A Stationary Bike in Virtual Reality
Rhythmic Exercise and Rehabilitation

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1 INTRODUCTION

A stationary bicycle is a powerful rehabilitation and exercising device, due to its natural rhythmic component. Our goal in this paper is to discuss benefits of a stationary bike usage supplemented with augmented feedback, music and virtual reality (VR). In addition, we present some of the existing applications, which disabilities it might help, the role of VR in rehabilitation and the bases of rhythmic rehabilitation.

Indoor exercising on the stationary bike might be a monotonous activity if not supported with some visual or auditory stimulation. Technology inclusive of different types of sensors and interfaces provides us with opportunity to make the stationary bike much more efficient and enjoyable tool. Our goal is to introduce a system which will serve for elderly people in retirement home, whom are not able or it is very difficult for them to train outdoor. The system will be adjusted to their needs and preferences.

The stationary bike based exercises are recommended for a wide group of medical conditions (see section 2.3). Adding VR to the stationary bike might give psychological and physiological benefits. Holden (2005) in her review of research of motor rehabilitation in VR punctuated four major benefits of this approach: "*(1) people with disabilities appear capable of motor learning within virtual environments; (2) movements learned by people with disabilities in VR transfer to real world equivalent motor tasks in most cases, and in some cases even generalize to other untrained tasks; (3) in the few studies (n = 5) that have compared motor learning in real versus virtual environments, some advantage for VR training has been found in all cases; and (4) no occurrences of cybersickness in impaired populations have been reported to date in experiments where VR has been used to train motor abilities*".

2 BACKGROUND

2.1 Existing Systems

Commercially available systems using a stationary bike augmented with VR have both fitness and rehabilitation applications. Most of them are concentrated on the visual aspects of VR. Systems like Holdings (2014), Sports (2014) and Mokka et al. (2003) are for active individuals to make their fitness more demanding and enjoyable. Also several rehabilitation applications were made with the stationary bike as a core of the system. Ranky et al. (2010) introduced Virtual Reality Augmented Cycling Kit (VRACK). It is a combination of a stationary bike and specific hardware and sensors, which allows for data acquisition (e.g. physiological) and stimulation by visual, audio and haptic feedback. Chen et al. (2009) has proposed rehabilitation system with only visual feedback for rehabilitation of spinal-cord injury. Chuchnowska and Sekala (2011) developed system for interactive rehabilitation of children under the age of three.

2.2 A Stationary Bike in Virtual Reality

One of the main features of VR, which makes it beneficial for exercise and rehabilitation is its ability to provide immersion (a feeling of being enveloped by, included in, and interacting with the virtual environment (Witmer and Singer, 1998)), sense of presence and control over the simulated environment. Ijsselsteijn et al. (2004) indicate that higher feeling of immersion and presence generate more fun thus higher motivation to exercise. If a person enjoys exercising it is more likely she or he will exercise and therefore accelerate rehabilitation process. Below, we present studies where a stationary bike was used in VR. The goal is to show how this fusion is already used and what more can be done.

Chuang et al. (2003) compared biking with and without VR. Results show that in VR participants can bike longer and over longer distances. Huang et al.

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(2008) compared different visual displays and concluded that that participants can exercise longer with head-mounted display (HMD) than without any display. Ijsselsteijn et al. (2004) indicate that higher immersion is correlated with faster cycling. The use of VR in motor rehabilitation might be justified by the fact that there is better transfer of the function to the real when exercising on robotic device with VR than these devices alone (Mirelman et al., 2009).

On the other hand Mestre et al. (2011) report that video feedback does not have any significant effect on performance, while video feedback joint with music clearly increased performance. This effect might be explained by higher immersion and participant's diverted attention when music was presented. Similar results were collected by MacRae (2003). To achieve greater commitment to the tasks executed in VR it seems necessary to add music to the video feedback (Mestre et al., 2011).

VR with exercising is used to get participants more immersed in a stimulating environment (Smith et al., 1998). Combining it with the stationary bike may enhance the psychological benefits of exercise e.g. motivation, enjoyment, fun, decrease the perceived exertion etc. In general, VR equipment was introduced to increase users' involvement and adherence at training sessions (Mestre et al., 2011). VR has a power to divert users' attention from unpleasant bodily sensation and hence delays the onset of boredom and fatigue (Annesi and Mazas, 1997). Annesi and Mazas (1997) noted the higher attendance at training with VR than stationary bike alone. Promising results were collected by Chuang et al. (2003) showing that VR might be the reason of decreased rating of perceived exertion (RPE). Similar thing was presented by Huang et al. (2008), where wearing HMD gave lower RPE in comparison to no-display conditions. In the study of Ijsselsteijn et al. (2004) participants using VR showed more interest, enjoyment and perceived more competence in exercise. In general VR gives opportunity to have enjoying and rewarding experience (Sveistrup, 2004; Grealy et al., 1999). Apart from the enjoyment and motivation, Chen et al. (2009) wrote, that use of VR in rehabilitation of patients with spinal cord injury can ease patients' tension and induce calm.

Among all the physical and psychological benefits shown above there is also a need for improvement. Adding music seems crucial to get even more engaging and efficient experience.

2.3 A Stationary Bike in Rehabilitation

A stationary bike has been used in rehabilitation of cognitive and physical skills in several disabilities and diseases such as a stroke (Ambrosini et al., 2011; Ranky et al., 2010; Chuchnowska and Sękala, 2011), multiple sclerosis (Mostert and Kesselring, 2002; Beier et al., 2014), spinal cord paresis (Chuchnowska and Sękala, 2011; Chen et al., 2009), and balance disorders (Chuchnowska and Sękala, 2011; Kim et al., 1999; Kim et al., 2001) and traumatic brain injury (Grealy et al., 1999). It also serves as a help for post-surgical population (Ranky et al., 2010). Specific functions, which might benefit from cycling therapy are a motoric activity, a circulatory system, breathing (Chuchnowska and Sękala, 2011), and balance control (Kim et al., 2001).

Based on the effect of transfer of function to walking (Ranky et al., 2014) bike exercise can be used in walking rehabilitation. Phadke et al. (2009) indicates that bicycle training normalizes reflex depression, which is a shared function with walking, while Snijders et al. (2011) writes that biking may regulate timing and amplitude of limb movement, which can be helpful for the rehabilitation of freeze of gait - a phenomenon observed in Parkinson's disease (PD).

2.4 Rhythmic Rehabilitation

Recent evidence suggests that auditory feedback can facilitate rehabilitation process (Sigrist et al., 2013). Rhythmic exercises with the use of a metronome help to improve both cognitive and physical skills. Significant improvement was observed among others, in gait rehabilitation in PD (Thaut et al., 1997) and after stroke (Thaut et al., 1997).

A project called Interactive Metronome (Koomar et al., 2001) revealed how the rhythm exercises can improve both physical and cognitive skills in humans. This program is directed towards young and adults with neurological problems, but also healthy patients for enhancement of cognitive and athletic performance.

Connection between 1) time, 2) cognitive and 3) physical skills are widely described in literature. Timing is crucial for: attention (Miyake et al., 2004; Taub et al., 2007), intelligence (Fink and Neubauer, 2005; Helmbold et al., 2006), working memory (Fink and Neubauer, 2005; Baudouin et al., 2006), processing speed (Wearden, 2008; Penton-Voak et al., 1996), motor skills (Bengtsson et al., 2009; Jantzen et al., 2007) etc. Its disorders are observed in ADHD (Houghton et al., 2011; Gilden and Marusich, 2009), autism (Wimpory et al., 2002; Nicholas et al., 2007), dyslexia

(Thomson et al., 2006; Hari and Renvall, 2001), or APD (Auditory Processing Disorders) (Kello, 2003) etc.

Cognitive rehabilitation must be ordered in layers, beginning with the most basic skills such as attention and concentration, then progressing to more complex skills such as memory, verbal, language, visuospatial, executive function, and social behavior (Gordon and Hibbard, 1992). The foundation skill is attention. It is necessary for good memory, executive function, communication, and executive control (Bennett et al., 1998). Attention training appears to generalize to other tasks (Rimmele and Hester, 1987). Thus, our program will be mostly concentrated on this cognitive skill.

3 A FUSION OF VR AND AUDITORY STIMULATION

3.1 Research Problem and Outline of Objectives

In this project we aim to incorporate VR and auditory feedback in a stationary bike platform.The possible benefits of this approach would involve not only physical exercise but increment in cognitive skills. We see it at as a powerful rehabilitation and also exercising system for people who can not perform difficult and power demanding exercises, but they still want and should exercise (e.g. elderly).

Based on the gathered evidence we know that biking performance and exercise enjoyment can change as a function of VR's elements (e.g. type of display, additional music, level of immersion etc.). Therefore we aim to explore of the idea of introducing music and soundscape in VR.

As soundscape we understand *'an environment of sound (sonic environment) with emphasis on the way it is perceived and understood by the individual, or by a society. It thus depends on the relationship between the individual and any such environment*" (Truax, 1978). To the best of our knowledge, there is no research that tested the effect of the soundscape on exercise performance in VR. We hypothesize that higher immersion produced by a more consistent virtual environment will be beneficial for both physical and psychocological effects of VR on exercise. Our experience taught us that visual events are accompanied by auditory experience. Thus, natural sounds placed in VR can increase perceived level of congruence and be necessary for the sense of presence. Another important aspect of each action is the auditory feedback generated by the movement. Getting not only visual but also auditory feedback of the experienced environment can increase the perceived level of control.

In our opinion is worth to consider feedback in a form of (1) ecologically valid sounds, which simulate real life sounds and build soundscape and (2) a synthetic rhythmic feedback, which can help to lower variability of performance while biking.

In general, this work will help us to analyze how the audio feedback, music and soundscape sounds increase or decrease the performance score during biking, to identify the properties of audio signals which constitute understandable and efficient feedback, to find humans preferences for synthesised or natural sounds accompanying their exercise.

The results of our investigation should help to improve the elderly exercising and facilitate understanding of the exercises procedures and aims, provide knowledge for designing proper feedback signal and support elderly with intuitive, comfortable, not stressful and even relaxing way of exercising.

3.2 Stage of the Research and Expected Outcome

In one of our basic experiments (Maculewicz et al., 2013) we checked how people follow the tempo on an exercising bike in several conditions. We had four main goals in this experiment. We wanted to investigate: If auditory feedback can help to keep guiding tempo? Should we use single or double feedback sound in cyclic movements? When, within one round of pedals, should be feedback produced (difference between two points)? Does the change of guiding sound change the influence of auditory feedback? Figure 1 visualizes the setup used in the experiment. Whenever participants was passing with pedal one of the magnet sensors, he or she heard sound coming from the headphones.

The results of our experiment showed that auditory feedback helps to keep a guiding tempo. It was proved that for this type of cyclic movement single feedback helps much better than double feedback. Moment of presenting feedback does not change accuracy of performance. Our results also showed that participants followed better tempo presented by drum sound than music at the same level of the tempo. Figure 2 shows in details those results. Presented measure is an absolute value of the difference between participant's results and presented tempo. The lower value, the participant's tempo was closer to the guiding tempo.

Based on the results of our rhythmic walking ex-

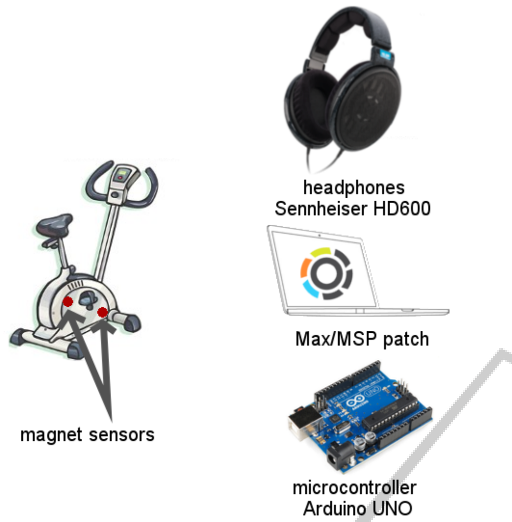

Figure 1: Presentation of the experimental setup. The red dots indicate placement of the magnet sensors, which was responsible for detecting participants' tempo. Feedback was presented when person was passing the magnet sensor with a pedal.

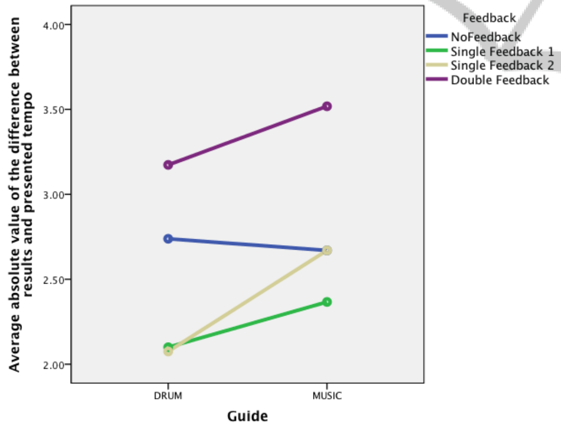

Figure 2: Presentation of the results of the experiment. X-axis presents type of guiding stimulus and Y-axis presents average absolute value of the difference between participants' results and presented tempo.

periment (Maculewicz et al., 2014) we hypothesize that different types of feedback can change preferred pedaling rate and therefore make users bike faster. If we find feedback which makes users bike faster but still in their preferred cadence we could motivate participants to exercise harder without change in RPE. Our second aim of this research program is to consider use of the music in VR exercises. People listen to the music during exercising for many reasons. They use it as a distraction from discomfort, for reduction of tension, or to block repetitive noises made during exercise (Stevens and Lane, 2001). Music can be also used as a cue for synchronization of their motion. Well-selected tracks may contribute to increase in motivation. They are adjusted to preferred tempo and presents desired energy level for exercise. We suggest to add music into VR can incorporate all of above mentioned benefits to the biking exercise experience. Music added in VR increases performance and commitment to the task in VR (Mestre et al., 2011). We are mostly interested in its rhythmic quality and therefore ability to induce rhythmic and stable exercise pace in motivational environment. As we wrote before, all of those components together can serve as a promising tool for improving cognitive and physical skills. Figure 3 presents a visual part of the VR environment which will be used in the future experiments. Incorporated elements (e.g. visualization of birds, trees in the wind etc.), which are associated with sounds, give opportunity for building rich soundscape. A visual part of VR will be built in Unity (Unity Technologies) and a sound part will be prepared in Max/MSP (Cycling'74) software.

Figure 3: Presentation of the visual part of VR which will be used in the forthcoming experiments.

3.3 Methodology

All formulated hypothesis will be tested by subjects in an experimental setting (in the laboratory and the real environment - retirement home). Quantitative and qualitative data acquired during experiments will be analysed with appropriate statistical methods (ANOVA, t-test etc.) selected based on the experimental and theoretical requirements. Mathematical methods will help to establish models of the efficiently working feedback systems.

Every specific experiment within this project will require consideration of the appropriate methods. Participants exertion and, in general, exercise experience might be measured with a few different tests (e.g. Perceived Exertion Scale (PES) (Borg, 1982) and The Subjective Exercise Experiences Scale (SEES) (McAuley and Courneya, 1994)). For their performance and efficiency we will measure biking tempo, distance, length of exercising session, heart beat etc.

4 SUMMARY

This paper presented a new, exploratory approach to augment stationary bike with VR platform with acoustic stimuli (music or soundscape). Based on the presented evidence we will follow two lines of research. One is to investigate impact of soundscape and/or music display on increasing the immersion VR experience while cycling. The second, to further investigate how auditory feedback can modulate pace of exercise and RPE of person exercising. This work is currently in progress.

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