Objective but not subjective effect of height in a virtual slack-rope balance task

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***Abstract*—Ten young adults performed a balance task in a virtual environment projected via a head referenced head mounted display. The task constituted of crossing a canyon along a slack-rope, positioned at three different heights (2,50 & 100 meters above a river) and in three velocities (slow, medium & fast). Time (s) of crossing of the canyon was measured as the outcome measure. The results show that the time was directly dependent upon the height of the rope above the river, i.e., the higher the rope, the slower the time, in the fast ($F(2,18)=5.24$, $p=0.016$) and in the slow ($F_{(2,18)}=8.469$, $p=0.003$) velocities. However, subjectively, all participants reported they felt no difference in their own performance in the different heights. Thus, this gap between the objective performance and the subjective perception of performance may indicate a height-time trade-off in performing a virtual balance task.**

Keywords—Balance, Head Mounted Display, Virtual Reality, virtual height, height-time trade-off

I. Introduction

Recurrent falls, as well as fear of falling, may result in decreased independence and participation [1]. There is growing evidence that balance training exercise may improve balance [2] and decrease the fear of falling [3].

Balance maintenance depends upon visual, proprioceptive & tactile and vestibular inputs, which, by a sensory re-weighting on-going process enable to maintain an upright posture and to perform daily activities [4-6]. When environmental conditions change, the postural control system must identify and selectively focus upon the sensory inputs that provide the most reliable information to maintain functionality [7]. Inappropriate visual field motion, unmatched to actual physical motion can exert a strong impact on postural control [8], and even force to altering the organization of locomotion pattern or lose balance while walking [9].

Virtual reality systems afford interactive virtual environments (VEs) in which the intensity of practice and sensory feedback can be systematically manipulated to provide individualized, real-life-like motor training situations and flexible, controlled settings for the study of complex experiential learning [10]. VEs projected via head mounted displays (HMD) enable full immersion within the virtual environment (VE).

Given the role of the visual system in balance and stability, as well as the characteristics of VR technology, the aim of this study was to validate a custom designed VE ("Slack Rope") for the study of balance performance and acquisition.

II. Methods

A. Population

10 healthy young adults (7F, 3M), Mean age (sd) 25.3y (2.3), Range:21-28. Exclusion criteria: Neurologic or orthopaedic dysfunction, Vestibular dysfunction, motion sickness, Vertigo and visual impairments. The study was approved by the Ariel University Ethics committee and all participants sighed an informed consent form.

B. The 'Slack Rope" virtual environment

The VE consists of a deep canyon separating between two mountain ranges (Fig 1A). A river flows at the bottom of the canyon, between the mountains. The rope over the canyon, connecting between the mountains is positioned at 2, 10, 50 & 100 meters above the river. The 'wind effect' causes side-to-side movements of the rope, as well as sound effects of blowing wind. Flocks of birds fly over and under the rope along with an auditory input of bird sounds. Velocity of advancing along the line, the size of the wind effect, as well as the presence of the birds can be controlled by the operator. Advancing along the rope is head referenced.

C. Protocol

Apparatus: the oculus rift HMD was used for projecting the VE (www.oculus.com/rift) (Fig 1B).

Prior to performing the task, in-order to familiarize the participants with the VE and rule out cybersickness participants were exposed to the VE in sitting and learned forward to control it

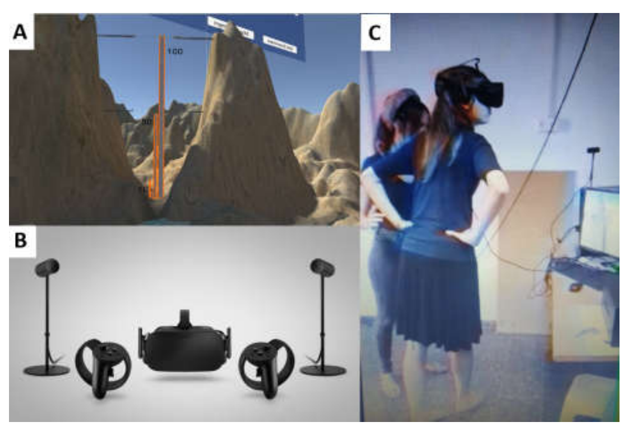

Figure 1: Setup of the experiment
A. The virtual Canyon. The red bars show the scaling of the 4 heights of the slack rope (2,10,50 & 100m) B. The Oculus Rift Head Mounted display system. C. A participant performing the balance task – crossing the virtual canyon. The participant's safety is supervised by a therapist

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'Home position': the participants were instructed to stand in a tandem stance, hands on their waist. If the participant moved out of this position, he/she was asked to return to the 'home position'

The balance task: participants were instructed to cross the canyon along the slack-rope, as fast as possible` while maintaining the home position, (Fig. 1C). Advancing along the slack rope was head referenced – anterior translation of the head increased the forward advancing speed.

A slack rope was preferred over a taut rope to add an effect of swinging or, blowing wind. The balance task was performed at three different heights above the canyon: 2, 50 and 100 meters. This was performed at three pre-selected velocities: slow, medium & fast (identical velocity for each subject). The order of the heights as well as the velocities was random, in order to prevent an 'order effect'. Following each iteration, the participants were asked whether they felt a difference in their performance compared to the previous iterations.

Outcome measures: The primary outcome measure was time (s) to complete the crossing of the canyon. Time was selected to evaluate the effect of height of the rope on performance, i.e., a time-height trade-off.

Statistical analysis: a Generalized Linear Model with Bonferroni correction was applied to analyze the difference in performance of the balance task, (time to complete the crossing of the canyon), in each of the three heights (2,50 & 100 m) for the three velocities (slow, medium & fast).

III. RESULTS

All participants completed the study, with no adverse effects.

The results show that the time of completing the balance task was directly dependent upon the height of the rope above the river, i.e., the higher the rope, the slower the velocity in the fast ($F_{(2,18)}$=5.24, p=0.016) and in the slow ($F_{(2,18)}$=8.469, p=0.003) velocities, while in the medium velocity there was no significant change ($F_{(2,18)}$=3.425, p=0.055). (Fig 2). In the fast velocity the height effect was already present in the 50 m height (p=0.025), while in the slow velocity, the significant difference was evident at 100 m (p=0.013)

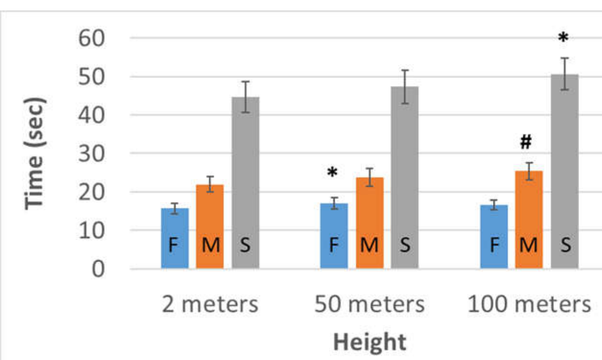

Fig 2: performance in the balance task.
Time (sec) to complete crossing of the canyon in the three pre-determined velocities (F, blue: fast; M, orange: medium; S, gray: slow), in the three different heights above the river (2 m, 50 m & 100 m). *p<0.05, #p=0.055)

IV. CONCLUSIONS

VR heights exposure has been shown to be comparable to real-world heights exposure [11]. Moreover, virtual high heights increased measures of fear (e.g., heart rate variability) and altered standing posture dynamics [11], and standing on the edge of an elevated surface elicited a stiffening strategy [12]

In the current study the participants were instructed to cross a virtual canyon, advancing along a slack rope. The rope was positioned at 3 different simulated heights above a river. The time for crossing the canyon was directly height dependent; the higher the slack rope, the longer time to cross, most notable in the fast and the slow velocities. Our results complement previous data showing that real and virtual [13] heights alter balance performance and increase stress.

Interestingly, despite the objective increase in time to cross the canyon, subjectively, virtual height did not seem to affect the performance, as all participants reported they felt no difference in their own performance in the different heights and velocities. This gap between the objective performance and the subjective perception of performance may indicate a trade-off between height of the slack-rope and time to complete the task in performing a virtual balance task.

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