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To cite this article: I P D Lesmana *et al* 2020 *J. Phys.: Conf. Ser.* **1569** 022010

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Manipulation of Virtual Environment to Examine Perception and Vision Aspects of Individuals Post-Stroke When Driving VRAC Simulator

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Abstract. Individuals post-stroke suffer deficiency of motor function and need more effort to exercise using cycling therapy. Virtual reality augmented cycling (VRAC) that incorporate compensatory strategies such as manipulation of virtual environment (VE) may change motor behaviour and increase exercise intensity while also being engaging and motivating. In this research, we try to examine perception and vision aspects of individuals post-stroke that affect the user interface to a VE when driving a VRAC by manipulating VE features such as gain related with human perception, and width and difficulty of path related with human vision. To examine those aspects, we divided two groups, namely healthy sedentary control (n=3) as reference and individuals post-stroke (n=7). From the examination results, it was obtained that both groups had given a good enough response to manipulation of VE features although there were no significant differences to individuals post-stroke when driving VRAC in wide path conditions. Manipulation of VE features affect cycling behaviours for individuals post-stroke and assist to transfer visual information in real world to virtual world for development of post-stroke rehabilitation using VRAC system.

Keywords-VRAC, virtual environment, VE, gain, width and difficulty of path, pedalling speed

1. Introduction

Individuals post-stroke try to get back deficiency of motor function by frequently conducting the same assignment of physical training over and over. The numbers of assignments that can be done by individuals post-stroke are restricted by physics of the environment and the presence of training apparatus. The other obstacle has been faced as long as the period of physical training with repetition is monotonous situation that can lead unsustainable training. Otherwise, physical training using heterogeneous environments for individuals post-stroke has been proved to improve their motor function and adherence to follow physical training regularly [1]. In addition, repeating the assignment of physical training by manipulating various training environment are an important factor to accelerate and enhance motor performance after stroke incident. This activity could stimulate motor imagery of brain processing [2, 3, 4].



Virtual environments (VEs) present to overcome limitation of real world physics, provide more flexibility to describe any condition of real world physics. The reason why VEs can be accepted and used in physical rehabilitation because of built-in flexibility of VEs. Physiotherapist can design many environmental scenarios in VEs to raise perceptual and motor function of patients [5]. However, VEs also have limitations because of their designer. Not all objects or components of real world physics such as visual, sense of touch or haptic, auditory, other sensory cues can be presented or met completely in VEs. For instance, to pay attention to an object in real world physics, user does not take much effort and does not need to know how his brain works, so information processing mechanism in the brain just goes away. It is totally different in VEs because user who interacts with VEs must calculate the position of observed object against position of user in real world physics such as field of view (FoV), direction, spatial frequency between objects, color contrast and texture, scale of objects. Therefore, limitation of VEs because of spatial and temporal display tolerances must be realized for specific rehabilitation applications.

Based on [6], gait and walking ability of people post-stroke had shown improvement after using virtual reality treadmill training. The speed of walking and length of step in cerebral palsy patients indicated better direction when using visual feedback [7]. The modification of optic flow speed to resolve abnormal gait in cerebral palsy patients had shown that speed of walking, cadence, length of step can follow three conditions of optic flow modulation: slow, normal, and fast to change abnormal gait behavior [8]. The term of optic flow explains the pattern of motion perceived interpreting parameters of speed and direction of objects that relocate in a visual scene like VE. Optic flow modulation could affect the change of gait parameters like velocity of gait, length of stride, and cadence that bring different stimulation on motor function in the legs [9]. The increase of speed of walking and cadence was affected by increasing optic flow speed such as two times the normal speed. In contrary, the slow optic flow speed caused the decrease speed of walking and cadence [8]. Moreover, the a positive change of cycling velocity is affected by modification of optic flow on speed of cycling in young people. On previous studies met in literature, the applied of optic flow modulation to change parameters of gait had been used in cerebral palsy patients and normal people. However, it has been never tested to improve abnormal gait behavior in people post-stroke.

Related with driving, modification of path lane in VE has changed user's behaviour. Based on [10], the wider path lane causes the driving speed to slowly increase. Similarly, the effect of path lane modification on trip speed and steering wheel control of car has been observed. From the experimental results show that the higher driving speed and the narrower the width of lane requires tight steering control and strong mental preparation to keep the position of the car on the right lane. This causes the rider to drive carefully. The mental workload of the car's rider would be examined on a change of driving speed to changes in lane width [11].

In this research, we try to examine whether the change of VE features such as gain, width and difficulty of path in virtual reality augmented cycling (VRAC) system gives effects to perception generated by visual system of individuals post-stroke to change their cycling behaviour and transfer skills to real world physics. [12, 13] explain VRAC system in more detail.

2. Methods

2.1. Cycling Apparatus

The design of VRAC is shown in figure 1. As shown in figure 1, a VRAC apparatus consists of two identical pedals completed with a load-cell sensor, an accelerometer sensor, and microcontroller unit (MCU) with wireless module to transmit data to box control (A). Other VRAC modules are a heart-rate sensor (B), two identical handlebar systems containing each strain gauge sensor placed on an aluminium plate (C), box control to collect data from each VRAC modules and transmit data set to the VRAC simulator (D), VRAC simulator and display unit (E).



Figure 1. VRAC apparatus; A: pedal module; B: heart rate measurement; C: handlebar module; D: control box; E: VRAC simulator.

The pedal modules shown in figure 1 have unique design to detect pressure balance between left foot and right foot. To keep the virtual cycle on vertical position, two pedal pressure between left and right foot must be maintained symmetrical, otherwise, the position of virtual cycle will turn to the stronger side of foot. An accelerometer is placed in the bottom of pedal module to measure tilt in dorsiflexion and plantar flexion of the ankle. The measure data from each pedal is transmitted to the box control through wireless communication. This design makes it easy to pedal VRAC apparatus.

The heart rate module is to keep the safety of VRAC training based on YMCA protocol. The heart rate of rider is also to adjust speed of virtual trainee. If the distance between rider and virtual trainee is too far, the heart rate of rider rises gradually to catch virtual trainee up. To prevent heart rate of rider will overtake maximum heart rate based on YMCA protocol, so virtual trainee must slow down his pedal and vice versa.

Handle bar system result binary values depended on the presence or absence of hand pressure on the steering module. To turn the virtual cycle to the left, rider must press the left steering module and release the right steering module. To turn the virtual cycle to the right, rider must press the right steering module and release the left steering module. If there is no emphasis on both the left and right steering modules, the virtual cycle will run straight. The design of steering module is simple by measuring the degree of bending of the aluminium plate using a strain gauge sensor that is attached to the surface of aluminium plate.

Box control collects sensor data from each VRAC module, sorts them, and transmits processed data to the VRAC simulator through bluetooth.

2.2. Participants

In this research, we involve 10 participants divided into two groups. First group, called healthy sedentary control participant, has 3 members aged 25-40 years. Second group, called post-stroke participant, has 7 members aged 41-65 years and has suffered post-stroke condition for 1-5 years. All subjects have to understand the goal and contents of the research and sign a form of informed consent to agree, participate, and follow acquisition data rules until finish.

2.3. Procedure

Firstly, subject sat in the correct position above VRAC pad as follows: posture as much as possible erect, knees bend 5° at maximum leg extension, both hand in the correct position on the handle bar. The VRAC training divided into three sessions, namely warm-up, exercise, cold-down. During warm-up and cold-down sessions, subject cycled at 0.5 kg on 50 rpm and maintained training intensity between 20 and 30 beats per minute above resting heart rate of subject. The VE of VRAC system applied a simulation of bike riding consisting of two avatars, one avatar as rider who represented subject and other avatar as virtual trainee. Speed of virtual trainee was based on target heart rate of rider and set by a physiotherapist. The rider was instructed to catch virtual trainee, maintain his cycling speed on safe range, and his heart rate not exceed his target heart rate.

During exercise session, VE of VRAC system has three manipulation conditions, namely gain, width and difficulty of path. Gains in VE divided into four conditions namely low gain (LG), normal gain (NG), high gain (HG), and double high gain (DHG). PG indicated that distance between subject and virtual trainee in safe range and rider cycled with real RPM. Meanwhile, LG was applied when rider sensed an decrease in speed of virtual trainee. On the contrary, when rider perceived that speed of virtual trainee increases gradually, HG was set. Similarly, DHG was applied when distance between rider and virtual trainee were too far. This gain rules resulted optic flow and were created to influence behavior of people post-stroke in the real world.

Each subject performed five trials using VRAC system with different gains. In addition to gains, manipulation of VE included width and difficulty of path. Width of path divided into two conditions, narrow (NR) and wide (WD) of bike path in VE. Furthermore, difficulty of path was related to the presence of obstacles such as boxes (OBS) on the path bike as seen on figure 2.

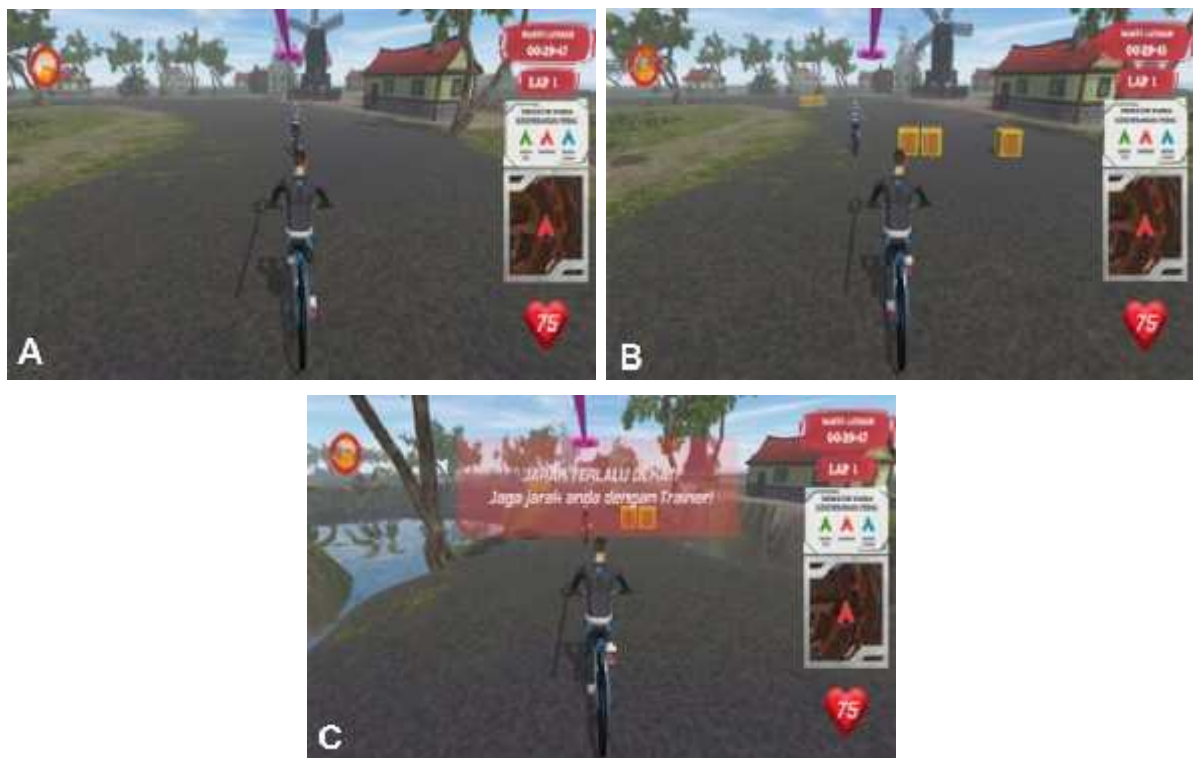


Figure 2. Virtual environment manipulation; A: wide path without box obstacles; B: wide path with box obstacles; C: narrow path with box obstacles

VE was displayed on Android Tablet located on the top of bike steering with the distance one meter from subject. The field of view in the VRAC was 80° as recommended by [14]. During the exercise session, physiotherapist gave direction to the subject to cycle virtual bike in reaction to VE with manipulations as explained before.

2.4. Data Extraction and Analysis

Revolutions per Minute (RPM) means number of times the crankshaft of a bicycle, rotates in one minute. The value of RPM is resulted by inertial measurement unit (IMU) with sampling rate 150 Hz. Characteristics of gain, width and difficulty of path of pedaling RPM is obtained from gain output which applied at exercise session. To get value of actual pedaling RPM, gain multiplier must be removed using easy arithmetic algorithm. Furthermore, actual pedaling RPM must be analyzed to extract information about manipulation of VE features.

Actual pedaling RPM data set is collected from three groups, namely young healthy control participants, older participants, and participants post-stroke when driving VRAC system. The difference RPM data between three groups are analyzed using analysis of variance (ANOVA).

3. Experiment Results and Discussion

3.1. Experiment Results

Experiment results of VRAC system are shown in figure 3 as a result of testing healthy sedentary control participants and figure 4 as a result of testing post-stroke participants. Based on both experiment results in figure 3 and 4, two groups, healthy and post-stroke, have the same pattern between groups and within groups when facing three VE testing (WD+OBS, WD, NR+OBS).

There are no serious problems faced by healthy sedentary control participants to respond the change in optic flow based on applied gain. As shown in figure 3, healthy control participants raise their pedaling speed dramatically from WD+OBS group to WD group at any gain order. On the contrary, their pedaling speed decrease from wide path (WD, WD+OBS) groups to narrow path (NR+OBS) group. On each group, the pedaling speed increase gradually to adapt each VE condition.

As seen on figure 4, individuals post-stroke have slow response to change in gain order from WD+OBS group to WD group. Even though their pedaling speed increase gradually between those groups, but there are no significant differences between LG and NG conditions. Otherwise, individuals post-stroke give a good response to change in gain order by decreasing their pedaling speed from WD to NR+OBS.

In conclusion, the change in gain order at any VE situation when driving VRAC system can be responded well by healthy sedentary control participants. Manipulation of VE including gain, width and difficulty of path do not bring fluctuating speed changes. Individuals post-stroke do not respond significantly to gain between path wide with or without obstacles, but give good responses because of difficulty of path by decreasing pedaling speed.

3.2. Discussion

Based on experiment results, two groups give a good response to manipulation of VE features including gain, width and difficulty of path. These manipulations affect behavior of individuals post-stroke to maintain speed of walking to be comfortable.

Individuals post-stroke participants had made a few changes to manipulate gain between wide path with obstacles or without obstacles in VE compared with healthy sedentary control participants. These situations may occur because of weak stimulation of VE for individuals post-stroke. It is need bigger stimuli of VE design for wide path to adjust their cycling behavior quickly. On the contrary, there is big impact to affect behavior of individuals post-stroke when driving in difficult path. Although, individuals post-stroke give a fairly good response to VE manipulation, but their pedaling speed are slower than healthy sedentary control participants. These facts correspond to pedal force of individual

post-stroke which only reaches a half of the normal pedal force from healthy sedentary control participants as explained in literature [13].

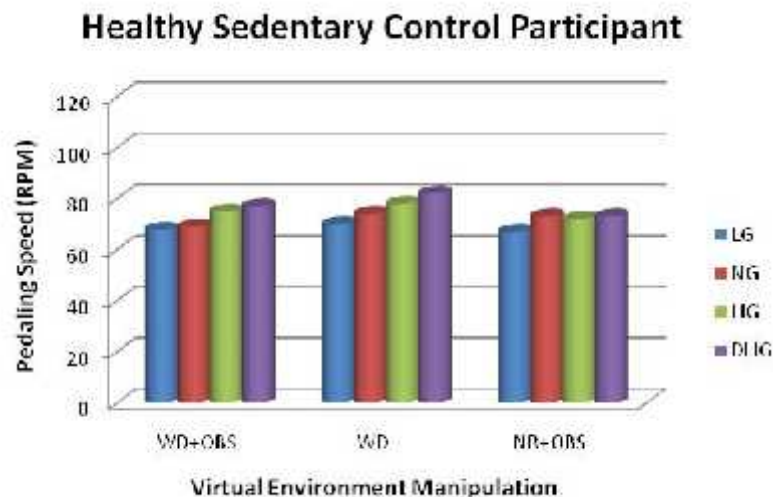


Figure 3. Healthy sedentary control participant's feedback (n=3, 5 trials) on manipulation of virtual environments including gain, width and difficulty of path

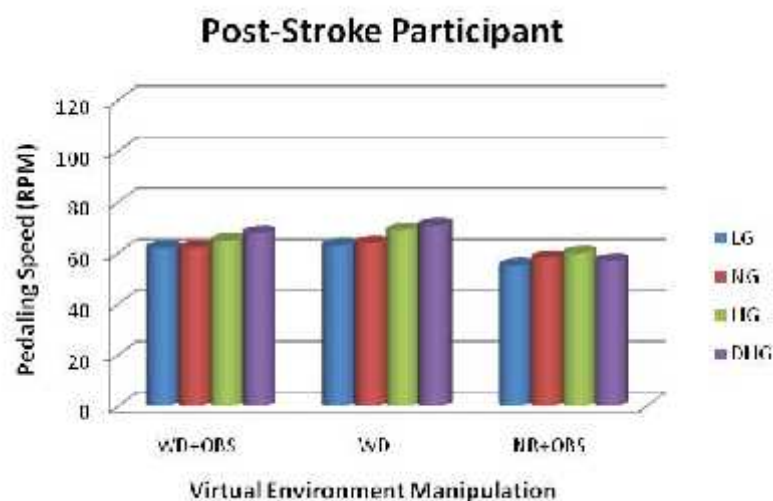


Figure 4. Post-stroke participant's feedback (n=7, 5 trials) on manipulation of virtual environments including gain, width and difficulty of path

4. Conclusion

To examine perception and vision aspects of VRAC system for individuals post-stroke is needed to manipulate VE features including gain, width and difficulty of path. Both healthy sedentary control and individual post-stroke participants had given a good enough reaction to change in gain and path conditions. These VE manipulations encourage participant's responses in particular individuals post-stroke to transfer skills in real world physics.

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