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Study on interaction-induced symptoms with respect to virtual grasping and manipulation ☆

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ABSTRACT

Owing to the popularity of various hand tracking interfaces, there have been numerous applications developed to provide intuitive hand interaction with the virtual world. As users start with great anticipation, they end up with dissatisfaction due to difficulties of manipulation or physical tiredness coming very short. Although the task itself is rather trivial in a real life situation, it requires much effort in the virtual environment. We address this awkwardness as 'VR interaction-induced fatigue symptom' and hypothesize its causes based on our observations. We argue that the source of the fatigue comes from the restricted sensory information of the VR interfaces, and that users try to accommodate the missing sensory feedback by excessive motion leading to wrong posture or bad timing. We demonstrate our hypothesis by conducting experiments of two types of virtual interaction scenarios: object transport and 3D selection. Furthermore, by analyzing the behaviors of users' action collected from our experiment, we derive essential factors to be considered in designing VR applications, and propose a conceptual interaction model for orchestrating virtual grasping.

1. Introduction

While recently developed hand-tracking-based interactive 3D VR applications (e.g., via Kinect or data gloves) become prevalent and popular, there remain interaction problems where people still experience difficulties in manipulation of virtual objects as well as some awkward sensation as a result of wrong grasping postures. As a result, people occasionally suffer from tiredness even after performing a sequence of trivial tasks. Tiredness or fatigue, generally defined as a difficulty in voluntary activities during repeated or sustained muscle contractions of specific tasks, can be classified into two categories: 'central fatigue' and 'peripheral fatigue'. Central fatigue may arise from the central nervous system (CNS) and result from proximal events including the neuromuscular junction. Peripheral fatigue predominately arises from muscle contraction or excitation (Scheidegger et al., 2010). By relating these two classifications to the fatigue that arises in the virtual environment (of which we dub as 'VR interaction-induced fatigue symptoms'), the difficulties and frustration that the user feels fit into central fatigue, and physical tiredness due to awkward posture fits into peripheral fatigue.

In this paper, we address the causes of the hand interaction-induced fatigue symptoms, and hypothesize that they are due to restricted sensory information of the VR interfaces. Since the VR interfaces can offer only limited feedback, a user tries to accommodate the missing sensory information by excessive finger motions leading to awkward and uncomfortable postures as well as bad timing in coordination. These undesirable behaviors yield to the fatigue symptoms which prevent users from having satisfactory virtual experiences and finally make users reluctant to rejoin in virtual environments.

Although there are many studies related to visual fatigue symptoms with respect to comfortableness and distress aspects coming from wearing display interface such as HMD and 3D projection devices, to the best of our knowledge, as the popularity of interactive 3D interface is rather recent, few researches have been reported on the interaction-induced fatigue symptoms with respect to VR applications. We focus on hand interaction in the virtual environment, and analyze the users' behavior to understand why they have difficulties in manipulation tasks so that we can further suggest a solution for creating comfortable and enjoyable VR experiences. Based on our observation, we have noticed that the grasping behaviors in virtual environment are very similar to those of motor-impaired patients in the real environment. We believe that this analogy comes from a deficit of afferent sensory feedback and efferent motor command of the internal pathophysiological model regarding to the control of

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grasping. Several studies have been reported that impaired people with lesions of their somatosensory pathways or those with cerebellum disorders experience some difficulties and awkwardness when manipulating actual objects (Nowak et al., 2003; Fellows et al., 2001). Specifically, grasping by those impaired shows excessive finger motions, time delayed grasping coordination and long grasping durations. We have found that similar grasping behaviors also exist within the virtual environment among the average users. We demonstrate this analogy by conducting experiments and we present the results in this paper.

For analyzing behavior factors contributing to interaction-induced symptoms, we select two representative types of interaction scenarios among virtual interactions: object transport and 3D selection. We analyze interaction factors as well as visual ones. Specifically, we present that exaggerated grip aperture, distance to early finger extension, erroneous trials, duration time, time-to-peak-velocity, maximum grip aperture size, velocity profile, and grip aperture size profile lead to interaction fatigue and dissatisfaction of the virtual environment.

Furthermore, in the discussion part, we propose conceptual interaction models for grasping control. Based on this model, we discuss the design guidelines to be considered to reduce interaction fatigue by focusing on the difficulties and awkwardness in manipulation of virtual objects.

2. Related work

While a human easily performs specific tasks with his hand in the real environment, he often feels difficulties or tiredness performing similar tasks in the virtual environment. Before addressing these interaction-induced fatigue symptoms that arise in the virtual environment, we first review the research reports related to human fatigue symptoms that arise in the real environment to describe concept of fatigue, and highlight reported studies related to physical fatigue due to the devices for interacting with virtual environment. Second, we present the empirical standards on the action of a human body. Finally, we show the grasping patterns of normal people in a virtual environment and those of impaired people in a real environment, and explain the internal pathophysiological model to describe the fundamental reasons behind the specific patterns of grasping behavior in diverse aspects.

2.1. Human fatigue symptoms in real and virtual environments

There are a number of studies related to human fatigue with respect to its definition, mechanisms, and phenomenon. Scheidegger et al. (2010) reviewed complicated phenomenon of motor fatigue and defined the fatigue as ‘any reduction in the maximal capacity to generate force or power output’. Central fatigue means the subjective sense of fatigue perceived at the level of central nervous system. It is not simply a sense of physical exhaustion, but includes an important cognitive or mental fatigue. On the other hand, peripheral fatigue is referred to as muscle fatigability due to disorders of muscle and neuromuscular junction. He also explained fatigue as a difficulty in initiating or sustaining a voluntary activity, and introduced means of self-reported questionnaires, such as the Fatigue Severity Scale.

Vollestad (1997) presented the study on human muscle fatigue with several exercise models, protocols, and assessment method to measure human fatigue. Davis and Walsh (2010) presented that mechanisms of fatigue are traced through kinesthetic effort and force by EMG (Electromyography) amplitude and frequency change during a task. Santos et al. (2010) presented influence of fatigue on hand muscle coordination and EMG-EMG coherence during three-digit grasping. They found that the MVC (Maximum Voluntary Contraction) force significantly reduced from initial trial to final trial immediately after the muscle contraction. Note that most studies on human fatigue have been done with respect to activities in the real environment.

In the late 1980s, more studies started to look into undesirable feelings that users suffer from engaging with the virtual environment, and coined it as cybersickness. LaViola (2000) discussed a number of the primary factors contributing to the cause of cybersickness and discussed some methods for reducing cybersickness in the virtual environment. He mentioned a number of symptoms of cybersickness, including eye strain, headache, pallor, sweating, dryness of mouth, fullness of stomach, disorientation, vertigo, ataxia, nausea, and vomiting. He further explained that cybersickness can give rise to significant problems and yet is also difficult to predict due to many factors contributing to its cause. He introduced a number of theories which attempt to explain why cybersickness occurs and its origin.

In regards to physical fatigue symptoms, visual fatigue symptoms have been mostly studied for various display environments. Among notable studies, VR-induced symptoms and effects assessed influences and sickness symptoms according to four VR displays—head mounted display, desktop, standard projection screen and horizontally curved large screen display. They have suggested that there is a need for continuing research in adjusting the display types and levels of symptoms experienced with the VR displays. They have also commented that some participants felt uncomfortable and distressing symptoms, the exact causes of which has yet to be identified (Cobb et al., 1999).

Ukai and Howarth (2008) presented that visual fatigue is caused by the discrepancy between accommodative and convergence stimuli in the stereoscopic images. In his paper, studies on changes in oculomotor function and in pupillary responses after viewing stereoscopic images are discussed with the evaluation of visual fatigue, particularly in relation to different methods of viewing stereoscopic displays.

Another aspect of physical symptoms concerns with muscle strain from wearing VR devices. Guill and Herd (1989) present the experimental results in trying to identify significant casual factors and mechanism for ejection-associated neck injuries on wearing HMD display. They described that the incidence of neck injuries is bound to reduce aircrew confidence in the efficiency and safety of their escape. Edward et al. (2008) discuss the guidelines for designing HMD display considering aircrew's fatigue as they react to the heavy weight of HMD display. They are in searching the answers about how the center of gravity influences their operational performance. There is also a usability study to determine if a wearable HMD display interferes their head pose and raise unwanted strains on the musculoskeletal system (James and Chris, 2007).

Yamaguchi (1999) presented a VR system called “Hyper Hospital,” a medical care system evaluated the safety features of a VR system from the physiological, neurological and psychological viewpoint. His motive for his study is on the safety of their VR system in terms of the physical fatigue. In his experiments, subjects were exposed to different intensities of physiological and psychological stimuli. For evaluation of VR safety features, physiological, biochemical, neurological, and psychological fatigue were measured before and after experiments.

All of the previous studies concerning with physical tiredness focus mainly on muscle strains which are passively acquired by either artificial stimulus exposure to the eyes or undesirable weights imposed by wearing VR devices. In this paper, we initiate the study investigating fatigue symptoms arisen by user's active gesture actions as to interact with virtual environment.