One factor that has been shown to have an effect on immersion is the inclusion of haptic feedback within the environment and it has garnered much attention (Deutsch et al., 2008; Stone, 2001). Haptic response simulates kinesthetic information such as force and pressure through various hardware devices seeking a more real environment. Visual stimuli are present in VR but a lack of haptic feedback throughout an interaction with the environment impedes humans from rousing one of our five central senses (Akay, 1998). Haptic feedback has been shown to increase the sensory fidelity of VR; with the addition of more senses stimuli into the VR experience or through refining a particular sensory channel can help a user decide to continuously attend to VR (Chertoff et al., 2010). The presence of haptic feedback has importance to VR applications because it provides another form of communication to users.

To expand the degree of interactivity, task enjoyment can be altered to improve the engagement of the patients. Burke et al. (2009) presented gaming principles for stroke patients that were shown to increase engagement through motivating tasks. Further studies expressed the increased levels of enjoyment while performing PT exercises within the VE (Ho, 2016; Jack et al., 2001). Virtual reality in the field of healthcare research has been shown to be useful and effective because of its customization, interactivity, and ability to influence commitment through engaging tasks. There appears to be various features of VR that can be exploited for healthcare application.

2. Review objectives

We have identified three key aspects, in the form of research questions, in virtual reality and their attractiveness for rehabilitation. This review aims to understand three aspects of VR in rehabilitation – immersion, enjoyment, and haptic feedback – and any influence they may have on the performance and outcomes of patients. This review will shed some light on the capabilities of VR in rehabilitation and its impact on intervention outcomes, as well as identify gaps in the VR rehabilitation domain. Three research questions (RQs) are as following:

Research Question (RQ) 1 – How does the level of VR immersion affect user performance and/or health outcome?

Immersion in VR has been studied across many domains, but its correlation to rehabilitation and health interventions has not been explicitly considered. Examining immersion and identifying potential relationship between immersion and patient performance and outcome could be of value to future researchers.

Research Question (RQ) 2 – What facets of VR enjoyment have been researched relative to improved patient adherence?

The aspect of interactivity and enjoyment associated with VR has been well established. The prospective benefit it provides to patient adherence (to rehabilitation plans) has not be fully explored.

Research Question (RQ) 3 – What influences do haptic feedback on individual performance in VR?

Researchers are currently testing different haptic feedback varieties during VR rehabilitation studies. Early studies show benefits of incorporating haptic feedback in VR-based rehabilitation studies (Boian et al., 2003). The utility of haptic feedback in VR has not been thoroughly examined and the findings for this RQ can inform the design of future VR rehabilitation devices.

3. Review method

We systematically searched for literature regarding patient performance and health outcomes and experience of VR-based rehabilitation to address the following RQs:

1. How does the level of VR immersion affect user performance and/or health outcome?
2. What facets of VR enjoyment have been researched relative to improved patient adherence?
3. What influences do haptic feedback on individual performance in VR?

3.1. Eligibility criteria

To be included in this review, the VR device and methods used had to be explicitly stated. The studies also had to be within the physical rehabilitation domain.

3.2. Information sources

The following online databases were searched to yield a broad spectrum of results:

- **Web of Science** was used to provide an all-encompassing scientific search.
- **Compendex** was used for a primarily engineering centered search.
- **IEEExplore** was used to provide an electronic based search.
- **PubMed** was used for a healthcare-oriented search.

The literature search was limited to year 2005 in considering how rapidly VR technology progresses. The total literature search period